CONTROL OF WATER INFILTRATION INTO NEAR SURFACE LLW DISPOSAL UNITS

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ABSTRACT

Water infiltration to buried waste is the prime problem of concern in designing waste disposal units for the humid areas. Conventional compacted clay layers (resistance layer barriers) have been subject to failure by subsidence and by permeability increases brought about by plant roots. A clay barrier with a rock cover sans plants is being investigated. Also a combination of a resistive layer overlying a conductive layer is being investigated. Laboratory studies indicate that this approach can be very effective and field evaluations are underway. However, it must be noted that subsidence will negate the effectiveness of any buried layer barriers. A surface barrier (bioengineering management) has been evaluated in the field and found to be very effective in preventing water entry into waste disposal units. This surface barrier is easily repairable if damaged by subsidence and could be the system of choice under active subsidence conditions.

INTRODUCTION

Infiltration of water into the waste is the foremost problem associated with near surface disposal of LLW. Up to this time, disposal unit covers have generally been constructed from soil materials. In the humid areas, these soil or clay covers have generally proved less than satisfactory; often the cover itself has served as the principal pathway for water entry into the waste (1). Water infiltrating to buried wastes, contacting the wastes, and then exiting the area can reasonably be expected to be the most important of radionuclide transport agents. Some radionuclides, such as tritium present as tritium oxide, and those present in anionic form, will essentially move with the flow of water; others present as multivalent cations will move much more slowly, but all will move to a greater or lesser degree. Clearly then, it is advantageous to reduce water infiltration to buried waste to as low a level as reasonably achievable. It is the purpose of this work to examine and demonstrate various approaches of achieving that goal.

Three kinds of waste disposal unit covers or barriers to water infiltration are being investigated in this work:

1.Resistive Layer Barrier
2.Conductive Layer Barrier
3.Bioengineering Management

The resistive layer barrier is the well known compacted clay layer and depends on compaction of permeable porous materials to obtain low flow rates. A simplified model is shown in Fig. 1.

Flow through porous media is described by Darcy's law (2). Investigations on flow through such layers have gone on for over 100 years, so further progress in this area can be expected to be slow.

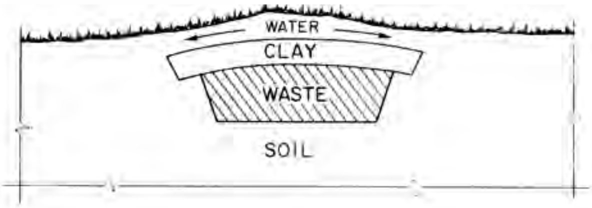

Fig. 1. Resistive Layer Barrier.

The conductive layer barrier (1) is a special case of the capillary barrier (3). Use is made of the capillary barrier phenomenon not only to increase the moisture content above an interface, but to divert water away from and around the waste. During such diversion water is at all times at negative capillary potential or under tension. A simplified model is shown in Fig. 2.

This system consists of a porous media underlain by a capillary break (rock layer). Infiltration barriers such as a conductive layer barrier or a clay layer barrier (or a combination thereof) must fail if subjected to substantial shearing caused by waste subsidence. Re-establishment of a layered system after subsidence failure is a difficult undertaking and is exacerbated by increasing complexity of the layered system.

CAUTION

Buried Multi-Layer Covers Must FailIf there is appreciable subsidence

The failure potential of in-ground layered systems during the subsidence period argues for development of an

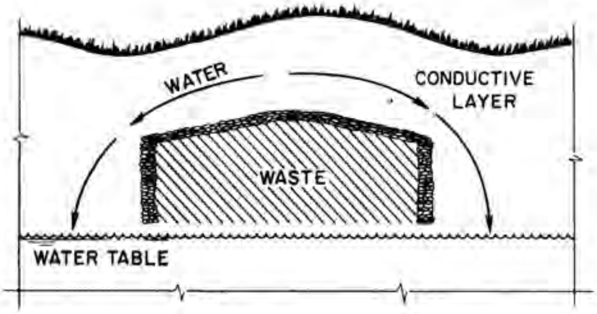

Fig. 2. Conductive Layer Barrier.

easily repairable surface barrier for use during that period. To that end a procedure called "bioengineering management" was developed (4). The bioengineering management technique utilizes a combination of engineered enhanced run-off and moisture stressed vegetation growing in a overdraft condition to control deep water percolation through disposal unit covers. A schematic model is shown in Fig. 3.

APPLICATION

The three procedures described in the introduction may be used singularly or in combination to protect disposal units from percolating water. The principles apply equally to above ground or below ground disposal. For example, a combination of Covers 1 and 2 could be ideal for a stabilized shallow land burial site or an above ground "tumulus"; e.g.

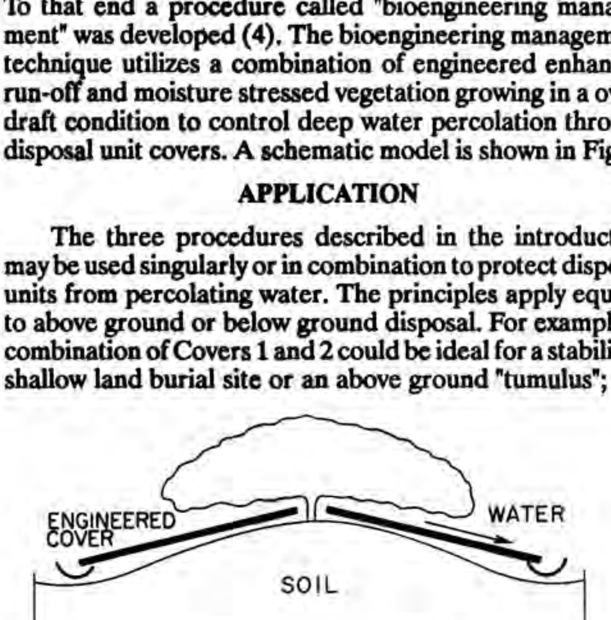

Fig. 3. Bioengineering Management.

the subsurface disposal could be below ground vaults and the above ground disposal unit could be earth mounded concrete bunkers. The bioengineering concept could be advantageous for either a tumulus or shallow land burial unit that would be likely to exhibit subsidence.

EXPERIMENTAL AND DEMONSTRATION

Bioengineering Management

In this section we will examine a procedure where the necessary run-off is provided by features installed at or above the soil surface rather than within the profile. The procedure has been described by Schulz et al., (4) and was designated bioengineering management. The principle advantage of the bioengineering management system is that subsidence can be easily managed by relatively simple, inexpensive maintenance of the above ground features rather than difficult reconstruction of below ground layers. It should be noted, that after a sufficient passage of time so that the organics have decayed out and the waste containers have completed failure, subsidence will cease and a layered system could be then installed which could last over geologic time periods.

In essence, the "bioengineering management" technique utilizes a combination of engineered enhanced run-off and stressed vegetation in an overdraft condition to control deep water percolation through disposal unit covers. To describe it further: if a waste burial site is selected so that incoming subsurface flow is negligible, then precipitation is the sole source of input water. In a simplified model, that water has three possible fates: (1) evapotranspiration, (2) run-off, and (3) deep percolation. Evapotranspiration has a definite limit governed by energy input. Ideally, deep percolation should be zero, leaving only the run-off component available for unlimited manipulation. Positive control of run-off becomes difficult with the use of compacted porous media trench caps as the sole barrier to water infiltration. The compacted material tends to become more permeable with the passage of time, due to fractures caused by waste subsidence and from the inexorable process of root growth followed by death and decay of the roots, thus creating water channels. Evapotranspiration is then not adequate to use all of the infiltrating water, and water percolates downward to the waste. As stated before, evapotranspiration has a theoretical maximum dictated by solar energy input to the system; only run-off remains available for nearly unlimited management. This run-off can be surface or sub-surface as long as it occurs before water reaches the waste.

Surface run-off can be managed to as high as 100 percent (perfect leak-proof roof, expensive and hard to guarantee). Alternately, run-off can be engineered rather inexpensively by using an impermeable ground cover over part of the surface to achieve high and controlled levels of run-off. Vegetation planted between areas of impermeable cover will extend over the cover to intercept incoming solar energy to evaporate water. Roots will extend under the cover in all directions to obtain water.

Such a system can be visualized similarly to a supermarket parking lot where trees are planted in islands among an extensive paved area with the island having curbing around them. Utilizing this concept, it should be possible, by combining engineered run-off with vegetation, to maintain the soil profile in a potential overdraft condition on a yearly basis.

Initial investigations of the bioengineering management technique were carried out in lysimeters at Maxey Flats, KY. Results obtained in seasonal 1984-85 and 85-86 were reported by O'Donnell et al. (5). In that work a fescue grass crop was used with an engineered cover of stainless steel. Following seasonal 1985-86 the grass cover was removed, a new stainless steel engineered cover was constructed and Pfitzer junipers were planted in the lysimeters. After establishment of the junipers, percolation data was again collected in 1988. This new data along with the earlier data is presented in Fig. 4. The performance of the woody junipers also was excellent in preventing deep percolation of water in the lysimeter.

The encouraging initial results obtained in the Maxey Flats lysimeter experiment has led to the establishment of a large scale field demonstration at Beltsville, Maryland. Fig. 5 is a photograph taken in the fall of 1988, two years after planting of the Pfitzer junipers. Alternating panels of aluminum and fiber glass were used as the hard cover. These plots or lysimeters are 70 ft long by 45 ft wide and the bottoms are 10 ft below grade. Fig. 6 shows a side view of construction details of a lysimeter.

Two bioengineered lysimeters were set up as shown in Figs. 5 and 6. These lysimeters were labeled lysimeters 1 and 2. The only differences between the two was the initial level of the water tables. The water table was 90 cm above the bottom in lysimeter 1 and 190 cm above the bottom in lysimeter 2. In addition to the two bioengineered lysimeters, two reference lysimeters were initially constructed. The reference lysimeters were similar except that they were merely cropped with fescue grass. They were labeled lysimeter 3 and 4. No hard cover was present but surface slopes were similar. Performance data of the reference lysimeters is given in Fig. 7.

The water table in the two reference plots, lysimeters 3 and 4, i.e. the plots cropped to fescue, rose until near the surface. At that time pumping of water from the water table was initiated to keep the plots from running over. The graphs of the water tables in the bioengineered plots (lysimeters 1 and 2) show an entirely different story as evidenced in Fig. 8. Here, in both cases, the water table is showing a decline. It appears that the bioengineering approach not only could be used to prevent water infiltration to a disposal unit; it also could be used for a remedial action in dewatering existing problem sites such as Maxey Flats.

On February 4, 1988 lysimeter 4 was pumped out to prevent overflow. It was then discontinued as a reference lysimeter and converted to a rock surfaced resistive layer barrier plot. Lysimeters 1 and 2 (bioengineered) and lysimeter 3 have been continued. A summary of run-off, evapotranspiration and pumping from those three lysimeters is given in Fig. 9.

Fig. 9 shows that there was very little run-off from the grass covered plot. The bulk of the precipitation was disposed of by evapotranspiration by the fescue crop but this was not adequate to prevent rise of the water table. About 80% of the precipitation was disposed of as run-off in the

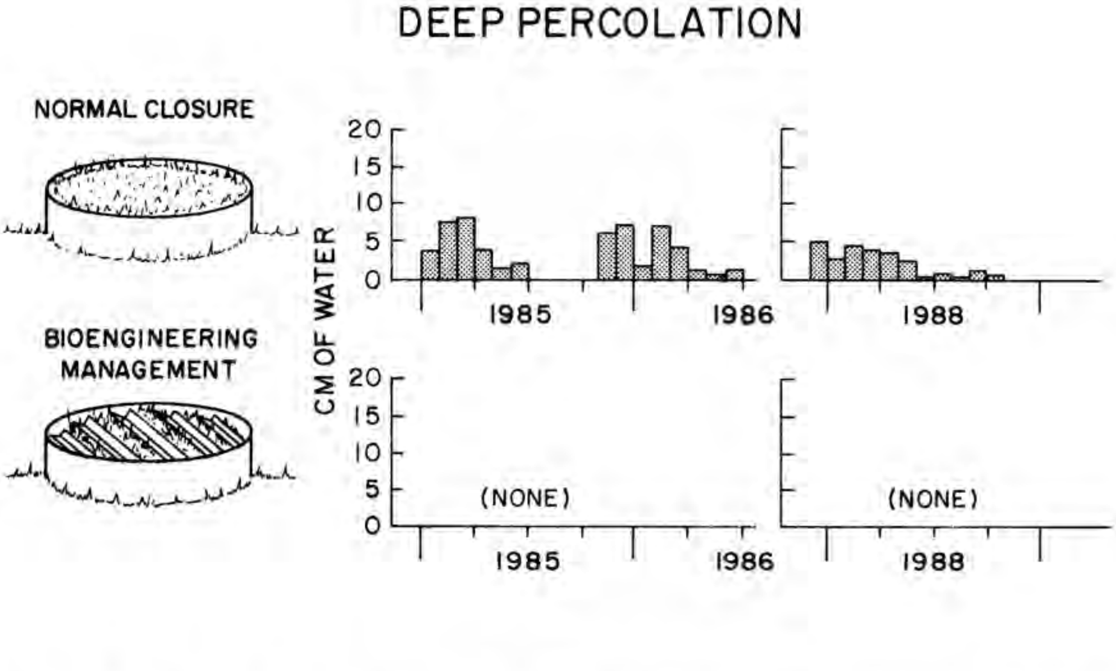

Fig. 4. Results of Lysimeter Experiments at Maxey Flats. No Pumping was Required at Any Time in the Case of Bioengineering Management, but Substantial Pumping was Required to Prevent the Water Table Rising Higher Than -2 Meters in the "Normal Closure" Lysimeter.

Fig. 5. Bioengineering Plots at Beltsville. Photo Taken in Fall of 1988, Two Years After Planting of Pfitzer Junipers. Run-off is 80% of Precipitation.

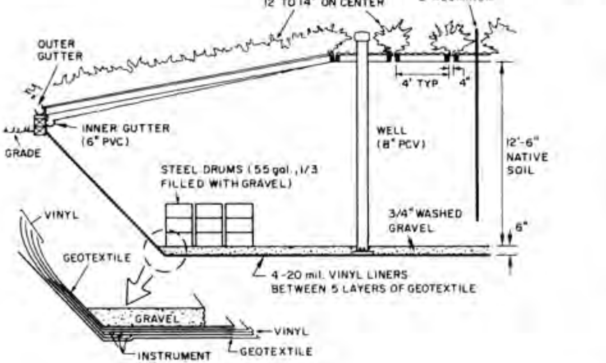

Fig. 6. Side View of Bioengineered Lysimeter. Surface Run-Off Collected From Both Engineered Surface and Soil Surface. Soil Moisture Content Measured With Neutron Probe. Water Table Measured in Well.

bioengineering plots and only about 20% as evapotranspiration. However, that combination effectively lowered the water table as shown earlier in Fig. 8.

Resistive Layer Barrier

As previously mentioned, on February 4, 1988, lysimeter 4 was pumped out, discontinued as a reference lysimeter, and converted to a rock surfaced resistive layer barrier plot. The primary reason for constructing that particular cover is the likelihood of such covers being used for uranium mill tailings. A side view of that plot or lysimeter is shown in Fig. 10. This lysimeter was completed in the fall of 1988 and data collection, measuring performance, has begun. The most important information to be gained here will be the relative weighing of the advantages and disadvantages of rock surface vs. a vegetated surface.

In addition to the UMTRA or rock surface-resistive layer barrier plot, construction of a vegetated resistive layer barrier plot is nearing completion. The primary purpose of this plot is for comparative measurements. Essentially this plot is similar to the rock surfaced plot except that topsoil replaces the rock layer and the plot will be planted to fescue

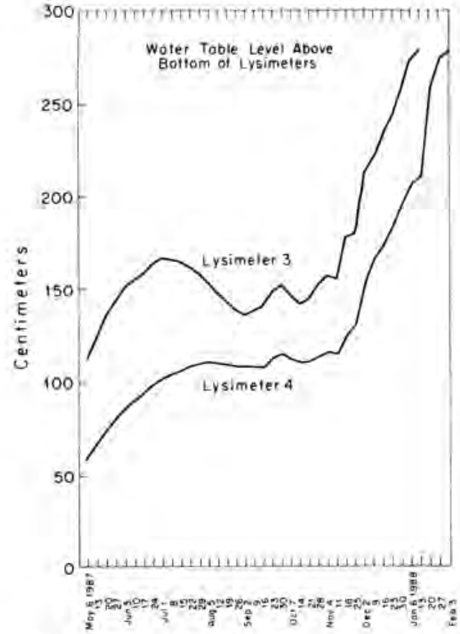

Fig. 7. Water Table vs. Time in Reference Lysimeters. Crowned Surface Cropped with Fescue Grass. Water Table Increased with Time until Pumping of Water Table was Necessary to keep Plot from Running Over. Surface Run-Off was 8% of Precipitation.

grass.

Conductive Layer Barrier

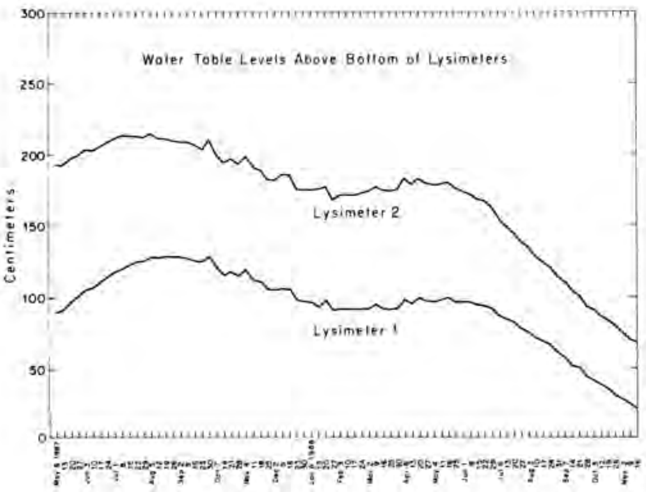

Fig. 8. Water Table vs. Time in Bioengineered Lysimeters. Decline of Water Table Levels with Passage of Time Shows Bioengineered Covers were very Effective in Preventing Water Percolation. Decline of Water Table Shows that this Procedure Could be Used for Remedial Action ("drying out") of Existing Water Logged Burial

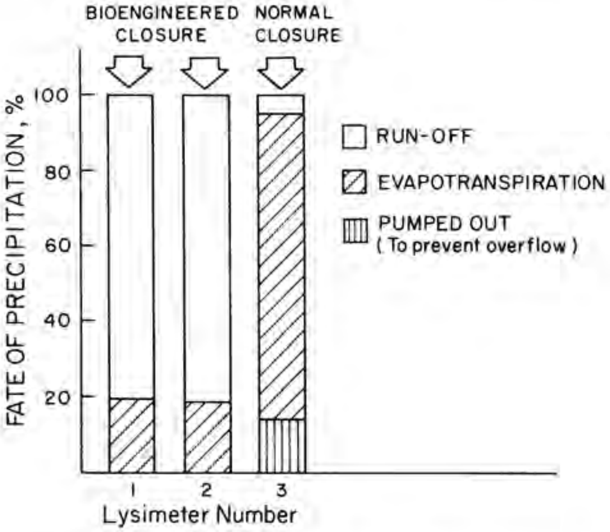

Fig. 9. Fate of Precipitation in Bioengineered and References Lysimeter. Pumping to Prevent Overflow was Required in Reference Lysimeter but Not Needed in Bioengineered Lysimeters.

If we consider the case of water flowing downhill in an unsaturated porous media we have the case shown in Fig. 11. The "holes" shown in the diagram could be a rock layer affording a capillary break or capillary discontinuity.

Under appropriate conditions, water everywhere in this depicted cross section will be under tension and there will be no leakage. This might then serve as an excellent means of protecting waste by conducting water around the waste. However, construction problems will certainly arise where a less than smooth surface ends up being constructed as depicted in Fig. 12. Fig. 11 simulates a conducting porous media such as a fine sandy loam soil smoothly laying on top of a rock layer. What happens if imperfections are constructed so that "pockets" of soil extend down into the rock layer? Fig. 12 represents that case. Again, there will be no leakage, provided conditions are such that the water in all parts of the conductive layer remain under tension.

The big question is, can conditions required to maintain the necessary soil water tension be practically maintained while using this procedure to effectively protect waste disposal units? To answer this question an apparatus schematically depicted in Fig. 13 was constructed.

The apparatus constructed to make the necessary measurements were called soil beams. Several "mini-soil beams" were constructed for use in the laboratory so a variety of candidate conductive layer materials could be quickly evaluated. A photograph of a laboratory scale "mini-soil beam" is shown in Fig. 14.

A number of materials were evaluated using the mini-soil beams. It was quickly established that it would be necessary to construct a resistive layer barrier above the conductive layer barrier to have a practical system. The standard was set that the resistive layer barrier have an easily achievable conductivity of not greater than 10^{-6} cm/sec. On this basis it was found that soil material such as

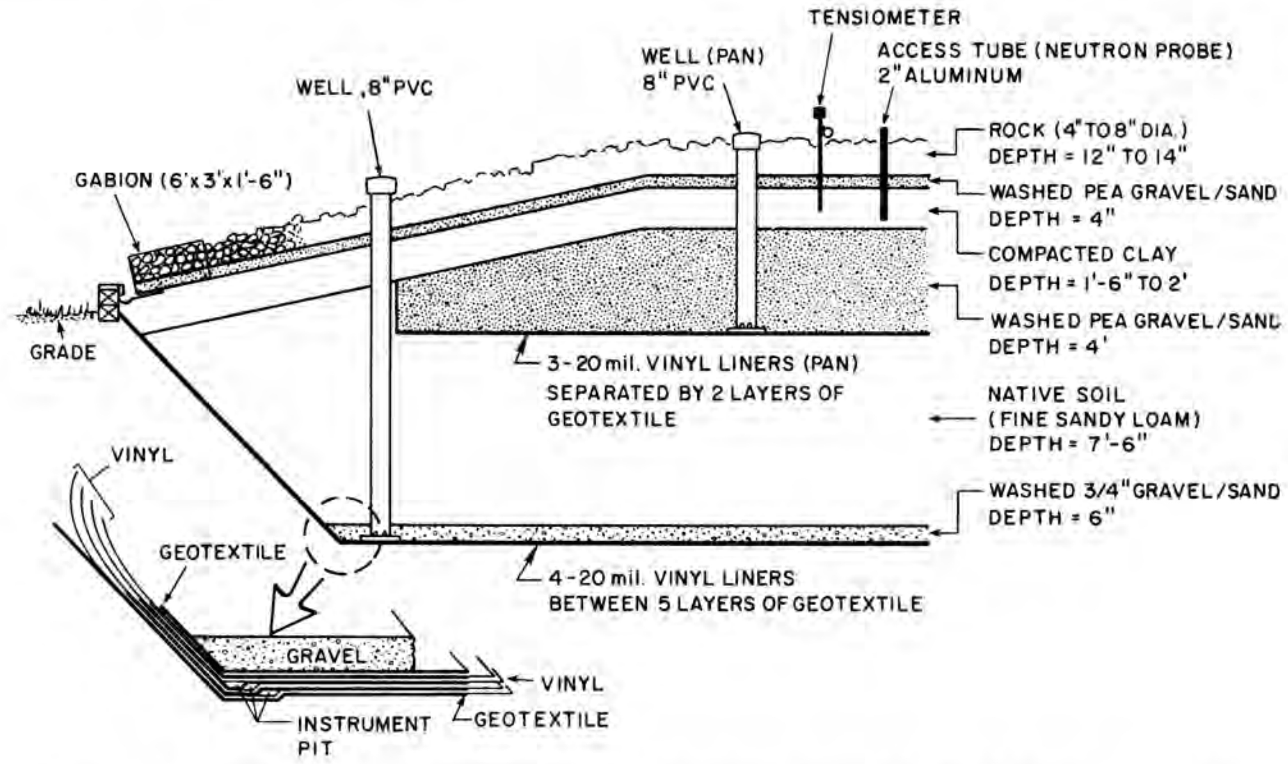

Fig. 10. Resistive Layer Barrier with Rock Cover. No Vegetation. Possible UMTRA Cover. Possible Advantages Over Vegetated Resistive Layer Barrier. (1) Clay Layer Remains Wet and More Efficient Barrier to Escape of Radon. (2) Initially, Superior Erosion Protection, and (3) No Root Penetration of Waste. Major Disadvantage: No Plant Transpiration, therefore Requiring a Clay Barrier of Extremely Low Hydraulic Conductivity. For Clarity, Repetitive Instrumentation not Shown.

fine sandy loam could provide an effective conductive layer barrier. That is, conduct around the waste 100% of water percolating through the resistive layer. However, the measurements showed that such materials would not provide the desired (factor of 10) safety margin.

Further investigations turned up a material, diatomaceous earth, that would fit these requirements. Measurements of tension vs. distance of flow are shown in Fig. 15.

The results of this experiment in the 4.5 ft long beam suggest that as long as the flow rate is no greater than 4.2 x 10^{-4} cm/sec the soil water will remain under tension regardless of the soil beam length. These results show that with the use of diatomaceous earth for the conductive layer and following the easily achievable standards set above for the resistive layer, it should be possible to construct a barrier that would allow no water leakage to a waste disposal unit. However, before final selection of the diatomaceous earth as the conductive layer material was made, it was felt prudent to conduct tests in a large scale soil beam. A large beam was constructed and used for this purpose. The large beam is shown in Fig. 16 and has a soil beam length of 21 ft. As shown in Fig. 17, a matric potential of about -15 to -20 cm

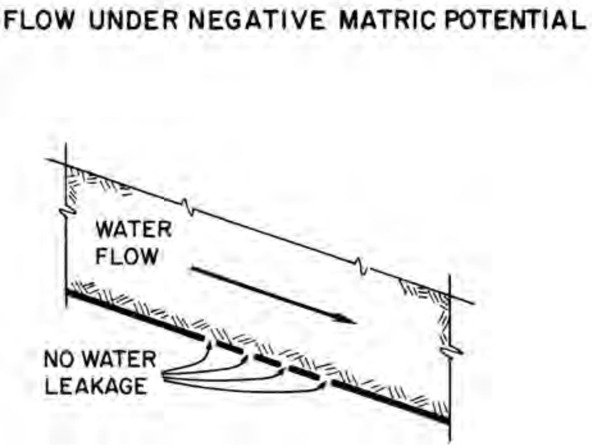

Fig. 11. Water Flow in an Unsaturated Porous Media.

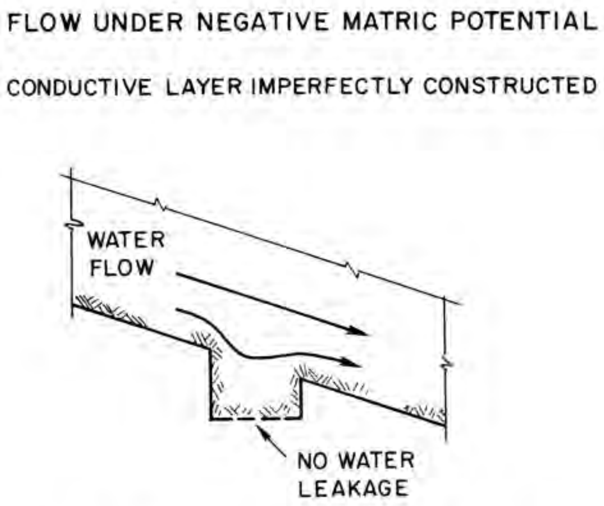

Fig. 12. Imperfectly Constructed Conductive Layer with "Pocket" Extending Down into Rock (or Capillary Break) Layer. No Leakage if Conditions Required to Maintain Tension are Met.

of water is maintained over the entire 21 ft length of the beam when the flow rate does not exceed 3.1×10^{-4} cm/sec.

The studies carried out in the large soil beam verified closely the data obtained in the mini-beam. Accordingly, diatomaceous will be used as the conductive layer material in the demonstration lysimeter. It has been estimated that purchasing and shipping the diatomaceous earth to job site any place in the U.S. will add about $0.50 per cubic feet of disposed waste. This is over the cost of using locally obtained soil and based on waste being 10 ft. deep.

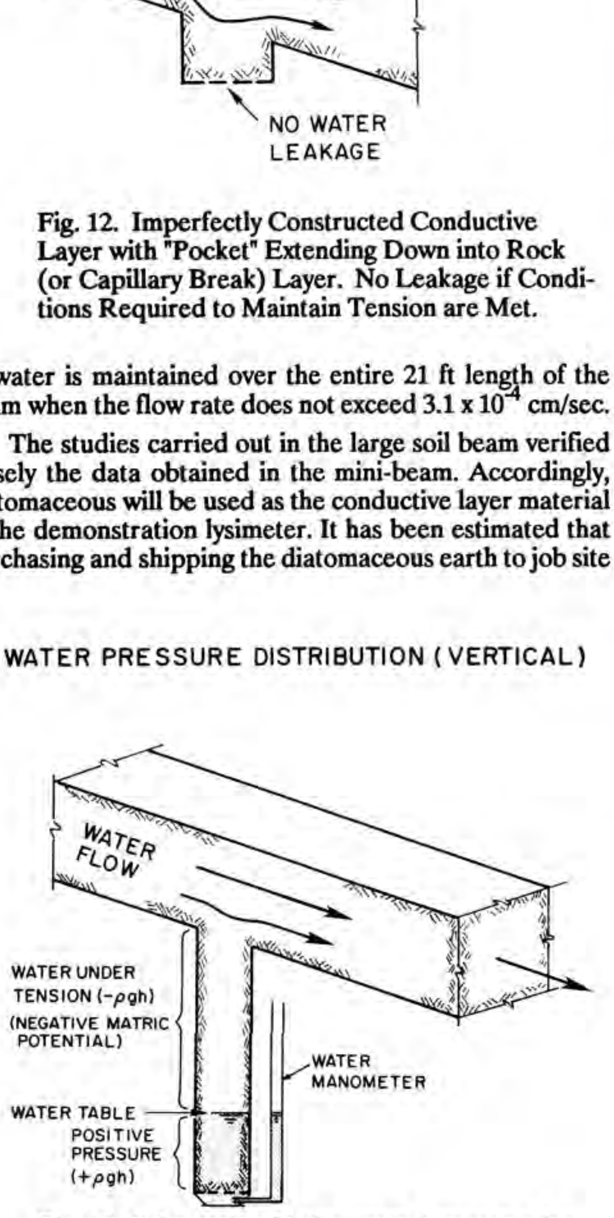

Fig. 13. Schematic of Laboratory Apparatus for Measurement of Water Tension Measurement with Different Materials and Varying Flow Rates.

Fig. 14. Mini-soil Beam used for Evaluation of Materials for Possible Use in Conductive Layer Barrier Application. This Soil Beam has a Total Length of 4.5 ft.

With the time consuming task of selection of the conductive layer material achieved, work on construction of a resistive layer barrier -- conductive layer barrier will be carried out this spring. Christiana clay has been selected as the resistive layer barrier. Testing has shown this material more than meets specifications. A cross section of the cover system to be constructed is shown in Fig. 18.

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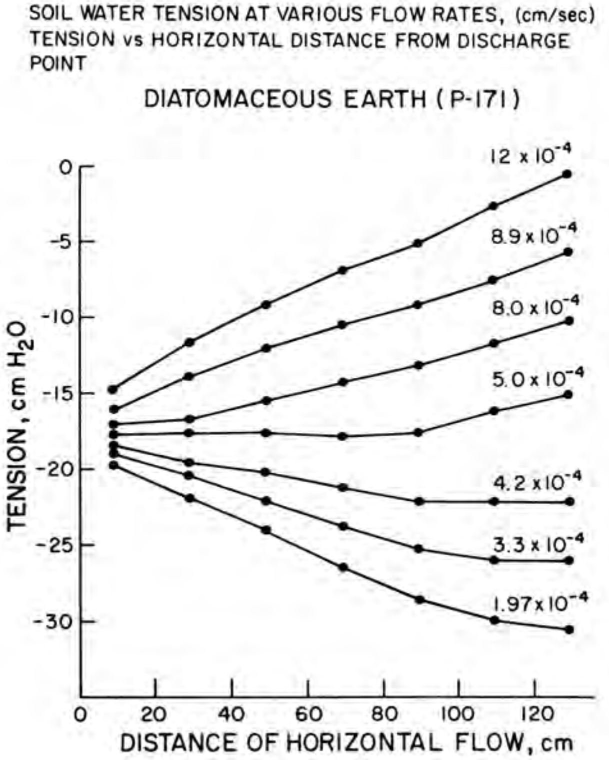

Fig. 15. Soil Water Tension at Various Flow Rates. Tension vs. Horizontal Distance from Discharge Point. Results Suggest that at Rates of 4.2 x 10^{-4} cm/sec or Less, Water Would Remain under Tension at Any Beam Length.

Fig. 16. Large Soil Beam Used for Final Selection of Diatomaceous Earth as Conductive Layer Material.

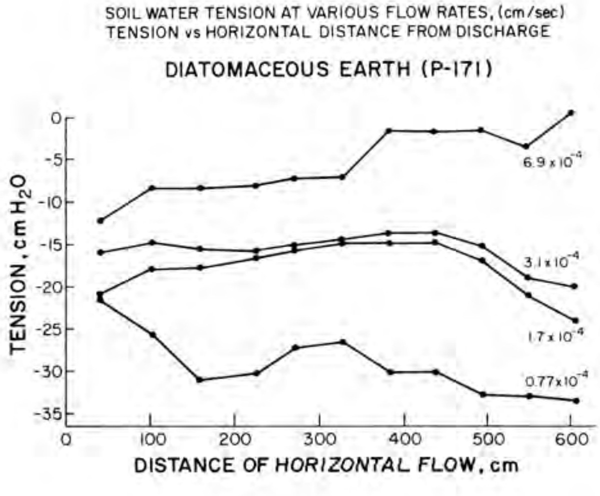

Fig. 17. Soil Water Tension at Various Flow Rates and as Determined Over a 21 ft. Long Flow Distance. At -15 to -20 cm Matric Potential Water Flow Rate is Approximately 3 x 10^{-4} cm/sec.

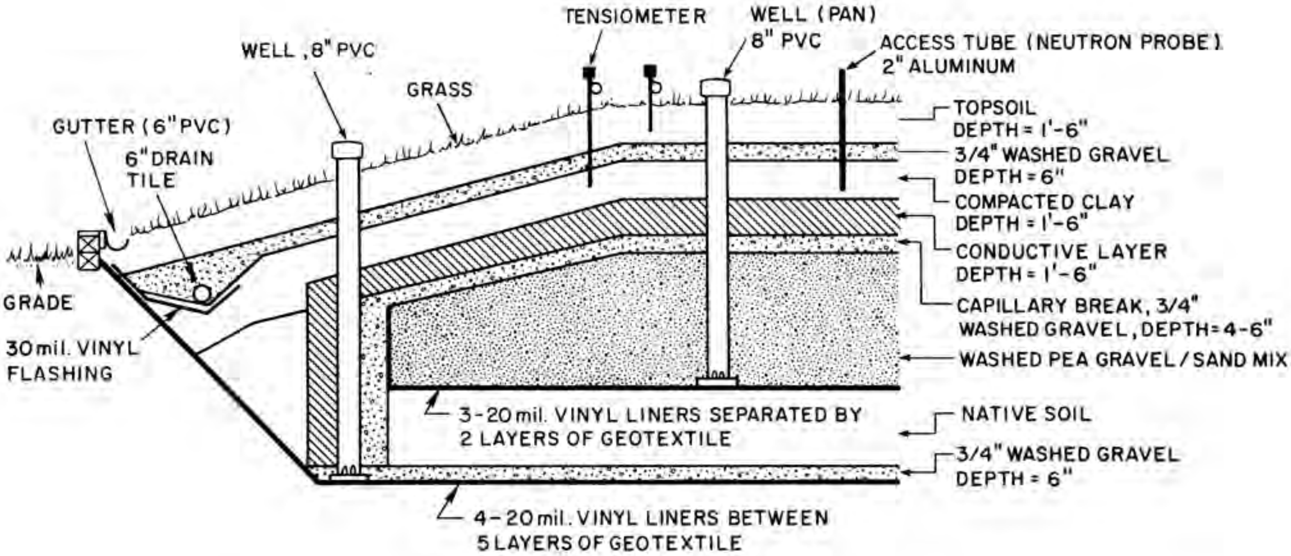

Fig. 18. Combination Resistive Layer Barrier - Conductive Layer Barrier. Resistive Layer Barrier Needs Only to Provide Protection to Approximately 10^{-6} cm/sec. Conductive Layer Barrier of Diatomaceous Earth will Readily Transport Percolating Water Around Waste.