DEVELOPMENT OF A TEST CELL TO EVALUATE EMBANKMENT INFILTRATION

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ABSTRACT

Envirocare of Utah, Inc. (Envirocare) has developed and constructed a test pad to evaluate potential infiltration through the designed cover system over the low-level radioactive waste disposal embankments incorporated at the facility. The general design of the test pad follows the recommendations set forth in the Alternative Cover Assessment Program (ACAP) that is currently funded by the U.S. Environmental Protection Agency (EPA) to assess potential alternatives to conventional landfill cover designs. The bulk of the test pad is below grade with dimensions approximately 16 feet wide by 28 feet long. The base of the test pad is a lysimeter built to the same dimensions as compliance lysimeters within the disposal embankments at Envirocare. The lysimeter collects all liquids to a single low point and directs the liquids through monitoring instruments within a manhole outside the test pad. The lysimeter is constructed to simulate the "top of waste" condition in Envirocare's embankments; consequently, the top of the lysimeter is sloped at an angle of approximately 2.8 percent, the design top slope of the embankment. A replica of the embankment cover is constructed directly above the lysimeter. This cover is constructed exactly the same as final cover is constructed upon the waste disposal embankments, utilizing the same QA/QC measures. The cover consists of (from bottom to top): six feet of compacted clay with a permeability of 1×10^{-6} cm/sec; one foot of compacted clay with a permeability of 5×10^{-8} cm/sec; six inches of a granular filter layer; one foot of sacrificial soil; six inches of a larger granular filter layer; and 18 inches of large grade erosion protection rock. Permanent monitoring equipment has been placed during construction at specific intervals throughout the test pad. Monitoring equipment consists of water content reflectometers (WCRs), matric water potential sensors (heat dissipation units; HDUs), and temperature probes. The monitoring equipment provides cross-sectional data of the moisture content and temperatures throughout the constructed cover. Additionally, surface water runoff is collected through a drainage trough and measured in order to perform a water balance over the entire test pad. To aid in the assessment, data collected from the site meteorological station will be used, including: wind speed, wind direction, air temperature, solar radiation, pan evaporation, and precipitation. The data collected through this test pad will be used to assess the applicability of the performance modeling that was accomplished as part of the original design of the embankments. Analysis of the data generated through this test pad will be the subject of future technical papers.

BACKGROUND

Envirocare is a commercially operated Low-Level Radioactive Waste (LLRW) disposal facility. Disposal is accomplished within engineered embankments consisting of a compacted clay liner, compacted waste layers, and a compacted clay/rock cover system designed to minimize the effects of water infiltration and reduce degradation to ensure long-term stability of the disposal site without the need for ongoing active maintenance (1). Infiltration fate and transport modeling (2) was conducted during the licensing action to ensure that the design would contain waste contaminants for at least 500 years. Conservative parameters were chosen to ensure the modeling analysis would provide a conservative estimation of embankment performance. Infiltration modeling was performed using the EPA Hydrologic Evaluation of Landfill Performance (HELP) model. Moisture content and time of travel through the embankment components were assessed using the UNSAT-H computer model.

Since the inception of Envirocare's Ground Water Quality Discharge Permit in 1993, state regulators have requested a plan be developed and implemented to assure that the performance of the embankment corresponds to the modeling analyses completed during the licensing action. A plan was originally submitted in December, 1993, that utilized Time Domain Reflectometry (TDR) instruments to assess a moisture content profile through the embankment cover. Problems arose with this plan due to potential air voids around the instruments (intimate instrument/soil contact is required for proper operation of these instruments), coaxial cable interferences within the bore holes, the affects of soil salinity, and the need for proper site-specific calibration of the TDRs. These problems were addressed and a second plan submitted in August, 1995. This plan addressed the previous concerns; however, both plans utilized destructive testing within the actual waste embankment cover system. Envirocare and state regulators agreed that non-destructive testing was necessary to avoid compromising the integrity of the waste embankment.

Exploring potential ideas for the satisfactory completion of this project resulted in an examination of similar research conducted under the Alternative Cover Assessment Project (ACAP). The ACAP is an EPA grant funded research project initiated in 1998; an initial report on the research was prepared in 1999 (3). The ACAP research was initiated to examine alternatives to traditional landfill cover designs; additionally, the project examined the applicability of many computer code models including HELP and UNSAT-H. The ACAP research has assessed RCRA Subtitle C and D landfill covers at numerous sites across the nation; however, all of the cover systems examined to-date have included a vegetated component; armored surface covers (as present at Envirocare) have not been assessed.

The typical ACAP research project design includes a small test cell, with a built-in continuous soil moisture monitoring system, overlying a lysimeter designed to directly measure infiltration through the cover. A similar design has been employed at Envirocare. Additionally, ACAP projects construct weather stations near the test cells to attain the necessary parameters for model verification. Envirocare currently operates a weather station from which this data may be obtained.

Infiltration Models

In order to ascertain the type of data collection required for this project, a knowledge of the associated models, along with their input parameters and assumptions, is imperative.

The HELP model (4, 5) is the most widely used model for landfill design due to its availability, comprehensive process incorporation, regulatory acceptance, and ease of use. The HELP code was written for the EPA specifically to evaluate landfill cover designs. This model is a quasi-two dimensional computer code that generally tends to over-predict the amount of drainage (infiltration) through the modeled cover layers (3).

The HELP model uses a simple water mass balance to estimate the drainage out of the system (infiltration; D). This mass balance may be defined mathematically:

$$D = P + SM - R_0 - ET - \Delta S \qquad \text{(Eq. 1)}$$

where P is the precipitation, SM is additional water input from snow melt, R_0 is runoff, ET is evapotranspiration, and ΔS is the change in water storage within the soil (and on the surface). From the input weather data, the code generates daily mean values for precipitation, temperature, and solar radiation. This weather data is then used to compute the variables in Equation 1 and calculate daily drainage values which are then summed to obtain an average annual infiltration through the cover system.

Inputs for the HELP model include the porosity, field capacity, wilting point, and saturated hydraulic conductivity for each layer within the system. Additionally, weather data may be input or taken from a national Oceanographic and Atmospheric Administration (NOAA) database. The field capacity is defined as the volumetric water content at a soil water suction of 0.33 bars. The wilting point is defined as the volumetric water content at a soil water suction of 15 bars. These two parameters are used to estimate water storage and relative unsaturated hydraulic conductivity within the cover system.

In the situation modeled by Envirocare, the UNSAT-H model (6) uses the HELP model infiltration predictions to estimate moisture content and flow velocity profiles through the cover system clays, waste layers, clay liner, and native soils to the surface of the water table underlying the embankment. The UNSAT-H code uses an implicit finite difference method to solve Richard's equation in one-dimension (vertical). The one-dimensional Richard's equation is:

$$C(\theta)\frac{\partial h}{\partial t} = \frac{\partial}{\partial z}\left(K(h)\frac{\partial H}{\partial z}\right) \qquad \text{(Eq. 2)}$$

where C(θ) is the specific moisture capacity (defined as the slope of the moisture retention curve, θ(h)), K(h) is the unsaturated hydraulic conductivity, h is the matric potential (pressure head) of the soil, H is the total hydraulic head, t is the time, and z is the vertical distance. Analytically established water retention data is used to empirically determine the θ(h) function using a van Genuchten water retention model.

In addition to the HELP model infiltration predictions, inputs for the UNSAT-H model include the specific node geometry used to solve the Richard's equation, boundary conditions (head and infiltration), initial conditions (head), and material properties for each layer (moisture retention data, saturated hydraulic conductivity, van Genuchten parameters).

DESIGN

From an analysis of the infiltration modeling parameters briefly described above, the most important parameter necessary for verification of the numerical modeling analyses is a quantitative analysis of the infiltration through the cover. Previous proposed model verification plans for Envirocare (discussed above) did not include a quantitative assessment of the amount of infiltration through the cover system. In order to achieve this primary goal, it was necessary to design a test cell separate from the actual waste disposal embankment and include a real-time infiltration measurement system.

General Test Cell Description

Figures 1 – 3 provides a graphical description of the final test cell design. The test cell is designed partially below grade and consists of a cover system identical to that used upon the waste disposal embankment overlying a lysimeter constructed to collect drainage through the test cell and provide real-time infiltration measurement.

Figure 1 shows a plan view and Figure 2 a west-east cross-section of the test cell. The test cell dimensions are 16 feet by 28 feet. These dimensions were chosen to match the size of the lysimeter (see below) with one foot overlap on all sides to limit external water infiltration. Moisture content, moisture potential, and temperature reading instruments are located both vertically and horizontally throughout the test cell. The entire test cell is constructed with an approximate slope of 2.8%. This parameter is necessary to model actual conditions within the waste disposal embankment (cover system design top slope is approximately 2.8%).

Drainage through the test cell (infiltration) is collected in the lysimeter and allowed to flow to a manhole that contains flow measurement instruments (rain gage and dosing siphon basin). Similarly, runoff is collected in a drainage trough at the base of the slope and conveyed through a flow measurement instrument (dosing siphon basin) and disposed in a leach field located southwest of the test cell. The drainage trough is protected from direct moisture accumulation by an HDPE geomembrane cover.

Lysimeter

The lysimeter at the base of the test cell is constructed identical to compliance lysimeters located within the waste disposal embankment. Details of the lysimeter and manhole are depicted in Figure 3. The lysimeter directs all water to a low point within the system where a PVC pipe collects the drainage and delivers it to the manhole (and the flow measurement instruments). The lysimeter consists of a compacted clay base overlain by an HDPE geomembrane liner. The collection pipe is welded into the HDPE geomembrane using a boot as shown in the drawing to ensure that all water is collected through the pipe; no water can leave the system through this "seam". A layer of rounded stone is placed into the lysimeter to maintain the strength of the system; allowing water collection without damaging the HDPE liner. This layer is overlain by a coarse sand layer that provides a base for the overlying compacted clay layers of the cover system. As shown in Figure 2, the top of the lysimeter is sloped at an angle of approximately 2.8%.

Cover System

The cover system overlays the lysimeter and is constructed with the same materials and controls as the waste disposal embankment. The facility cover design employed in the test pad is shown in Figure 2 and consists of the following elements (from bottom to top):

- a 6-foot thick layer of clay compacted to a permeability of 1×10^{-6} cm/sec;
- a 1-foot thick layer of clay compacted to a permeability of 5×10^{-8} cm/sec;
- a 6-inch thick coarse rock filter drainage zone;
- a 1-foot thick sacrificial soil layer (freeze-thaw barrier);
- a 6-inch thick coarse rock filter transition zone; and
- an 18-inch thick large rock Rip-Rap erosion barrier.

Monitoring Instruments

In order to assess the necessary parameters without compromising the integrity of the cover system (and thereby compromising the results of this study), monitoring instruments have been built into the test cell at specific locations during construction. The specific monitoring locations are shown in Figures 1 and 2.

Water Content Reflectometers (WCRs) are used to measure moisture content within the soil. WCRs are similar in operation to Time Domain Reflectometers (TDRs); however, they are more adaptable for high saline environments as found in the soils at Envirocare. The manufacturer contends that, with proper calibration, WCRs retain their accuracy in any soil type. The WCRs consist of two parallel 30 cm stainless steel rods connected to a shielded circuit board to supply power and monitor the signal. Moisture content is measured by reading the frequency or period of a wave pulse sent down the rods. Signal reflection is influenced by the dielectric constant of the material between the rods. A higher dialectric material will have a slower response signal. Since water is more dialectric than most materials, a wet or moist material will reflect much slower than a drier material. Specific calibrations for individual soils may be conducted and the output signal may be easily transformed into a moisture content reading. An important aspect of WCRs is that intimate soil/rod contact must be maintained throughout the length of the instrument in order to obtain accurate readings.

Soil matric potential probes (Heat Dissipation Units; HDUs) are used to quantitate the matric potential of the soil. An HDU is a small, fragile instrument with a ceramic cylinder approximately 1.5 cm in diameter and 3.2 cm long. The instruments consist of a heating element needle and a thermocouple surrounded by a ceramic cylinder. During data collection, a constant current source applies 50 milliamps to the heating element for 30 seconds and the corresponding temperature increase within the surrounding soil is measured by the thermocouple. This temperature increase may be correlated to a matric potential through fitted calibration curves. Due to inconsistencies in construction of these instruments, each instrument has a unique calibration curve. Therefore, individual instrument calibrations where performed prior to construction of the test cell.

Matric potential is the amount of tension retained within the soil due to small amounts of water in the soil matrix; it corresponds to the pressure work required per unit quantity of water to move water within the system to a neighboring point at the same elevation. Matric potential is otherwise known as pressure potential or pressure head. Gradients in matric potential are important because they show the movement of water within the system. Matric potential is especially important for assessing moisture retention of the soils in relation to plant growth. However, the cover systems at Envirocare contain armored surfaces, not vegetated; therefore, matric potential is not essential for this assessment, but may be used as a redundant measure of moisture content and to provide a measure of moisture gradients throughout the test cover system.

Temperature probes are used to measure temperature gradients throughout the test cell.

Monitoring locations were chosen in order to attain a moisture profile down the slope of the test cell. The monitoring locations are labeled WCR-1 through WCR-5 and are depicted in Figure 1. Two locations are situated on the crest of the test cell, two near the lower end of the test cell, and a fifth at the midpoint. In order to obtain a three-dimensional profile of drainage within the test cell, each monitoring location contains specific monitoring points at four different depths. These depths are depicted in Figure 2:

- Depth A is located at the approximate midpoint of the sacrificial soil;
- Depth B is located at the approximate midpoint of the 5 x 10^{-8} cm/sec clay layer;
- Depth C is located approximately four feet from the bottom of the cover system; and
- Depth D is located approximately two feet from the bottom of the cover system.

Each specific monitoring point consist of a WCR, an HDU, and a temperature probe. The instruments are placed in an evenly spaced radial pattern around the center of each monitoring location at each specific monitoring point.

The sixth monitoring location, THERM-1, is being utilized to analyze the frost and evaporative zone depths. Therefore, this monitoring location consists of various WCRs and temperature probes in the sacrificial soil, rock filter drainage zone, and upper clay.

Monitoring instruments are also included to analyze the amount of water collected by the lysimeter (infiltration) and the drainage trough (runoff). Water collected by the lysimeter is conveyed through a drainage pipe to the lysimeter drainage measurement manhole. At this point, the water is measured using a 0.01 inch tipping bucket rain gage or, if flows become great, a dosing siphon basin calibrated to dose at approximately 90 liters. Runoff from the drainage trough is conveyed through a separate dosing siphon calibrated to dose at approximately 90 liters.

Dosing siphon basins are enclosed, fixed-volume cylindrical vessels with a dosing siphon mounted to the base. Dosing siphons consist of a trap with a vent pipe on one end and a "bell" covering the other end with a snifter pipe extending into the open end of the trap. When the fluid within the basin rises above the open end of the snifter pipe, air is sealed in the bell and trap. Once the fluid builds up to a level where the fluid pressure exceeds the pressure of the air within the trap, the air is forced through the trap and the siphon is "tripped," releasing fluid until the fluid level reaches the level of the open end of the snifter pipe. Therefore, a specific quantity of liquid is released each time the siphon is "tripped" (this volume is calibrated at approximately 90 liters for the instruments used in the test cell). An electronic counter monitors the number of times that the siphon "trips" to yield a flow measurement through the instrument.

All instruments are tied into a datalogger and information is downloaded periodically to a notebook PC to analyze data. Power is supplied to the system using a battery that is recharged continuously using a solar panel located at the test cell. The datalogger has been programmed to collect the following data:

- Temperature is collected every minute with an hourly average computed for output
- WCR measurements are collected once every hour
- HDU measurements are collected once a day at noon

Furthermore, the site has a weather monitoring station that provides hourly data for the following parameters: pan evaporation, temperature at two meters off the ground, temperature at nine meters off the ground, solar radiation, mean wind speed, and mean wind direction (and standard deviation). This data is downloaded for analysis once a month.

CONSTRUCTION

Excavation for the test cell began on August 3, 2001. The lysimeter was completed on August 10, 2001.

In order to provide a realistic examination of the waste disposal embankment cover system, the cover system layers needed to be constructed to the specifications and controls provided in Envirocare's Construction QA/QC Manual (CQA/QC) utilized in the waste disposal embankment. This manual requires that an approved compaction method be constructed by qualified personnel. Approval, granted by the Utah Division of Radiation Control (DRC), is accomplished through the satisfactory completion of a test pad. The test pad method is designed to prove that appropriate construction controls will be attained when the demonstrated construction techniques are utilized. Due to the sensitivity of the instruments, it was necessary to institute a new compaction method for both of the clay layers using hand compaction equipment. The test pad was performed and approval was received on August 17, 2001.

Initially, the monitoring instruments were to be placed within the clay layers by completing compaction of the clay layers to a depth slightly greater than the desired monitoring depth, digging a small trench in the compacted material, inserting the instruments into the compacted material through the sidewall of the trench, replacing the material in the trench, and hand compacting to specification. However, it was determined that this plan would be difficult to accomplish and would be time consuming due to the solidity of the compacted clay. Furthermore, it was determined that normal compaction techniques would ensure the intimate soil/rod contact necessary for proper operation of the WCR instruments. Therefore, the initial installation method was abandoned for a simpler method where the instruments are placed on completed lifts of compacted material with subsequent lifts placed and compacted above them.

Test cell construction and instrument installation consisted of completing clay compaction to the level of the depth D instruments using normal compaction methods (nine-inch loose lift of material compacted to 95% of a Standard Proctor using a padfoot compactor with 8-9 inch teeth). At this time, the five monitoring locations and depth of each monitoring point were surveyed and the instruments were placed upon the completed lift of compacted clay at the specific monitoring points. All cables were labeled and run to a single side of the test cell (east) for datalogger connection after test cell completion. A nine inch loose lift of clay was placed above the instruments and compacted to specification using the approved hand compaction technique (the padfoot compactor could not be used because the teeth would damage the instruments). After the first lift of material above the instruments was compacted to specification, further lifts were placed using normal compaction processes (padfoot compactor) until the next instrument depth was reached. This process was continued for the other two specific monitoring point depths (B and C) within the compacted clay layers.

The fourth specific monitoring point (depth A) is located within the sacrificial soil which is an uncompacted freeze-thaw protection layer. This layer was placed in two separate lifts; the instruments were placed on top of the first lift prior to placing the second lift. No compaction was necessary for this material; however, care was taken to maintain intimate soil/rod contact for all of the WCR instruments within this layer.

Monitoring location THERM-1 included placing temperature probes throughout the rock layers to obtain a vertical temperature profile throughout the upper portion of the cover system. Additionally, WCR instruments were placed in the rock layers by experimentally "sandwiching" the probe rods with two pieces of geonet and placing the assembly into the rock layers. This experiment was necessary to attempt to attain intimate contact throughout the length of the instrument probes so that an accurate reading of moisture content within the rock filter drainage layer could be attained.

Construction of the compacted clay layers (and associated instrumentation) was completed and DRC inspection and approval (CQA/QC requirement) was received on September 7, 2001. The completed clay surface protruded approximately one foot above the ground surface. A clean vertical cut of the clay was made where the collection drainage trough was to be constructed. HDPE geomembrane was then placed within the trough area and filter rock was placed upon the test cell and within the trough (see Figure 2). The excess geomembrane was wrapped over the filter rock to eliminate direct precipitation falling into the trough. The sacrificial soil and rock layers were then completed over the test cell. Construction of the test cell was completed on September 10, 2001.

A berm was constructed around the test cell to ensure upstream runon did not interfere with measurements. All of the instrument cables are wired to a programmable datalogger in an enclosure to the east of the test cell. All construction was completed and data collection began on September 19, 2001.

DISCUSSION AND OBSERVATIONS

General construction of the test cell was relatively straight-forward considering the engineers and contractors assigned to construct the test cell construct similar systems daily, albeit on a much larger scale. The addition of monitoring instruments into the design provided a unique challenge during construction. Wiring of the instruments to the datalogger was accomplished after construction of the test cell was completed. Some problems occurred during construction relating to the monitoring instruments and these problems were not detected until the datalogger connection was completed. These problems are discussed below.

As mentioned above, the HDU instruments are small, fragile ceramic devices. Upon wiring the instruments into the datalogger, it was discovered that only one of the level D instruments and two of the level C instruments were functioning properly; however all of the level A and B instruments are operational. It is not apparent if the lower level (greater depth) instruments were destroyed by equipment during placement and compaction or if their fragile frame could not manage the stresses associated with this deep burial and the associated overall compaction. The destruction of these instruments is not critical due to two factors: (1) these instruments are not essential to the analysis, they simply provide a redundant measure of moisture content and a measure of moisture gradients throughout the test cell; and (2) at least one instrument "survived" on each monitoring level of the test cell, thereby allowing some data to be obtained for all monitored depths. It is advised that future test cell construction examine a safer way to install these delicate instruments. A potential solution is to utilize the trench scheme that was initially examined for this project.

Another problem encountered dealt with the WCR instruments. Upon initially wiring the instruments to the datalogger, no readings were detected. Normal operation and programming of the datalogger places a specific range for the frequency output from the WCRs. This normal output is typically less than two milliseconds, but is much larger for a soil with a high electrical conductivity. The salinity of the site soils used in construction of the test cell are extremely high, providing a high electrical conductivity within the soils. Therefore, it was determined that readings could be detected by raising the threshold of the datalogger program. The datalogger was reprogrammed and, after several attempts, appropriate readings were obtained for all but one of the WCR instruments (this one outlier was obviously shorted and was disconnected from the system). To obtain these higher detection limits, the datalogger was reprogrammed to read the data in hertz instead of milliseconds. Frequency readings from instruments within the higher saline clay originally ranged from approximately four to 25 milliseconds. Since these initial readings, the higher measurements have been consistently lowering as the entire test cell equilibrates. Current (January) measurements are almost all between 3.5 and 6.5 milliseconds. Calibrations have been performed equilibrating the frequency measurement to a moisture content for each of the soil types (sacrificial soil, 5×10^{-8} cm/sec clay, and 1×10^{-6} cm/sec clay).

An additional problem encountered with the WCR instruments was the "experimental" geonet sandwich placed around the instruments within the rock layer. This experiment obviously failed because readings from the two instruments placed in this manner are the same as the test instrument in air. Therefore intimate contact was not maintained and these instruments do not provide valid data. However, this was only an experimental measurement and does not provide vital data for the primary goal of the test cell.

Through the first four months of data collection, all instruments that are operating properly appear to be providing consistent data. The entire test cell is in the process of reaching a state of equilibrium and this is evident in much of the preliminary data collected. However, the data also shows that equilibration of the test cell is not yet complete and may require many months to reach stability.

Temperatures and moisture contents within the sacrificial soil layer correspond extremely well to monitored site weather data. An extremely wet storm was recorded in late November which corresponds exactly to a large increase in moisture content and decrease in moisture potential within this layer. Furthermore, temperatures within this layer have been dropping with the air temperature throughout the months of November and December. Current temperatures at the midpoint of the sacrificial soil layer are two to three degrees Celsius (˚C); temperature at construction was approximately 20 ˚C.

In general, the temperature and moisture content of the clay layers has gradually dropped throughout the initial four month monitoring period. As expected, moisture content within these layers has been unaffected by the external weather and is gradually drying out since the layers were placed wet to attain the desired compaction specifications. Some unusually readings have been attained; however, equilibration is continuing and these unusual measurements are decreasing with time. Temperatures within the clay layers range from 10 – 15 ˚C. Currently, the temperature at the surface of the clay is approximately 8 ˚C.

Neither dosing siphon has "tripped" yet. This is expected since the previous precipitation was absorbed into the sacrificial soil layer, increasing the moisture content while still remaining below saturation. Furthermore, it is expected that the lysimeter dosing siphon will never attain enough water to "trip". One tip of the tipping bucket range gauge within the lysimeter collection manhole has been recorded. This occurred in late September and is attributed to the excess moisture present during construction of the test cell.

CONCLUSIONS

Infiltration through landfill embankment cover systems may be approximated using numerical modeling techniques. However, numerous assumptions about physical conditions present and water storage within the embankment add uncertainties to the modeling results. The test cell described in this paper will provide data that will be used to substantiate the numerical modeling performed during licensing activities at Envirocare. Previous studies (7, 8) have shown that a water-balanced lysimeter test system is currently the only available method that can quantify the performance of landfill covers and validate numerical models.

Typical studies in this area (primarily the ACAP) have attempted to validate numerical modeling techniques. Absolute validation of a model is unrealistic since this validation would require testing over the entire range of parameters. Typical validation techniques are designed to assure that relatively accurate accounts of natural conditions are explained through modeling.

However, validation of the model itself is not a critical path for the assessment performed by Envirocare. Validation is only necessary to confirm that the numerical modeling performed during design of the embankment provides a conservative estimate of actual conditions at the site. Conservative modeling is more important than accurate modeling for the embankment design at Envirocare.

Preliminary data show consistent moisture content and temperature measurements within the test cell, which is currently in the process of equilibrating. Years of data collection and processing will be necessary to validate the conservative estimates used in the original design modeling. The test cell described in this report provides a basis for future verification of modeling techniques and embankment design.

ACKNOWLEDGEMENTS

The author would like to acknowledge Bruce Smith for overseeing construction of the test cell and Broken Arrow for completing the construction. Completion of the project could not have been accomplished if it not for the wiring and datalogger programming and troubleshooting by Brad Lyles of the Desert Research Institute. The wisdom and knowledge provided by Dr. Glendon Gee of Pacific Northwest National Laboratory and Bill Albright of the Desert Research Institute has proved invaluable to the success of this project. Furthermore, thanks to Kenn Lutz for constructing and completing the design drawings.

REFERENCES

1. Utah Radiation Control Rules R313-25-22
2. Adrian Brown. "Volume I. Final Report on Infiltration Modeling, Input Parameters and Results" Report 3101B.97124, December 4, 1997. In: Envirocare of Utah, Inc. Application for Renewal Radioactive Material License Number UT2300249, revision 6, Appendix M, March 16, 1998.
3. Wilson, G.V., Albright, W.H., Gee, G.W., Fayer, M.J., Ogan, B. "Alternative Cover Assessment Project: Phase I Report." Prepared for the U.S. EPA, contract no. 44-0000-2038, August, 1999.
4. Schroeder, P.R., Aziz, N.M., Lloyd, C.M., Zappi, P.A. "The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide for Version 3," EPA/600/R-94/168A; US EPA Office of Research and Development, Washington D.C. (1994)
5. Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., Peyton, R.L. "The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Guide for Version 3," EPA/600/R-94/168B; US EPA Office of Research and Development, Washington D.C. (1994)
6. Fayer M.J., Jones, T.L., "UNSAT-H version 2.0: Unsaturated Soil Water and Heat Flow Model," PNL-6779, Battelle Memorial Institute, April, 1990.
7. Khire, M. V., C. H. Benson and P. J. Bosscher, "Water balance of two earthen landfill caps in a semi-arid climate." In: Proceedings of 1997 International Containment Technology Conference and Exhibition,, St. Petersburg, FL (1997).
8. Khire, M.V., C.H. Benson and P.J. Bosscher, "Water balance of earthen final covers at humid and semi-arid sites." *J. of Geotech. And Geoenv. Eng., ASCE*, 123:744-754 (1997).

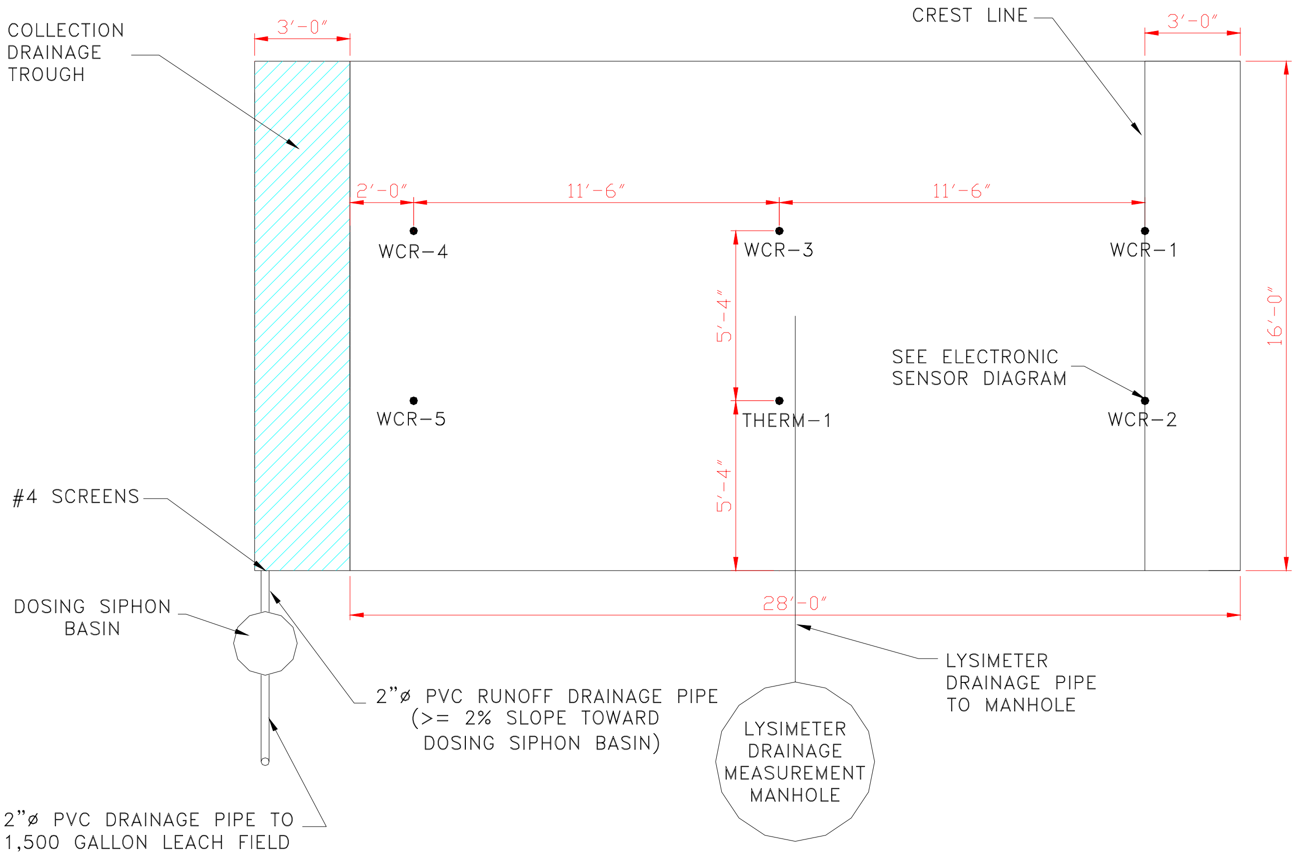

Fig. 1. Test Cell Plan View

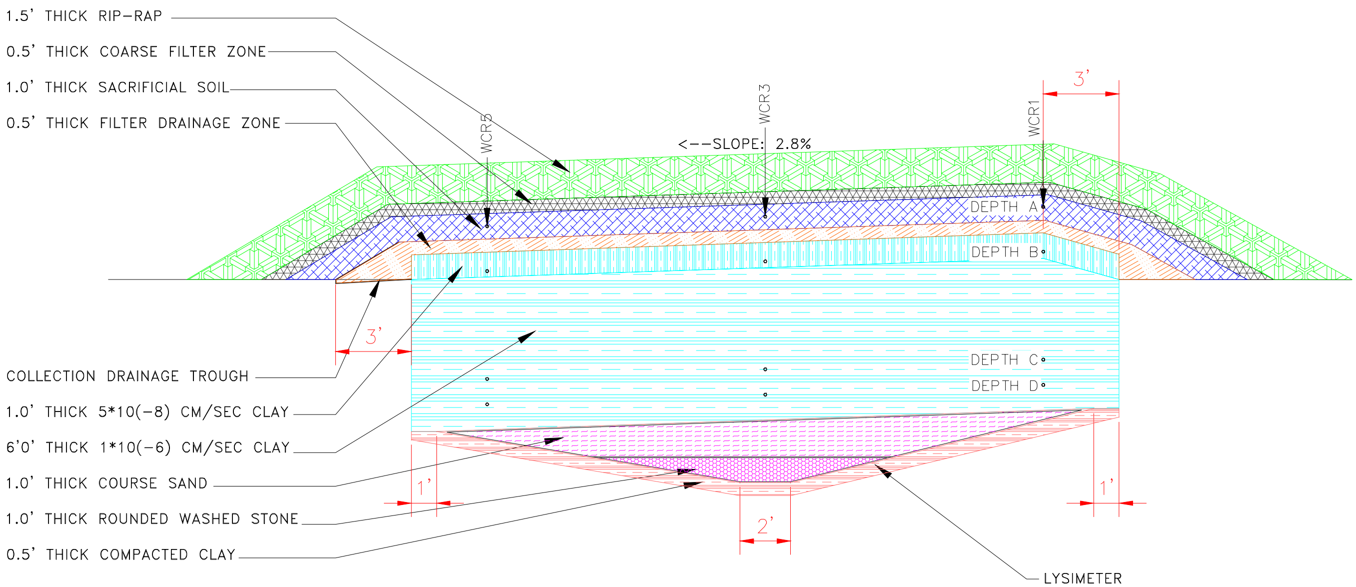

Fig. 2. Test Cell Cross-Section

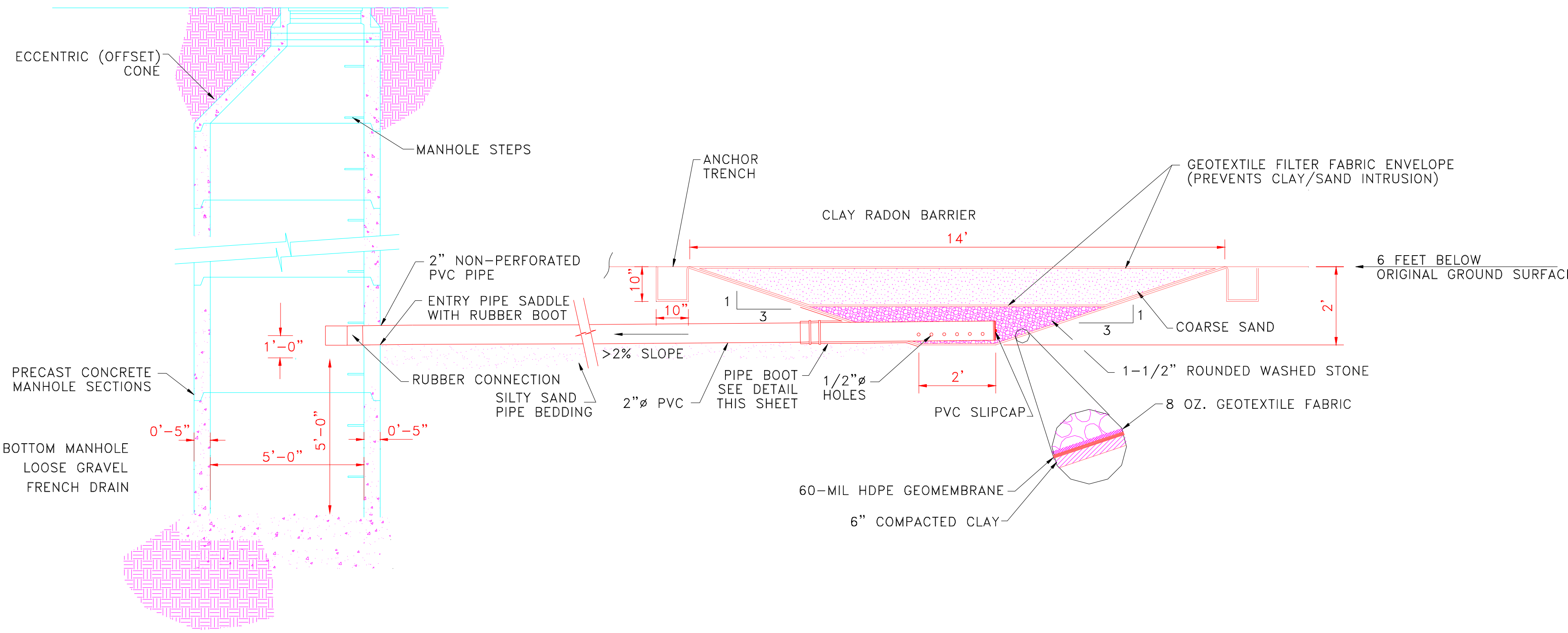

Fig. 3. Lysimeter Details