COMPACTED CLAY PERFORMANCE IN A LANDFILL FINAL COVER SYSTEM

The Omega Hills Landfill is located approximately 20 miles northwest of Milwaukee, Wisconsin. It is an 83-acre site that contains approximately 14 million cubic yards of waste. The hydrologic performance of three final cover systems were studied using instrumented test plots in the landfill. Two plots consisted of silty loam soils placed over thick sections of compacted clay and the third plot consists of a sand layer placed between two compacted clay layers to utilize the "wick effect".

The objective of the project was to determine the hydraulic performance of the different final cover systems installed at Omega Hills. Precipitation, runoff, percolation, air and soil temperature and soil moisture tensiometer data was collected using a data logger at the site. Throughout the monitoring program, data was collected during periods of severe drought as well as periods of heavy precipitation. Water budget calculations were performed to determine if water was entering the landfill, being stored in the cover system or was lost to evapotranspiration. Test pit excavations were also used to determine in situ conditions of the final cover systems.

Field data collected indicates that fully penetrating cracks developed in the compacted clay cover, which allowed increased water percolation into the landfill. Drought conditions may be much more damaging to a final cover system than a continuous supply of moisture. The use of a multi-layered cover system did not reduce percolation rates due to water storage in the upper clay layer. The upper clay layer became severely cracked and allowed rapid infiltration of water into the intermediate sand layer.

THE OMEGA HILLS FINAL COVER TEST PLOT STUDY: THREE-YEAR DATA SUMMARY

by

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ABSTRACT

Instrumented test plots have been installed at the Omega Hills Landfill, located near Milwaukee, Wisconsin, to collect data on the hydrologic performance of three final cover designs. Each of the test plot designs employs natural soils installed on 3H:1V landfill sideslopes. Two designs incorporate different thicknesses of local silty loam topsoils over thick sections of compacted clay soils. The third design is a multi-layered cover, intended to take advantage of the so-called "wick effect" by placing a sand layer between two compacted clay layers, with topsoil above. In addition, two cover vegetation species mixes are being evaluated in separate test areas. Data collection began in August of 1986, and included a significant period of drought in 1988, as well as periods of heavy precipitation. After approximately three years of data collection, several observations appear to be significant. The propagation of cracks within the clay soils appears to be all-important to the performance of the cover designs evaluated. The upper clay layer of the multi-layered design has developed substantial cracking which has apparently allowed transmission of large amounts of infiltrated moisture to the intermediate sand layer. However, percolation from the base of the multi-layered cover has remained relatively low, apparently due to the continued moist and homogeneous conditions in the clay layer below the intermediate sand. The two all-clay test sections initially showed very little percolation. However, percolation has increased substantially through time, again apparently related to the development and propagation of cracks through the clay soils. A summary of the collected data is presented, as well as observations and interpretations based on field observations and test pits.

BACKGROUND

The Omega Hills Landfill, operated by Waste Management of Wisconsin, Inc., is located approximately 20 miles northwest of the center of Milwaukee, Wisconsin. The 83-acre site has been active since the 1970's, and has recently completed filling of its approximately 14 million cu yd licensed capacity. Waste Management of Wisconsin has conducted a very substantial program of environmental measures to control offsite leachate migration, provide gas control and energy conversion and to extract and treat leachate from within the site. This program won recognition in the American Society of Civil Engineers 1986 Outstanding Civil Engineering Achievement Awards.

DESCRIPTION OF TEST PLOTS

The final cover test plot study is a research project being conducted by Waste Management to evaluate the performance of several final cover designs as part of development of a new leachate control program for the site. The objective of the study is to evaluate the hydrologic performance of alternative cover designs, especially with respect to the percolation of precipitation moisture into the landfill.

Three cover designs and two vegetation species mixes are arranged in three instrumented test plots and in two vegetation assessment areas, located on the western outboard slope of the Omega Hills Landfill. Three main concepts are being evaluated in the test plot study, in comparison with the approved final cover design for the site: 1) the use of a thicker topsoil layer to promote vegetative growth and thus enhance evapotranspiration; 2) the use of a multi-layered find/coarse/fine soil arrangement to limit the percolation out of the upper fine-grained soil via the so-called "wick effect"; and 3) the use of a more vigorous and multi-specied cover vegetation to fully exploit the available root zone to enhance evapotranspiration. A detailed description of the design and construction of the test plots was provided by Montgomery, et. al.[1] The test plot designs are as follows (see also Figure 1):

• Test Plot 1: (Existing Cover Design)	6 in. topsoil, primary seed mix 48 in. compacted clay
• Test Plot 2: (Thicker Topsoil Design)	18 in. topsoil, primary seed mix 48 in. compacted clay
• Test Plot 3: (Wick Effect Design)	6 in. topsoil, primary seed mix 24 in. compacted clay 12 in. intermediate sand layer 24 in. compacted clay
• Vegetation Assessment Area 1	6 in. topsoil, alternative seed mix 48 in. compacted clay
• Vegetation Assessment Area 2	18 in. topsoil, alternative seed mix 48 in. compacted clay

The cover clay soils utilized had very high silt and non-expansive clay content (USCS CL), and were placed and compacted in approximately 6" lifts using conventional earth moving equipment to in-place densities corresponding to lab permeabilities of less than 1×10^{-7} cm/sec. The topsoil was an uncompacted clay loam to silty clay loam. The intermediate sand layer in Test Plot 3 was composed of a clean, washed medium sand.

The primary seed mix contains tall fescue (Festuca arundinacea), creeping red fescue (Festuca rubra), annual ryegrass (Lolium Multi-florum), perennial ryegrass (Lolium perenne), and Kentucky bluegrass (Poa pratense). The alternate seed mix contains smooth bromegrass (Bromus inermis), birdsfoot trefoil (Lotus corniculatus), tall fescue (Lestuca arundinacea), creeping red fescue (Festuca rubra) and perennial ryegrass (Lolium perenne).

Test Plots 1, 2 and 3 are instrumented for collection of hydrologic data, and are also monitored for vegetation growth parameters. Figure 2 is a schematic layout of one of the test plots, and indicates the location of the instrumentation. Figure 3 is a schematic section through one of the test plots, showing the runoff and percolation monitoring system, as well as the soil moisture monitoring instrumentation. Figure 4 depicts the overall layout of the instrumented test plots and vegetation assessment area, all located on the western outboard slope of the Omega Hills landfill.

Construction of the basal percolation collection systems and placement of the clay cover soils was conducted in September through November of 1985. Topsoil placement and instrumentation of the test plots was completed by July of 1986, and data collection began in August.

DATA COLLECTION

Precipitation, runoff, percolation, air and soil temperature, and soil moisture tensiometer data is collected using a data logging system, which allowed remote access to data via telephone modem. Precipitation data is collected using a heated tipping bucket rain gage. Runoff and percolation data is collected for each test plot using pressure transducers installed in collection tanks (refer to Figure 2). The transducers indicate water level within the tank, with the ratio of tank area to plot area used to obtain runoff and percolation depths. Test Plot 3 utilizes a collection tank for collecting flow from the intermediate sand layer, as well as for percolation and surface runoff (See Figure 4). Air temperature and relative humidity data is collected using sensors monitored by the data logger. Cover soil temperature is also monitored using the data logger, with sensors buried at depths of 1, 3 and 5 ft below the surface of the 3H:1V sideslopes of the landfill. Two nests of soil moisture tensiometers are installed in each instrumented test plot, with from 5 to 7 tensiometers (with tips at different levels) in each nest. Each of the tensiometers was equipped with a pressure transducer wired to a multiplex input to the data logger. Data logger collection frequency was hourly from August, 1986 through September 1989, when it was altered to four-hourly.

Soil moisture data was also collected using a neutron probe. Seven galvanized steel access tubes were driven into each test plot, and the probe was field-calibrated using laboratory soil moisture data from field samples.

Vegetation density and root penetration data was collected approximately twice-yearly, for both the alternative seed mix assessment areas, as well as for non-instrumented sections of Test Plots 1, 2 and 3.

Data collection has been continuous since mid-August 1986, and the collected data is believed to present an accurate description of overall test section performance. However, some problems have been encountered in the data collection program, summarized below:

- The heated tipping bucket rain gage occasionally malfunctioned, requiring the use of daily precipitation data form the NOAA observation station at Germantown, Wisconsin (3.2 mi NW of the landfill) to fill in the gaps.

- The tensiometer pressure transducers experienced a high rate of failure, and monitoring was discontinued in September 1988. Soil moisture monitoring with the neutron probe has continued.

- Evaluation of vegetation density and root penetration, and comparison of the primary and alternative seed mixes was very difficult, due to the immaturity of the vegetation stand (even in 1989), disturbance caused by instrumentation maintenance and mowing, and the effects of the drought of 1988.

One of the most reliable sets of data from the test plot data are the monthly summaries of hydrologic balance for Test Plots 1, 2 and 3. This data, for the period August 1986 through August 1989, is presented in Table I.

CLIMATE DURING DATA COLLECTION PERIOD

The data collection period includes three complete years of September-through-August data, beginning in September 1986. These years had widely different climactic characteristics.

The 12 month period September 1986 through August 1987 was "near-normal", except for a period of extraordinarily high rainfall in September 1986. This rainfall occurred with the cover vegetation in its initial growth stages, and produced substantial runoff, as well as surprisingly large flow of moisture from the intermediate sand layer of Test Plot 3 (See Table I). The remainder of 1986 and the growing season of 1987 provided a near average climate, and the vegetative cover developed substantially.

The period September 1987 through 1988 was dominated by the severe drought of 1988. Although temperature and moisture conditions were near-normal through April, the months of May through August were characterized by substantially below average rainfall, and temperatures averaging as much as 10°F above average. These conditions quickly reduced the cover vegetation to a dry, dormant state, and obvious cracking of the surface of the cover soils became evident.

The last year of data collection, September 1988 through August 1989 saw a return to moist conditions. Substantial rainfall in September of 1988 restored the vegetation to an active growing state, but also apparently allowed moisture influx to deeper portions of the cover via cracks which had developed in the preceding dry conditions. After a relatively mild winter, a generally wetter-than-average growing season produced lush vegetation growth in the summer of 1989.

TEST PIT EXCAVATIONS

The hydrologic response of the test plots observed through the summer of 1988 indicated that moisture flow in several sections of the cover was much more rapid than would be expected under porous media flow conditions. These areas, especially the upper clay of Test Plot 3, exhibited substantial flow rates which suggested that in homogeneities had developed, possibly by cracking due to drought conditions. In addition, the extent of root penetration and the development of altered soil structures within the covers was of interest. For these reasons, a series of test pits were excavated into the cover sections in September 1988.

Five test pits were excavated in the buffer strip adjacent to each test plot and in the vegetation assessment areas. The soil profile in this buffer strip is representative of each adjacent test plot. The purpose of the test pit excavations was to characterize the final cover soil profiles and to aid in the interpretation of the hydrologic budget data.

The 4 ft by 10 ft test pits were excavated to 6 ft deep via a track mounted backhoe. Samples were taken at approximately one foot increments or when material characteristics changed and soil moisture contents (dry weight basis) were determined. Shrinkage limits were determined on the upper and lower clay for Test Plots 1, 2 and 3 following ASTM D427 procedures. Key results of the test pit investigation are listed below.

- The upper 8 to 10 inches of clay in all three test plots appeared weathered and exhibited a medium to coarse sized blocky structure.

- Occasional larger cracks, 1/4 to 1/2 inch wide, extended 35 to 40 inches into the clay, beyond the topsoil/clay interface, in Test Plots 1 and 2 and through the entire upper clay in Test Plot 3. A noticeable curvature of cracks downslope was observed, particularly in Test Plots 1 and 2.

- A continuous root mass penetrated 8 to 10 inches into the clay below the topsoil/clay interface. Further root penetration occurred along crack planes approximately 30 inches below the topsoil/clay interface.

- The clay texture at the base of each test plot exhibited higher moisture contents and no evidence of cracking.

- No distinguishable separations between lifts associated with placement of the clay were observed in any of the profiles.

- Shrinkage limits ranged from 10 to 12% moisture content on a dry weight basis (approximately 20 to 24% on a volume basis). The shrinkage limit is the moisture content at which the soil volume will not change upon further drying. Moisture content data taken via the neutron probe during the dry period in June-July 1988 indicated levels close to the shrinkage limit in the upper clay of all three test plots suggesting that more substantial cracking than observed (due to dessication and shrinkage) would be unlikely.

- Soil profile characteristics in the vegetation assessment areas were similar to Test Plot 1 and 2 profiles with roots observable at cleavage faces between cracks.

SUMMARY OF COLLECTED DATA

A. Observed Cover Percolation

Percolation rates through Test Plots 1 and 2 were low for the first year of data collection (0.06 inches and 0.27 inches, respectively). However, the '87 - '88 data shows an increase in total percolation to 0.18 inches and 1.19 inches for Test Plots 1 and 2, respectively, despite the drought conditions. Review of the data suggests that the compacted clay may have been gaining moisture in 1986 and early 1987 and that equilibrium conditions were reached as percolation from all of the test plots became more continuous after March, 1987. The sudden production of percolation at the base of Test Plot 2 in April 1988 could be due to development of crack flow conditions, or could be due to substantiated hydraulic gradients from spring moisture. The '88 - '89 data indicate a further increase in percolation rate, to slightly above 2 inches for Test Plots 1 and 2. Percolation in this last year of data collection has been much more continuous than in the past.

The timing of percolation from Test Plots 1 and 2 during 1987 was only slightly related to the timing of precipitation events, suggesting that moisture transmission was via porous media flow in a low conductivity environment. Test Plot 1 percolation was more strongly correlated with precipitation events since April 1988 and September 1988 suggesting that some cracking through the cover may have occurred, yet the bulk transmission rate has remained low. Test Plot 2 percolation timing has behaved similarly.

Test Plot 3, containing the intermediate sand drain layer, has performed much differently regarding percolation rates than was anticipated in the conceptual design. The upper clay/topsoil unit has allowed substantial percolation of moisture into the intermediate sand layer, from the very beginning of data collection (see Table I). Discharge from the intermediate sand layer occurs within hours of the start of precipitation events suggesting rapid transmission of water in the upper clay due to flow through cracks. Percolation from the base of Test Plot 3 has been much more constant than for Test Plots 1 and 2, and indicates conditions more likely to be homogeneous, as confirmed in the test pit investigation.

B. Runoff

Runoff production during the first year of data collection was substantial from each test plot, with Test Plot 1 producing over 7 in. of runoff. However, these runoff depths are dominated by response to the very heavy rains of September, 1987, and are also probably due to the immature growth of the cover vegetation. It is interesting to note that runoff from Test Plot 3 was even higher than that for Test Plot 1, if the moisture flow from the intermediate sand layer is included.

Runoff production declines substantially in the second and third years of data collection. The obvious reason for low runoff in 1987-1988 is the drought. However, the intermediate sand layer continued to produce moisture in response to the small rainfall events which occurred in the summer of 1988, indicating very rapid percolation through the cracked soils of the upper clay layer. During the 1988-1989 period, runoff from Test Plots 1 and 2 was similar, while runoff from Test Plot 3 was the largest. This surprising result may be due to the continued poorer condition of the vegetation on Test Plot 3. The collected data does not indicate that the greater topsoil thickness (and hence possibly larger rapid infiltration capacity) of Test Plot 3 serves to reduce runoff.

C. Evapotranspiration

The calculated evapotranspiration (ET) term of the water budget accounts for a significant fraction of total precipitation for each of the test plots. Approximately 90% of the total two year precipitation was calculated as lost to ET in Test Plot 1 and 94% in the thicker topsoil, Test Plot 2. Lower ET rates were calculated for Test Plot 3 (approximately 57% of the total two-year precipitation in 1987 and 1988). This was attributed to the substantial moisture flow through cracks in the upper clay layer and interception by the intermediate sand layer, thus reducing moisture availability for evaporation or transpiration. Evapotranspiration percentages are higher for later periods of the study, when vegetation was better established and without the influence of the record rainfall rates occurring in September

1986. Thus, the 18 inch topsoil is apparently providing some increase in evapotranspiration, but the anticipated increase in ET moisture retention capacity (and hence ET) of the upper clay in Test Plot 3 has not occurred. Calculation of ET values for the third year of data collection awaits reduction of neutron probe soil moisture data.

D. Soil Moisture Content Variations

Monthly soil moisture storage changes were interpreted from CPN neutron probe data collected at 6 inch to 12 inch intervals at seven locations in each test plot. Little horizontal variation of soil moisture content within each test plot was noted. However significant variations in moisture content occurred with depth. In general, drying influences were seen through the upper three feet of each cover during summer months, particularly during the drought period in 1988. Below depths of 3 feet in Test Plots 1 and 2 moisture contents remained fairly static.

The observed hydrologic responses of Test Plot 3, where substantial moisture was transmitted through the upper clay layer, correlated with moisture content data in that lower clay moisture contents have remained very stable. This suggests that the intermediate sand layer is providing an effective barrier to upward migration of moisture in drying periods.

In general, the tensiometer data correlated with the neutron probe data regarding long-term moisture content fluctuations. The value of the tensiometers in monitoring short-term infiltration response was limited, due to the substantial failure rate. The limited data suggest that soil moisture contents below several feet in depth did not show rapid response to rainfall. The tensiometers did however indicate a deep and long lasting drying during the drought of 1988.

The maximum depth of soil moisture which could be absorbed by the cover sections is in the range of 18 to 24 inches. Even considering the fact that more than half of this amount will be very tightly held by the clay-rich soils, soil moisture storage represents a relatively large reservoir through which the much smaller monthly and yearly percolation depths pass. Therefore, it is important to review the soil moisture storage changes (Table I) when interpreting the water balance results, especially with respect to calculated evapotranspiration.

E. Soil Temperature

Data from the nest of soil temperature probes indicates substantial moderation of temperature fluctuations in the soil cover, as compared to air temperature. At a depth of 5 feet below the cover surface, soil temperatures ranged from approximately 80°F during the high temperatures experienced in August 1988, to no colder than 45°F during the winter months.

Soil temperatures fluctuated over a greater range at a depth of 1 foot, but dropped below freezing only several times throughout the three-year period. The longest period of freezing at 1 foot depth was approximately 8 weeks, in early 1989. However, the soil at 3 feet in depth was well above freezing during this period. Apparently, heat being generated within the landfill is keeping the cover soils substantially warmer in the winter months than would be expected in Wisconsin, and therefore probably limiting the effects of freeze-thaw action on the cover soils.

F. Vegetation Growth Summary

Cover vegetation growth characteristics were assessed annually in 1986 and 1987, twice in 1988 and once in 1989, by evaluating percent cover, above ground biomass productivity (except 1989) and root growth development on each test plot and in the vegetation assessment areas. In general, vegetation suffered during the drought in 1988, with productivities lower than observed in the first year of growth. Vegetation growth in 1989 was much more vigorous than preceding years.

Percent cover analyses typically indicated slightly better growth on the vegetation assessment areas (alternative mix) than in the test plot area (primary mix). Biomass productivity comparisons between the primary mix and alternative mix areas have been difficult due to mowing which occurred at different times in 1986 and 1987. However, productivities were generally higher for the alternative species mix, and were also higher on the 18 inch topsoil plots. Biomass productivity on Test Plot 3 tended to decline through the growing season, suggesting that moisture transmission through the upper clay unit was producing droughty conditions which hampered plant growth. This observation is also consistent with the much lower calculated evapotranspiration rates for Test Plot 3. Root densities have been consistently higher in the 18 inch topsoil (Test Plot 2) and have progressively become more dense and more deeply penetrating into the clay soils. The density data was not noticeably different for primary vs. alternative vegetation mixes.

CONCLUSIONS

A great deal of data on final cover performance has been obtained from the Omega Hills Test Plot Study, of a type which is not generally available. The principal long-term value of the project may be the development of this large body of record information, which could be utilized for development of improved analysis techniques or alternative cover design development. Regarding the specific objectives of this project, the following conclusions can be drawn at this time:

1. The timing and response of percolation data suggests, and the test pit investigations have tended to confirm, that the development and propagation of cracks in the cover

soils dominates the factors controlling percolation performance. The apparent impact of dessication cracks in the cover soils indicates that drought conditions may be much more damaging to cover performance than a continuous supply of moisture.

2. Analysis procedures which are based on assumptions of either saturated or unsaturated porous media flow may not be applicable to many practical landfill cover situations without careful evaluation.

3. The multi-layered cover design did not result in lower percolation rates due to retention of soil moisture in the upper clay layer. To the contrary, the upper clay became thoroughly cracked, allowing rapid infiltration of moisture to the intermediate sand layer.

4. The thicker topsoil utilized in Test Plot 2 has not noticeably reduced cover percolation. The effects of increased moisture retention in the thicker topsoil during the dormant season may outweigh the possible effect of increased evapotranspiration.

5. Although the alternative vegetation species mix appears to produce a more vigorous vegetation cover, comparison of the two sets of vegetation regarding cover percolation performance is not possible.

The above conclusions are based on data drawn from a particular set of soils, construction and climatic conditions, over a specific observation period. Extreme caution should be taken in attempting to generalize these conclusions to other sites or conditions.

PROJECT STATUS

Data collection for the instrumented test plots and the alternative vegetation areas is continuing, and is expected to be conducted for the next several years. Additional test pit investigation of representative areas across the landfill is planned, with possible additional data analysis and/or modeling at some time in the future.

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TABLE I - PAGE 1 OF 3

SEPTEMBER 1986 THROUGH AUGUST 1987
RECORDED MONTHLY PRECIPITATION, RUNOFF, PERCOLATION AND
COMPUTED MONTHLY WATER BALANCE

	PRECIPITATION		TEST PLOT 1				TEST PLOT 2				TEST PLOT 3				
MONTH	LONG TERM[1]	ACTUAL[2]	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	SAND	STORAGE	CALC ET
SEP	2.88	9.78	4.40*	0.00	1.30	4.08	2.80*	0.00	1.72	5.26	2.80*	0.20	4.90*	2.18	-0.30
OCT	2.25	1.63	0.40*	0.00	0.00	1.23	0.18	0.00	0.13	1.32	0.32	0.18	0.80*	-0.07	0.40
NOV	1.98	0.86	0.00	0.00	0.00	0.86	0.00	0.00	0.00	0.86	0.00	0.00	0.04*	-0.20	1.02
DEC	2.03	0.86	0.00	0.00	-0.59	1.45	0.00	0.00	-0.13	0.99	0.00	0.00	0.40*	-0.53	0.99
JAN	1.64	0.65	0.00	0.00	0.16	0.49	0.00	0.00	-0.20	0.85	0.00	0.00	0.50*	0.53	-0.38
FEB	1.33	0.89	0.31	0.02	0.27	0.29	0.08	0.00	0.20	0.61	0.26	0.01	0.04*	0.26	0.32
MAR	2.58	1.81	0.00	0.00	-0.16	1.97	0.00	0.00	0.00	1.81	0.08	0.06	2.15*	-0.20	-0.28
APR	3.37	4.31	1.60	0.0	-0.70	3.37	0.82	0.06	-0.99	4.42	0.06	0.34	1.39	-1.12	3.64
MAY	2.66	1.32	0.00	0.00	-0.43	1.75	0.00	0.05	-0.59	1.86	0.00	0.19	0.53*	-0.66	1.26
JUN	3.59	1.48	0.10	0.00	-1.51	2.89	0.10	0.03	-2.11	3.46	0.07	0.13	0.14	-1.45	2.59
JUL	3.54	7.28	0.19	0.01	0.70	6.38	0.20	0.05	0.66	6.37	0.09	0.27	2.34	0.92	3.66
AUG	3.09	4.41**	0.11	0.03	0.97	3.30	0.13	0.08	1.32	2.88	0.12	0.21	0.16	0.99	2.93
TOTAL	30.94	35.28	7.11	0.06	0.01	28.06	4.31	0.27	0.01	30.69	3.80	1.59	13.39	0.65	15.85

Notes: All units in dimension of inches of water depth.

Precipitation Data: (1) Long Term Normal Recorded at Milwaukee Mitchell field NOAA Station based on the 1951-1980 record period.
(2) Measured On-Site at Omega Hills Test Plots

CALC ET = Calculated Evapotranspiration
STORAGE = Change in moisture content from Neutron Probe data, expressed in inches.

* Estimated for period Sep 4-24, 1986 and for later periods of tank overflow.
** On-site record augmented using Germantown NOAA Station Data for periods of site raingage failure.
-- Soil moisture storage data for period Oct. 1988-Aug. 1989 to be compiled in October 1989.

TABLE I - PAGE 2 OF 3

SEPTEMBER 1987 THROUGH AUGUST 1988
RECORDED MONTHLY PRECIPITATION, RUNOFF, PERCOLATION AND
COMPUTED MONTHLY WATER BALANCE

	PRECIPITATION		TEST PLOT 1				TEST PLOT 2				TEST PLOT 3				
MONTH	LONG TERM[1]	ACTUAL[2]	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	SAND	STORAGE	CALC ET
SEP	2.88	3.28	0.05	0.02	0.00	3.21	0.18	0.09	0.26	2.75	0.02	0.14	0.46	0.13	2.53
OCT	2.25	1.11	0.00	0.00	-0.76	1.87	0.14	0.02	-1.25	2.20	0.03	0.08	0.03	-0.92	1.89
NOV	1.98	2.49	0.15	0.00	1.08	1.26	0.00	0.03	1.32	1.14	0.00	0.01	0.32	1.25	0.91
DEC	2.03	3.61**	0.11	0.01	-0.27	3.76	0.14	0.23	0.00	3.24	0.27	0.12	0.71	-0.13	2.64
JAN	1.64	2.52**	0.32	0.02	0.49	1.69	0.47	0.03	0.66	1.36	0.76	0.05	0.28	0.33	1.10
FEB	1.33	0.43**	0.13	0.05	0.00	0.25	0.05	0.05	0.07	0.26	0.04	0.01	0.49	0.13	-0.23
MAR	2.58	1.08**	0.00	0.03	0.27	0.78	0.13	0.06	0.26	0.63	0.04	0.05	0.21	0.59	0.19
APR	3.37	3.54**	0.52	0.03	-0.43	3.42	0.20	0.52	-0.46	3.28	0.18	0.18	1.45	-0.79	2.53
MAY	2.6	0.37	0.02	0.0	-1.57	1.92	0.03	0.14	-1.85	2.05	0.02	0.12	0.35	-1.52	1.40
JUN	3.5	0.97**	0.05	0.01	-1.67	2.58	0.07	0.02	-2.51	3.38	0.02	0.06	0.04	-1.85	2.70
JUL	3.54	1.21**	0.07	0.00	-0.38	1.52	0.03	0.00	-0.73	1.91	0.0	0.03	0.01	-0.59	1.71
AUG	3.09	2.16**	0.03	0.01	0.27	1.85	0.10	0.00	0.33	1.73	0.02	0.02	0.21	0.26	1.64
TOTAL	30.94	22.77	1.45	0.18	-2.97	24.11	1.54	1.19	-3.90	23.93	1.45	0.87	4.56	-3.11	19.01

Notes: All units in dimension of inches of water depth.

Precipitation Data: (1) Long Term Normal Recorded at Milwaukee Mitchell field NOAA Station based on the 1951-1980 record period.
(2) Measured On-Site at Omega Hills Test Plots

CALC ET = Calculated Evapotranspiration
STORAGE = Change in moisture content from Neutron Probe data, expressed in inches.
* Estimated for period Sep 4-24, 1986 and for later periods of tank overflow.
** On-site record augmented using Germantown NOAA Station Data for periods of site raingage failure.
-- Soil moisture storage data for period Oct. 1988-Aug. 1989 to be compiled in October 1989.

TABLE 1 - PAGE 3 OF 3

SEPTEMBER 1988 THROUGH AUGUST 1989
RECORDED MONTHLY PRECIPITATION, RUNOFF, PERCOLATION AND
COMPUTED MONTHLY WATER BALANCE

	PRECIPITATION		TEST PLOT 1				TEST PLOT 2				TEST PLOT 3				
MONTH	LONG TERM[1]	ACTUAL[2]	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	STORAGE	CALC ET	RUNOFF	PERC	SAND	STORAGE	CALC ET
SEP	2.88	4.81**	0.13	0.79	2.54	1.35	0.26	0.02	2.24	2.28	0.11	0.06	0.71	2.706	1.23
OCT	2.25	1.95	0.05	0.03	-0.22	2.09	0.03	0.02	-0.33	2.23	0.00	0.04	0.01	-0.53	2.43
NOV	1.98	3.70	0.18	0.50	0.70	2.30	0.15	0.59	2.19	1.51	0.00	0.23	0.96	--	--
DEC	2.03	1.22	0.13	0.16	0.11	0.82	0.03	0.24	0.20	0.75	0.06	0.14	0.70	--	--
JAN	1.64	0.57	0.00	0.08	0.05	0.44	0.00	0.26	0.07	0.24	0.09	0.08	0.52	--	--
FEB	1.33	0.30	0.00	0.04	0.11	0.15	0.00	0.25	0.13	-0.08	0.01	0.03	0.25	--	--
MAR	2.58	1.22	0.25	0.19	0.05	0.73	0.70	0.27	0.13	0.12	2.03	0.10	0.90	--	--
APR	3.37	0.89	0.08	0.05	-0.38	1.14	0.07	0.09	-0.59	1.32	0.01	0.11	0.17	--	--
MAY	2.66	3.41	0.14	0.07	-0.27	3.47	0.14	0.10	-0.66	3.83	0.08	0.12	0.32	--	--
JUN	3.59	3.05**	0.23	0.13	-0.05	2.74	0.18	0.31	-0.59	3.15	0.07	0.23	0.30	--	--
JUL	3.54	5.08**	0.26	0.08	-0.27	5.01	0.20	0.08	-0.33	5.13	0.06	0.22	0.15	--	--
AUG	3.09	6.17**	0.23	0.07	0.49	5.38	0.20	0.12	1.39	4.46	0.08	0.24	0.22	--	--
TOTAL	30.94	32.40	1.68	2.19	2.86	25.62	1.96	2.35	3.85	24.94	2.60	1.60	5.21	--	--

Notes: All units in dimension of inches of water depth.

Precipitation Data: (1) Long Term Normal Recorded at Milwaukee Mitchell field NOAA Station based on the 1951-1980 record period.
(2) Measured On-Site at Omega Hills Test Plots

CALC ET = Calculated Evapotranspiration
STORAGE = Change in moisture content from Neutron Probe data, expressed in inches.
* Estimated for period Sep 4-24, 1986 and for later periods of tank overflow.
** On-site record augmented using Germantown NOAA Station Data for periods of site raingage failure.
-- Soil moisture storage data for period Oct. 1988-Aug. 1989 to be compiled in October 1989.

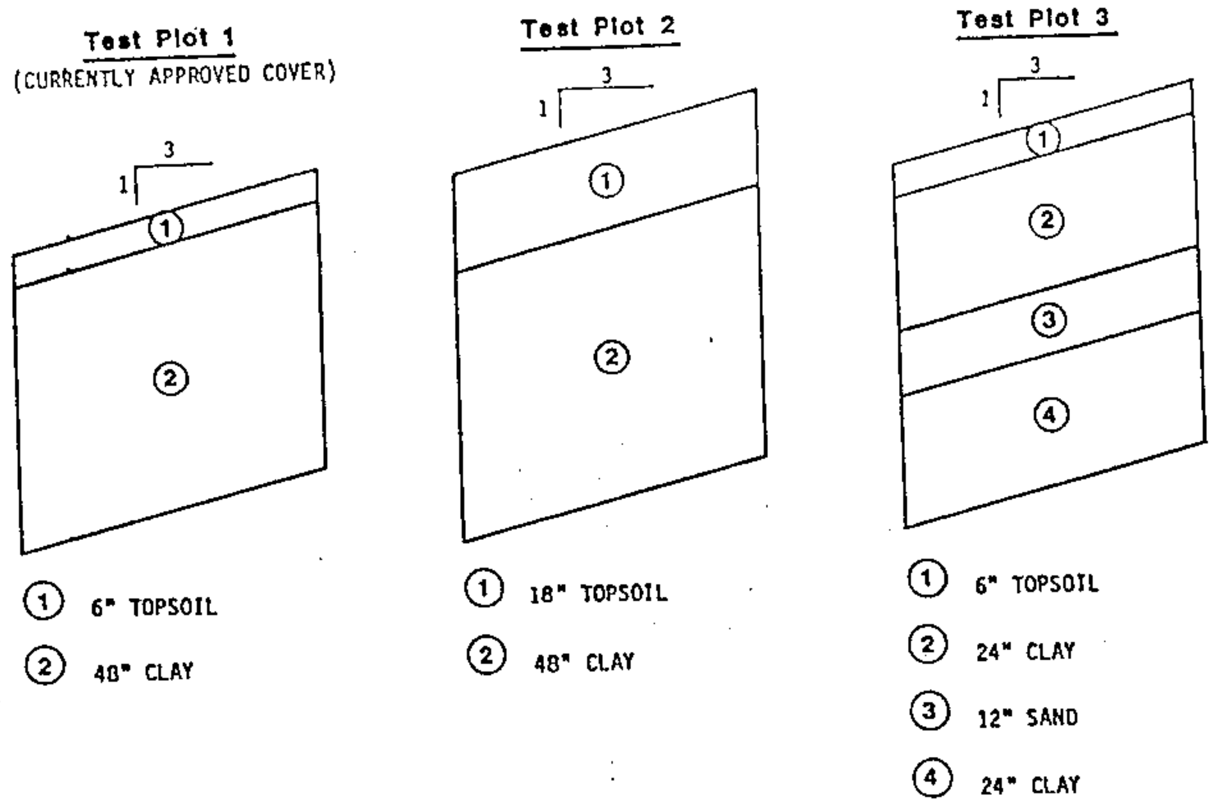

FIGURE 1: COVER DESIGNS INSTALLED AT OMEGA HILLS TEST PLOT SITE

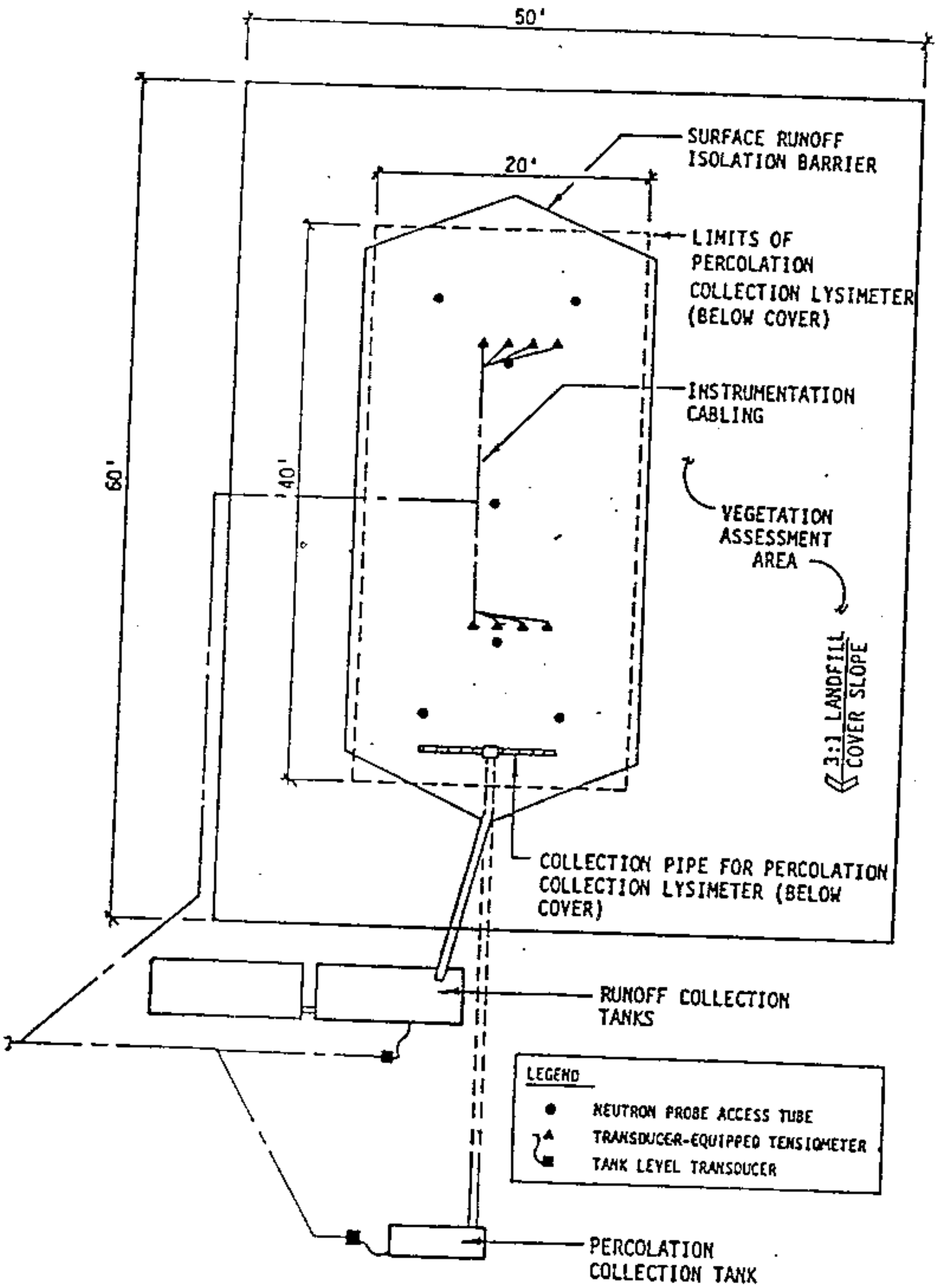

FIGURE 2: PLAN VIEW OF TYPICAL TEST PLOT

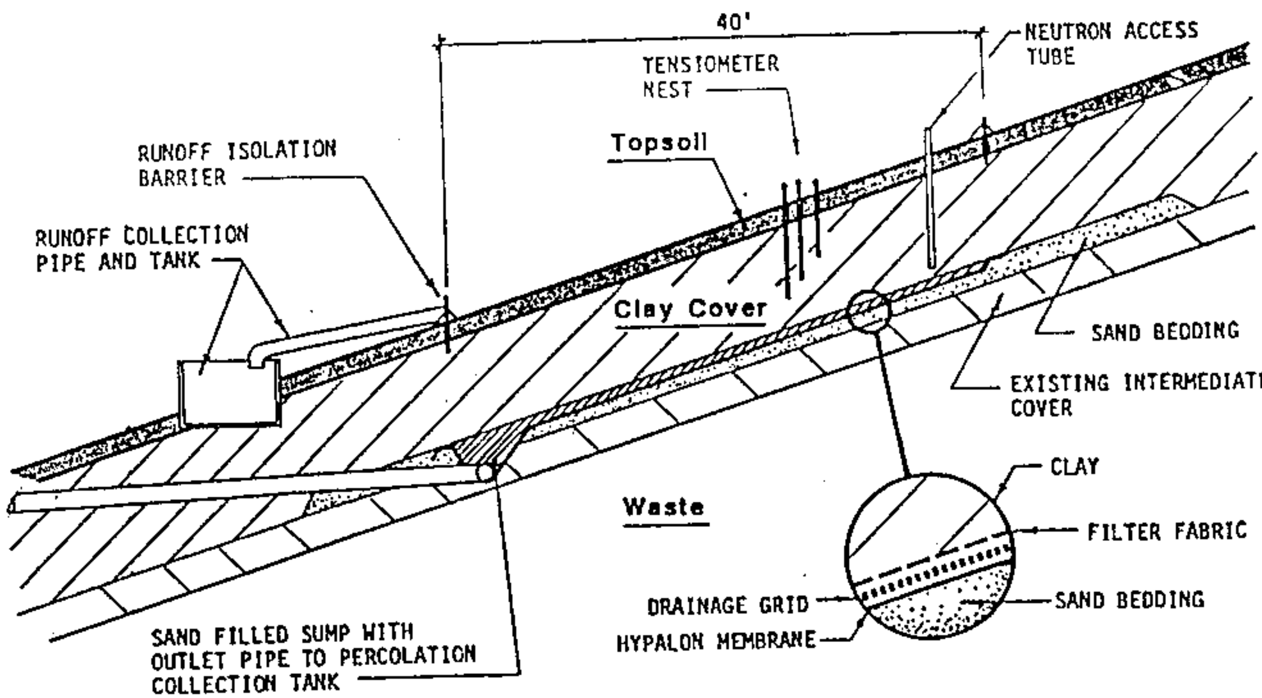

FIGURE 3: SCHEMATIC SECTION OF TYPICAL TEST PLOT

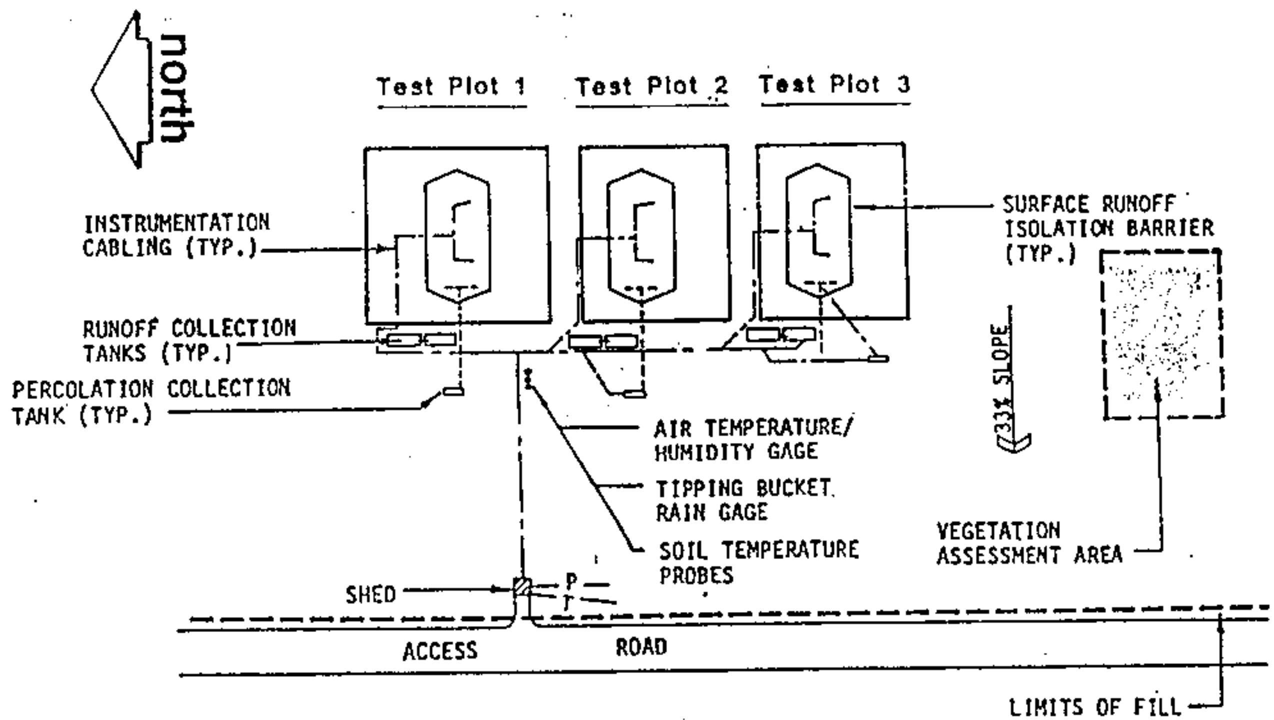

FIGURE 4: SCHEMATIC SITE PLAN

Parsons is an environmental engineer in Warzyn's Milwaukee, Wisconsin office. They have both been involved with the test plot project since its beginning.

REFERENCES

1 Montgomery, R.J., Phillippi, T.C., and Vrabec, S.H., "Field Evaluation of Natural Soil Landfill Cover Designs at Omega Hills Landfill, Wisconsin", in Proceedings of the Ninth Annual Madison Waste Conference, University of Wisconsin-Madison, 1986.

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This article was presented at the 1989 Annual Meeting of the National Solid Waste Management Association, Washington, D.C. For more information about the study, contact Robert J. Montgomery, Project Manager, Warzyn Engineering, P.O. Box 5385, Madison, WI, Phone: 608-273-0440.