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Project Summary

Landfill Research at the Boone County Field Site

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From June 1971 until August 1980, the Municipal Environmental Research Laboratory constructed and monitored five municipal waste landfill test cells in Boone County, Kentucky. Primary objectives were (1) to evaluate leachate quantities and characteristics, gas composition, temperature conditions, and a soil liner for leachate control and (2) to compare the performance of a field-scale cell with smaller, similarly constructed cells.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Five test cells containing municipal solid waste were constructed at the Municipal Environmental Research Laboratory's Boone County Field site near Walton, Kentucky, during 1971 and 1972. Cells 1 and 2D were constructed similarly to normal landfill cells and contained 286,000 and 72,450 kg of dry refuse, respectively. The base of Cell 1 was lined with a 0.76-mm synthetic liner, on top of which was placed a 45.7-cm-thick, compacted, clayey silt liner. Both the synthetic and soil liners were provided with drains for leachate collection. A 0.6-m, compacted soil cover was placed over the refuse in Cell 1. A continuous synthetic liner was placed on the sides and base of Cell 2D. Cover over the refuse consisted of 0.3-m of compacted soil beneath a 0.3-m surficial layer of pea gravel. A grid of 150-mm-high clay dikes was constructed within the gravel to promote uniform percolation into the refuse. (See Figure 1).

Cells 2A, 2B, and 2C were constructed in identical, cylindrical steel pipes, 1.83 m in diameter by 3.66 m long. These small-scale cells contained approximately 2100 kg of dry refuse each. These units were constructed to compare performance of small-scale systems with the field-scale cell (2D) and to evaluate variations within identical cells.

Cell construction data are summarized in Table 1. All cells were monitored for leachate quantity and characteristics, gas composition, temperature, and settlement until they were closed in August 1980.

Findings

Leachate Volume

Leachate was initiallly collected from both the upper and lower pipes of Cell 1 approximately 2 months after construction. The observation unit adjacent to the cell in which leachate was collected collapsed in February 1979, and after that, volume measurements were not possible. At that time, 1.07 million liters of leachate—representing 27.5% of the precipitation recorded at the site—had been collected.

The leachate volume predicted by using the water balance method is shown together with the cumulative leachate volume in Figure 2. At the time leachate volume measurements ceased, 1.07 million liters had been collected—only a 6% difference from the 991,600 liters predicted by the water balance method. If yearly average evapotranspiration values had been used, rather than ones computed from actual climatic conditions (precipitation and temperature) experienced, the difference would have been 33%. This

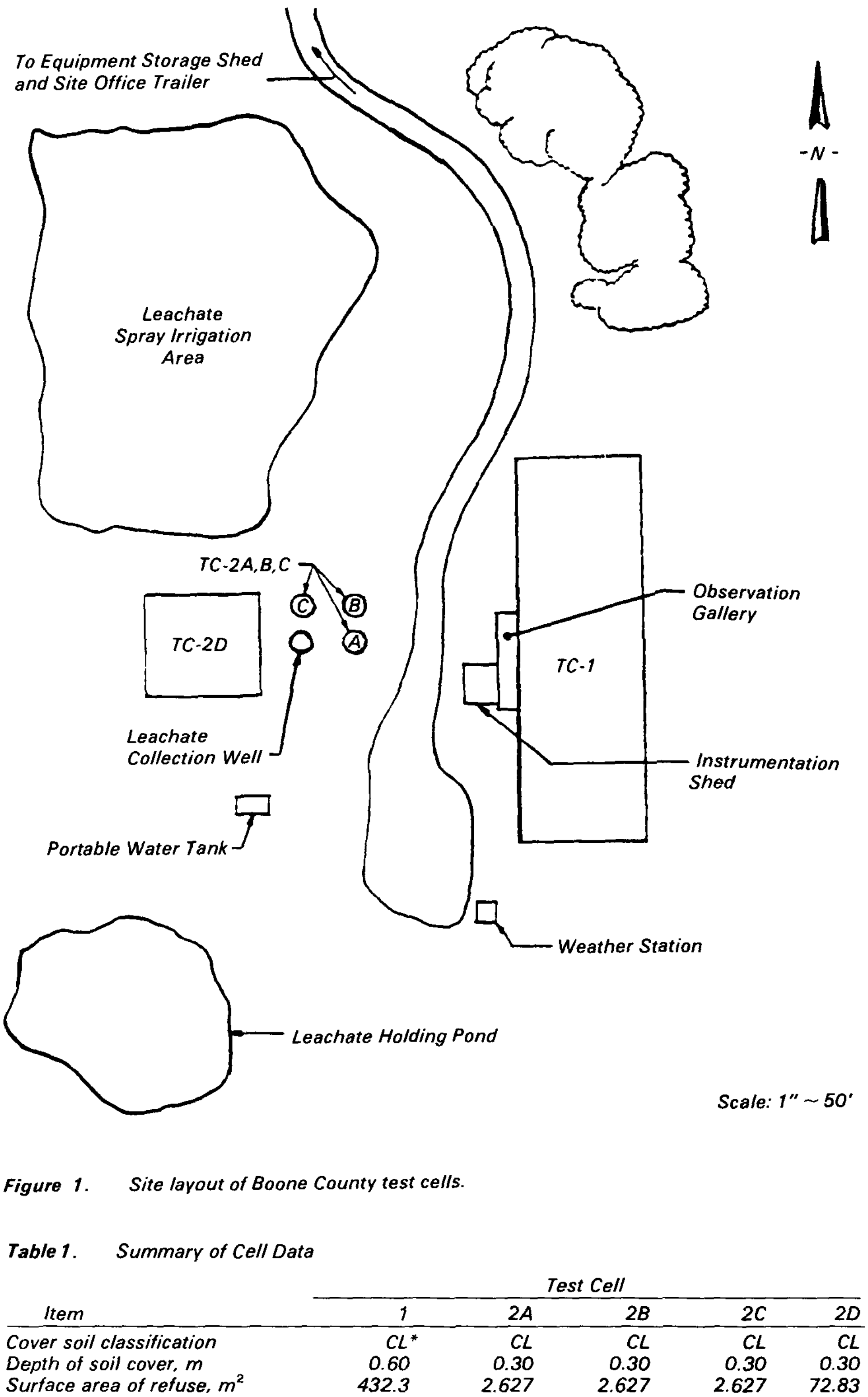

Figure 1. *Site layout of Boone County test cells.*

Table 1. *Summary of Cell Data*

	Test Cell				
Item	1	2A	2B	2C	2D
Cover soil classification	CL*	CL	CL	CL	CL
Depth of soil cover, m	0.60	0.30	0.30	0.30	0.30
Surface area of refuse, m^2	432.3	2.627	2.627	2.627	72.83
Maximum depth of refuse, m	2.56	2.56	2.56	2.56	2.44
Mass of refuse, kg (dry)	286,000	2,046	2,113	2,135	72,450
Dry density of refuse, kg/m^3	429	304.3	314.1	317.6	407.7
Moisture content of refuse, % wet wt.	27.6	22.5	27.1	24.1	31.8

*USCS soil classification

large difference indicates that leachate volume design calculations should be based on extreme as well as average values. Leachate was also collected during the summer and fall, which is rarely predicted by the water balance method.

One of the objectives of the Cell 1 tests was to evaluate the effectiveness of the soil liner in containing leachate. The quantity of leachate from the pipe beneath the soil liner was equal to or greater than that volume from the upper pipe until January 1972. This was caused by leaving the valve closed on the upper pipe except for weekly sampling, thereby inducing sufficient head to cause leakage into the lower pipe. Flow quantity remained relatively constant after 1972 through a wide yearly variation in total leachate flow; this indicated soil liner saturation and relatively constant head and soil permeability throughout the later years of cell life. Tests of the soil liner at closure showed reductions in permeability of the soil of 2 to 3 orders of magnitude, from the original 2×10^{-5} to 4×10^{-7} to 2×10^{-8} cm/sec.

Although greater than 99% of the total leachate flow was collected from the upper pipe, it appears that the Hypalon®* liner and the soil liner were functioning together and that the large percentage of the leachate collected in the upper pipe was not due to the soil alone. Apparently the Hypalon® sheet blocked deep percolation, forcing flow along the refuse-soil interface, and resulted in the high percentage of leachate being collected in the upper pipe. If a free-draining granular layer had been placed between the Hypalon® and the base of the soil liner, a more definitive evaluation of the soil liner effectiveness could have been made.

The experimental design for Cells 2A-2D called for the input of approximately 500 mm of precipitation each year into all of the cells. Average annual rainfall at the site exceeded 1,000 mm, so all of the cells were periodically covered—the cylinders with caps, and 2D with nylon-reinforced Hypalon®. Generally, about 100 mm of precipitation fell on the cells before they were covered for a 2- to 3-month period. During the final year of the project, the covers were left off. Evaporation and transpiration losses were further reduced by use of the 0.3-m gravel layer overlying the soil cover; this layer prevented vegetative growth and shielded the water stored on top of the soil cover from direct sunlight. Leachate volume collected from the four cells is shown in Figure 3.

*Mention of trade names or commerical products does not constitute endorsement or recommendation for use.

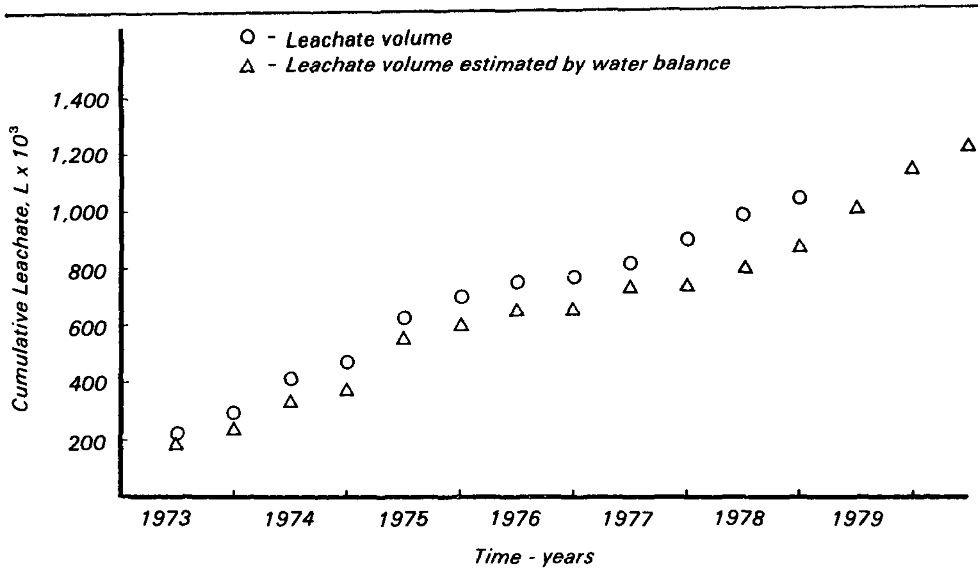

Figure 2. Cumulative leachate volume for Cell 1.

Test Cell 2C produced very little leachate during the reporting period in comparison with that produced in Cells 2A and 2B. A test boring in the cell showed no free water stored in the cylinder. The assumption was that a leak had developed at a welded joint near the surface of the soil cover and very little of the precipitation had actually entered the refuse mass.

Leachate quantities collected from Cells 2A and 2B at the end of the project differed by only 5%. Leachate collected from 2D began to exceed precipitation in mid-1975. At project completion, leachate equal to 7,000 mm of precipitation had been collected, whereas the input was only 4,570 mm. Possible causes of this large difference might have been leakage through the sidewalls and liner of the cell or through the Hypalon® cover that was periodically placed on the cell.

Graphic predictions of refuse field capacity compared well with moisture contents of refuse samples taken during closure. Based on the experience with the four cells, an appropriate design value for field capacity would be 55% moisture on a wet-weight basis.

Leachate Characteristics

Leachate samples from the test cells were generally analyzed biweekly. A summary of peak concentrations and values recorded at closure is included in Table 2. Many of the peaks occurred within a relatively short time period, during which the cells were reaching field capacity. Apparently those peak concentrations resulted during the initial water contact, when the supply of leachable substances and the contact time were both high. Note that these leachate concentrations were from relatively shallow (2.5 m) batch cells in which there was no daily or intermediate cover soil.

Total solids concentration history and mass removal curves for four of the test cells are presented in Figures 4 and 5. The concentration or cumulative mass removal has been plotted against the cumulative leachate volume rather than time, since the leachate concentration trends and subsequent mass removals are more related to leachate volume than to time. Leachate volume and mass removal data are also normalized by dividing by the dry weight of the refuse to account for the different sizes of the cells.

Typical of many of the parameters was a pattern of increasing concentration until field capacity was reached, followed by a gradual decline. Individual leachate sample concentrations showed no dilution effects during periods of high flow. This pattern was adequately described with a simple exponential equation developed by considering the cell as a well-mixed reactor. The least squares fit of the equation to the concentration history of COD for Cell 2A is depicted in Figure 6. Though such an equation was useful in describing leachate characteristics over the 9-year period of the experiment, its accuracy for long-term predictions remains uncertain. This uncertainty is exemplified by the findings that the total chloride remaining in samples of 9-year-old refuse was 70 times greater than the leachate chloride predicted by the equation. Since some of the chloride remaining in the refuse may not be leachable, verification of the equation would require that studies be conducted well beyond the amount of leachate per unit of dry refuse reached in this research program.

One of the primary objectives of Cell 1 was to evaluate the effectiveness of soil

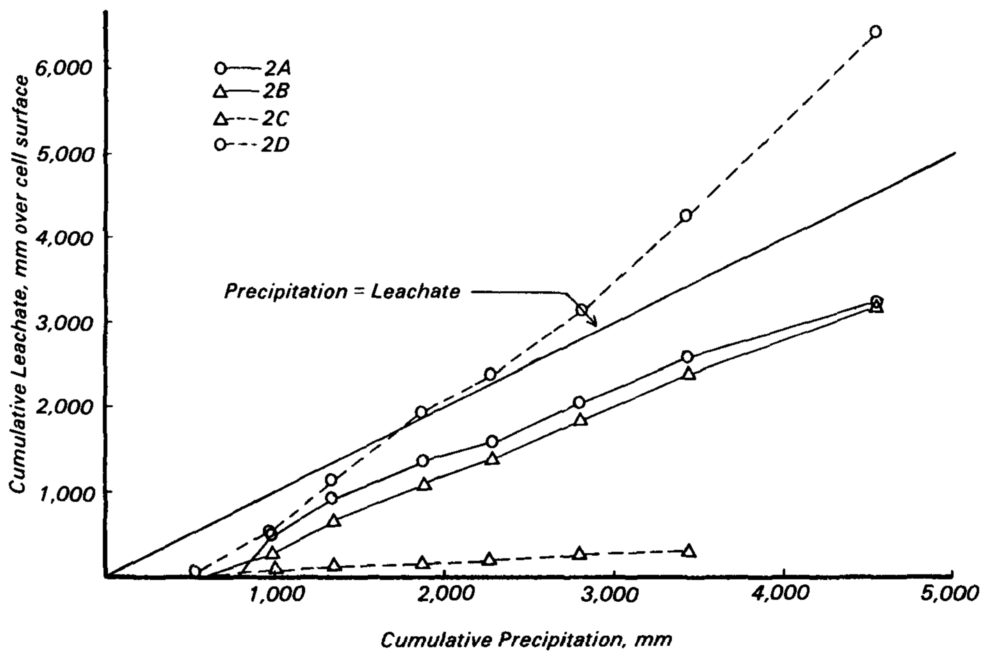

Figure 3. Leachate volumes for Cells 2A-2D.

Table 2. *Leachate Concentrations**

Parameter	Test Cell 1 Upper Concentrations		Test Cell 2D Concentrations		Test Cell 2A Concentrations		Test Cell 2B Concentrations	
	Peak	At Closure	Peak	At Closure	Peak	At Closure	Peak	At Closure
pH (lowest)	5.10	--	4.6	--	4.4	--	4.4	--
pH (highest)	7.07	--	7.0	--	6.2	--	6.0	--
COD	37,500	280	41,869	600	57,370	6,100	61,600	6,400
BOD_5	30,000	43	79,120	400	62,560	5,000	72,220	5,700
Kjeldahl-N	700	23	1,413	14	1,560	63	1,897	43
Ammonia-N	552	18	947	10	1,035	23	1,185	30
Orthophosphate	61	1.4	82	1.6	390	42	185	31
Sulfate	1,160	9	1,280	23	2,215	30	2,275	41
Alkalinity	8,870	760	8,963	460	11,535	710	13,880	830
Acidity	3,620	660	5,057	560	6,720	1,400	6,843	1,300
Conductivity	12,200	930	16,000	870	17,000	1,400	18,000	1,600
Total Solids	23,600	1,400	36,252	1,200	46,484	2,700	45,628	3,000
Sodium	1,040	42	1,375	25	1,900	33	1,700	23
Potassium	1,950	41	1,893	24	2,225	31	2,939	30
Chloride	1,749	66	2,940	73	3,558	96	2,450	99
Iron	616	200	1,492	210	1,547	520	2,902	480
Magnesium	374	27	411	19	486	18	617	22
Manganese	184	1.9	58	1.6	109	4.7	115	5.1
Calcium	2,360	190	2,300	130	2,470	170	4,000	290
Zinc	104	0.3	67	0.4	150	0.3	360	1.4
Hardness	7,500	590	6,713	400	7,067	570	10,575	810

Concentrations in mg/L, except for pH and conductivity (micromhos/cm).

liners for leachate control. Less than 9,000 liters of leachate was collected from the drain pipe beneath the soil liner during the first 7-1/2 years of the project—a total that represented less than a third of the soil pore volume. Even after 9 years, iron and COD values were only 50% of those for leachate that had not passed through the soil liner. Total solids attenuation averaged 31% over the project. Desorption from the soil of hardness, chloride, calcium, and sulfate occurred during the later part of the study. A complete evaluation of the soil liner's efficiency in collecting and attenuating leachate could not be performed because of interference from an underlying synthetic liner, variable soil thickness, and a small hole discovered in the soil liner during closure.

Leachate samples from Cell 1 were used for bioassays during 1972. The 96-hour LC_{50} was 2.5% and 2.1% for two series of tests on fathead minnows.

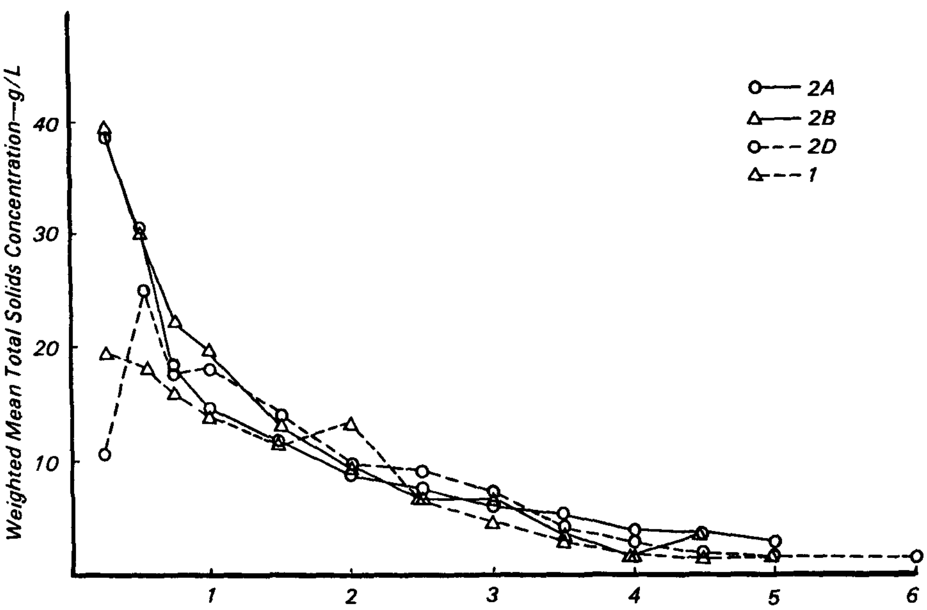

Figure 4. *Total solids concentration history for Cells 1, 2A, 2B, 2D.*

Microbiologic studies of leachate and waste samples indicated that significant numbers of fecal indicators had continued to survive and reproduce for 9 years. Pathogens were also identified in waste sampled from Cell 1 at closure, even though inoculated bags containing poliovirus type 1 and *Salmonella derby* indicated inactivation within 10 days of the initial construction of Cell 1.

Gas, Temperature, and Settlement

Gas samples were obtained from various locations within the cells. Oxygen was depleted quickly in all cells, and thereafter it generally remained at less than 3% at most probe locations for the entire project. The characteristic early carbon dioxide bloom appeared in all cells. Within 2 weeks after cell construction, CO_2 levels reached as high as 45% in the center of Cell 1 and 38% in the center of Cell 2D. Levels in the small-scale cells were slightly lower. Peak levels of CO_2 were reached in all cells at about the time field capacity was achieved. Thereafter, levels dropped slowly to 30% to 40% at the conclusion of the project. Carbon dioxide levels ranged from 5% to 20% higher by volume in Cell 2D than in the small-scale cells for the first 3 years, but they were similar thereafter.

Very little methane was detected until the cells reached field capacity. The earliest appearance of methane in Cell 1 was at the base of the cell and beneath the liner. Methane concentrations greater than 10% were not detected in the small-scale cells until 2 years after similar levels were reached in 2D. Peak methane concentrations recorded in the small cells were 25% in 2A, 20% in 2B, and 26% in 2C. The peak concentration detected in 2D was 57.9%. Though results were erratic, methane levels in the small cells appeared to be similar. Little similarity existed between the methane history in 2D and in the small cells, 2A, 2B, and 2C.

Thermocouples and thermistors were placed at various locations within the five cells and in the surrounding soil. Peak temperatures as high as 124°F were recorded near the surface of 2A and 2B. Peaks declined with depth in the small cells, but they were similar at three levels within 2D. After about 1-1/2 years, soil and refuse temperatures at similar depths were generally within a few degrees, indicating the end of active aerobic decomposition. Except near the surface of Cell 1, lower annual temperatures were recorded in the soil, and the highs were about the same in both the refuse and the soil. A time lag also existed between soil and refuse peaks. This amplitude difference and time lag was thought to be due to specific heat differences or perhaps minor residual aerobic activity within the refuse.

Settlement in the small-scale cells was quite similar, with more than half the total recorded during the first 14 months following cell construction. Final settlement in these cells ranged from 15.2% to 17.1% of total cell refuse depth. Settlement over the surface of 2D averaged only 10.6% of refuse depth, probably because of the 30% higher initial in-place refuse density than in 2A, 2B, and 2C. Estimated total settlement at the deepest point in Cell 1 was 12% of the refuse depth. The initial refuse density in Cell 1 was 35% higher than that in 2A, 2B, and 2C.

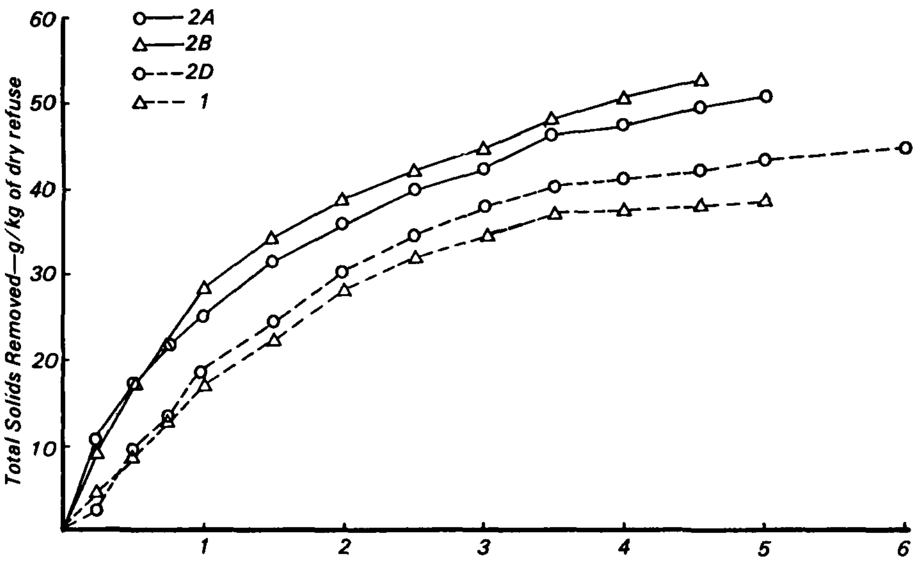

Figure 5. *Total solid mass removal for Cells 1, 2A, 2B, 2D.*

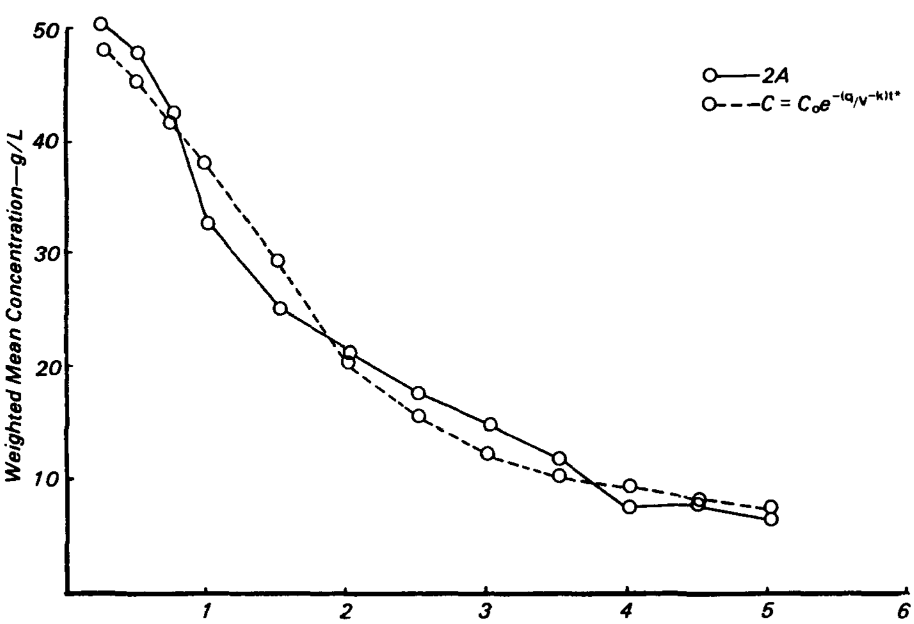

Figure 6. *Comparison of COD concentration for Cell 2A. (*Eq. 4 of full report)*

Performance Comparison

One of the primary objectives of the research was to compare the behavior of a field-scale test cell (2D) with similarly constructed small-scale cells. We hoped to determine whether factors of scale were involved or whether the small cells produced duplicate results so that future research efforts might use small, less expensive cells to predict field behavior.

Composition and initial moisture content were statistically similar, and refuse depths varied only 5%. The in-place wet refuse density in Cell 2D was 45% greater than the average refuse density in the small cells. Leachate collected from Cell 2C was so substantially different from Cells 2A and 2B that the leachate data were not used in any comparative analysis. Leachate production from Cell 2D was much greater than that from the remaining small-scale cells (2A and 2B), and it exceeded precipitation. By the end of the project, Cell 2D had produced nearly twice the leachate per unit of collection surface area than had Cells 2A and 2B.

Only minor differences in temperature, settlement, and gas composition were noted when comparing the performance of the small-scale cells. Temperatures were essentially the same in 2D as in the small cells except for some surficial heating as a result of the cover over 2D. Settlement in the large cell was only two-thirds of that in the small cells, perhaps because of the initial 45% greater wet refuse density. Compared with Cell 2D, the small-scale cells (2A, 2B, and 2C) showed a substantial difference in methane gas concentration, with delayed production and lower concentrations.

Leachate concentration trends in Cell 2D were similar to those in the small-scale cells, but typically the magnitude of peak concentrations and mass removals were lower—quite possibly because of diluting sidewall leakage. Since this leakage could have passed through a portion of the refuse, it was impossible to correct the concentration data simply on the basis of excess water. This large difference in leachate production from Cell 2D was probably sufficient to preclude comparisons of cell performance based on leachate characterisitics.

Graphic comparisons of weighted mean leachate concentration histories and mass removals for Cells 2A and 2B indicated that performances were generally similar. To compare concentrations statistically, the Chow test for stability of coefficients was used. Essentially, this method compares the least squares fit of two linear equations describing the data from Cells 2A and 2B with the fit of a single equation developed from the combined set of data. The F statistic calculated from a ratio of the residual sum of the squares of the linear equations is used as the measure of statistical comparability. A log transform of the exponential equation (Figure 5) was used for the necessary linear equations and least squares fitting. Results of this test showed similarity for only 3 of 12 leachate parameters for Cells 2A and 2B at the 0.05 level of significance. Comparison of Cell 2A with 2D indicated similarity for only 1 of 12 parameters. Because of the lack of statistical comparability, we could not conclude that similarly constructed and operated cells would perform similarly.

A 45% greater initial in-place wet refuse density in Cell 2D than in the smaller cells and the much greater volume of leachate collected precluded performance comparisons between the different-sized cells. Differences in settlement, gas composition with time, peak leachate concentrations, and mass removals were all apparent in the cell data. Though we cannot conclude that 2D would have performed differently if the refuse density and leachate volume had been the same, these operational problems are only minor compared with the range of conditions that may be encountered in a field situation. Thus, it is doubtful that small-scale, batch-type cells can provide accurate predictions of sanitary landfill behavior; but they may be useful in describing performance ranges.

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***Dirk Brunner** and **Norma M. Lewis** are the EPA Project Officers (see below).*
The complete report, entitled "Landfill Research at the Boone County Field Site," (Order No. PB 84-161 546; Cost: $14.50, subject to change) will be available only from:
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