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a current report on solid waste management

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USE OF THE WATER BALANCE METHOD FOR PREDICTING LEACHATE GENERATION FROM SOLID WASTE DISPOSAL SITES

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INTRODUCTION

The land serves as the ultimate repository for over 90 percent of our Nation's solid waste. Incineration, shredding, and resource recovery processes reduce the amount of solid waste but produce residues requiring disposal. Because of the importance of land disposal to solid waste management systems, it is imperative to thoroughly consider the potential environmental impact of land disposal site selection and operation. Of particular concern in this report is potential contamination of ground and surface waters by leachate.

Leachate is liquid which has percolated through solid waste and has extracted dissolved or suspended materials from it. Whenever water comes into direct contact with solid waste, it will become contaminated. There are many materials in solid waste which are readily soluble in water. Other water soluble materials are generated as products of the biological degradation of the solid waste. Still other materials become soluble through the action of leachate upon them. Table 1 illustrates some of the chemical and biological characteristics found in leachate and compares fresh leachate to a typical domestic waste water.

Generally, the more water that flows through the solid waste, the more pollutants will be leached out. Thus, proper sanitary landfill site selection precludes tracts where ground or surface waters would flow through the waste. Furthermore, the proper sanitary landfill design and operational approach is to eliminate or minimize percolation of moisture through the solid waste. With the smaller amounts of percolation, the pollutants tend to be more concentrated, but the rate at which they are transmitted to the surrounding environment is not so apt to exceed the capability of the natural surroundings to accept and attenuate most of them to some degree.

Recognizing the importance of percolation in the environmental assessment of a potential leachate problem at a land disposal site, this paper analyzes the factors effecting percolation and its relationship to leachate generation and discusses a methodology to estimate leachate generation. This methodology is based on the water balance method commonly used in the soil and water conservation fields.

TABLE 1

CHARACTERISTICS OF LEACHATE AND DOMESTIC WASTE WATERS

Constituent	Range* (mg/l)	Range + (mg/l)	Range‡ (mg/l)	Leachate§ Fresh	Leachate§ old	Waste water§	Ratio§
Chloride (Cl)	34-2,800	100-2,400	600-800	742	197	50	15
Iron (Fe)	0.2-5,500	200-1,700	210-325	500	1.5	0.1	5,000
Manganese (Mn)	.06-1,400	--	75-125	49.	--	0.1	490
Zinc (Zn)	0-1,000	1-135	10-30	45	0.16	--	--
Magnesium (Mg)	16.5-15,600	--	160-250	277	81	30	9
Calcium (Ca)	5-4,080	--	900-1,700	2,136	254	50	43
Potassium (K)	2.8-3,770	--	295-310	--	--	--	--
Sodium (Na)	0-7,700	100-3,800	450-500	--	--	--	--
Phosphate (P)	0-154	5-130	--	7.35	4.96	10	0.7
Copper (Cu)	0-9.9	--	0.5	0.5	0.1	--	--
Lead (Pb)	0-5.0	--	1.6	--	--	--	--
Cadmium (Cd)	--	--	0.4	--	--	--	--
Sulfate (SO_4)	1-1,826	25-500	400-650	--	--	--	--
Total N	0-1,416	20-500	--	989	7.51	40	25
Conductivity (μmhos)	--	--	6,000-9,000	9,200	1,400	700	13
TDS	0-42,276	--	10,000-14,000	12,620	1,144	--	--
TSS	6-2,685	--	100-700	327	266	200	1.6
pH	3.7-8.5	4.0-8.5	5.2-6.4	5.2	7.3	8.0	--
Alk as $CaCO_3$	0-20,850	--	800-4,000	--	--	--	--
Hardness tot.	0-22,800	200-5,250	3,500-5,000	--	--	--	--
BOD_5	9-54,610	--	7,500-10,000	14,950	--	200	75
COD	0-89,520	100-51,000	16,000-22,000	22,650	81	500	45

*Office of Solid Waste Management Programs, Hazardous Waste Management Division. An environmental assessment of potential gas and leachate problems at land disposal sites. Environmental Protection Publication SW-110.of. [Cincinnati], U.S. Environmental Protection Agency, 1973. 33 p. [Open-file report, restricted distribution.]

+Steiner, R. C., A. A. Fungaroli, R. J. Schoenberger, and P. W. Purdom. Criteria for sanitary landfill development. Public Works, 102(3): 77-79, Mar. 1971.

‡Gas and leachate from land disposal of municipal solid waste; summary report. Cincinnati, U.S. Environmental Protection Agency, Municipal Environmental Research Laboratory, 1975. (In preparation.)

§Brunner, D. R., and R. A. Carnes. Characteristics of percolate of solid and hazardous waste deposits. Presented at AWWA [American Water Works Association] 54th Annual Conference, June 17, 1974. Boston, Mass. 23 p.

THE WATER BALANCE METHOD

The infiltration fraction of precipitation is the principle contributor to leachate generation from a sanitary landfill.* The infiltration into the soil cover and any subsequent percolation down to the solid waste will be determined by surface conditions of the sanitary landfill and by the climatological characteristics of the site's location.

Therefore, in order to assess the leachate problem for a given area, a procedure that provides for a detailed analysis of the existing surface and climatological conditions is needed. The water balance method is presented as a satisfactory and feasible procedure for performing the required task.

The following presentation is based on the water balance method as developed by C. W. Thornthwaite in the soil and water conservation field.[6,7,8]

Basic Concepts and Terminology

Before discussing the specific engineering application of the water balance method to sanitary landfills, it is important to first understand the basic concepts and terminology of the method itself. The following is a brief discussion of the water balance method--its basic concepts and terminology.

The water balance, as developed in the soil and water conservation literature, is based upon the relationship among precipitation, evapotranspiration, surface runoff, and soil moisture storage. Precipitation represents that amount of water added. Evapotranspiration, the combined evaporation from the plant and soil surfaces and transpiration from plants, represents the transport of water from the earth back to the atmosphere, the reverse of precipitation. Surface runoff represents water which flows directly off the area of concern. The soil moisture storage capacity represents water which can be held in the soil.

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* Other contributors include the water of decomposition, the initial moisture content of the solid waste and infiltration of ground water. All of these factors will be assumed negligible for a properly sited and designed sanitary landfill, relative to the infiltration fraction of precipitation.

The water added by precipitation will either evaporate directly back to the atmosphere from the soil surface, be utilized by plants through transpiration, serve to recharge a dried soil to field capacity,* or become downward percolation or surface runoff. The relative amounts of each of these depends in large measure on the relationship between precipitation and evapotranspiration.

The water balance method centers around the amount of free water present in the soil. Until the field capacity of the soil is reached, the moisture in the soil is regarded as being a balance between what enters it as a result of precipitation and what leaves through evapotranspiration. If the monthly+ moisture loss from the soil through evapotranspiration is compared with the monthly precipitation, an accounting of the soil moisture can be made by a simple bookkeeping procedure. The moisture in the soil is analogous to a bank account where precipitation adds to the account, and evapotranspiration withdraws from it.

Since the precipitation and evapotranspiration are governed by different climatic factors, they are not often the same either in amount or in distribution through the year. However, almost all areas of the United States can be characterized by two seasons during the one-year cycle--a wet season and a dry season. During the wet months, precipitation will exceed evapotranspiration and water recharge to the soil will occur. During the dry months, there will be less precipitation and a high evapotranspiration demand will cause a moisture deficit in the soil. In most arid and semi-arid areas, moisture recharge during the wet season theoretically will be too small to attain field capacity, resulting in little or no water surplus. However, the opposite is true in humid areas, resulting in a definite downward percolation.

The three critical factors that must be considered in the water balance method are the concepts of soil moisture storage, evapotranspiration and surface water runoff.

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* "Field capacity" is defined as the maximum moisture content which a soil (or solid waste) can retain in a gravitational field without producing continuous downward percolation.

+ The bookkeeping can be based on yearly, monthly, weekly, or daily values with the latter providing the best estimate of percolation. For the purposes of this paper, an accounting based on mean monthly values provides an estimate within the desired accuracy.

Soil Moisture Storage. One way in which the cover soil of a sanitary landfill influences the amount of percolation is through its capacity to store water. The amount of storage mainly depends on the soil type, structure and its attendant field capacity, as well as the depth of the soil layer itself.

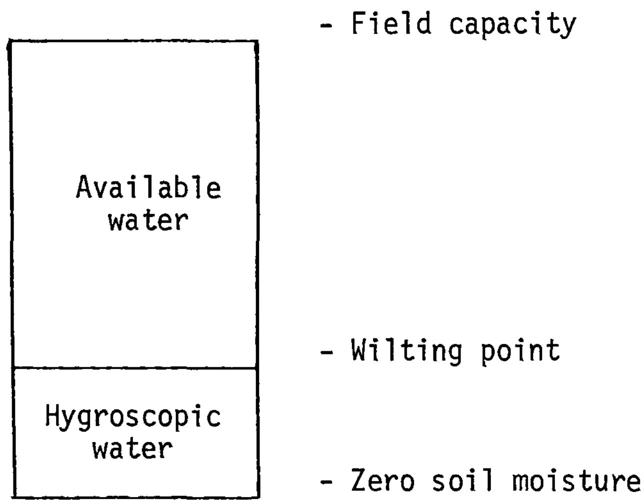

Figure 1. Soil Moisture Storage

As illustrated in Figure 1, the total amount of water stored in the soil at field capacity consists of two components. First is the "hygroscopic water" which ranges from zero moisture content to the wilting point.* This amount of water is tightly bound to the soil particles, is not available to the plants for tanspiration, and will never be depleted from the soil. The second component is the "available water" which ranges from the wilting point to the field capacity. This water will undergo capillary movement and is all subject to evapotranspiration losses.

In the water balance method we are concerned with the available water component of the soil moisture storage. It is this portion that varies, being depleted by evapotranspiration losses and recharged by infiltration additions.

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* Defined as the moisture content below which moisture is unavailable for withdrawal by plants.

The amount of available water that can be stored in a given profile will depend on the depth of root zone and on the soil type and structure. This amount can vary from a few millimeters for a shallow rooted crop in a sandy soil to several hundred millimeters for a fine textured soil with a deep rooted crop. Approximate field capacities, wilting points and amounts of available water for several different soil types are given in Table 2. These values will be used in the water balance calculations made later in the paper.

TABLE 2

SOIL MOISTURE
MILLIMETER WATER PER METER SOIL

Type of soil	Field capacity*	Wilting point*	Available water
Fine sand	120	20	100
Sandy loam	200	50	150
Silty loam	300	100	200
Clay loam	375	125	250
Clay	450	150	300

* Thornthwaite, C. W., and J. R. Mather. Instructions and tables for computing potential evaportanspiration and the water balance. Centerton, N. J., 1957. p. 185-311. (Drexel Institute of Technology. Laboratory of Technology. Publications in Climatology, v.10, no.3).

Evapotranspiration. The amount of available water present in the soil that is lost to the atmosphere from a given area depends on the type of soil and vegetation. It is also closely related to the climatic factors that affect the soil moisture content, principally precipitation, temperature and humidity.

Evapotranspiration occurs as the result of evaporation from the soil and transpiration by the vegetative cover. Of the two, most of the soil moisture lost to the atmosphere is due to transpiration.

Actual measurements made in soil lysimeters have shown that the rate of evapotranspiration drops as soil moisture is depleted.[9,10] When the soil moisture is at or near field capacity, evapotranspiration occurs at its maximum potential rate. However, as the soil moisture content approaches the wilting point the amount of available water begins to restrict the rate of evapotranspiration, resulting in reduced actual water losses. In the water balance method, this effect will be taken into account.

The evapotranspiration values used in this paper are those developed by C. W. Thornthwaite. His method for accounting for the effect of soil moisture on evapotranspiration rates is also used. This is done by application of his soil moisture retention tables as explained in the Appendix. Generally, Thornthwaite's values show that for humid areas there is essentially no difference between the potential and actual evapotranspiration rates during the wet season when sufficient water is available in the soil. However, the actual evapotranspiration rate drops off during the growing season as the soil moisture becomes depleted.

It should be pointed out that Thornthwaite's method for estimating evapotranspiration may not provide the best estimate for all areas of the country. The literature presents several methods, each tailored for different areas of the country.[10] Therefore, it is left to the discretion of the design engineer to select the method best suited for his area.

<u>Surface Runoff.</u> Some fraction of the incident precipitation will run off the site and be lost to overland flow before it has a chance to infiltrate. The amount of surface runoff will depend upon many factors, including the intensity and duration of the storm, the antecedent soil moisture condition, the permeability and infiltration capacity of the cover soil, the slopes, and the amount and type of vegetation cover.

In performing the water balance, one must select a method for estimating the runoff fraction of the incident precipitation during each month of the year. The approach used herein will be to apply empirical runoff coefficients which are commonly used to design surface water drainage systems. These coefficients will provide a means of estimating surface runoff quantities for given site conditions. Table 3 presents coefficients used in the "Rational Formula" for various surface conditions. By applying the coefficients to the mean monthly precipitation, an estimate of "mean monthly surface runoff" can be calculated. Although this method will in most cases underestimate surface runoff, it was felt that ignoring the surface runoff totally would result in a misleading assessment of the leachate generation potential.

TABLE 3

RUNOFF COEFFICIENTS*

Surface conditions	Runoff coefficient
Grass cover:	
Sandy soil, flat, 2%	0.05 - 0.10
Sandy soil, average, 2-7%	0.10 - 0.15
Sandy soil, steep, 7%	0.15 - 0.20
Heavy soil, flat, 2%	0.13 - 0.17
Heavy soil, average, 2-7%	0.18 - 0.22
Heavy soil, steep, 7%	0.25 - 0.35

* Chow, V. T., ed. Handbook of applied hydrology; a compendium of water resources technology. New York, McGraw-Hill, [1964]. 1v. (various pagings).

Water Balance Calculations for a Sanitary Landfill

As shown in Figure 2, the water routing through a sanitary landfill basically consists of two phases--routing through the soil cover and routing through the compacted solid waste beneath. The soil cover is that phase which interfaces directly with the atmosphere and will determine the amount of infiltration into the soil and percolation into the solid waste. The solid waste phase and its attendant moisture storage capacity will determine the quality and time of first appearance of the leachate. Therefore, a water balance can be performed on the soil cover phase to determine the amount of percolation. The solid waste phase can then be analyzed in relation to the percolation amounts to determine the extent of potential leachate problems.

Treating the moisture regime of the soil cover as a one dimensional system, the water balance method can be used to calculate the percolation of water into the solid waste. In applying the method, the surface conditions of the sanitary landfill site must be well defined. The type and thickness of the cover soil, the presence or absence and type of vegetative cover, and the topographical features are the primary surface conditions that will affect percolation.

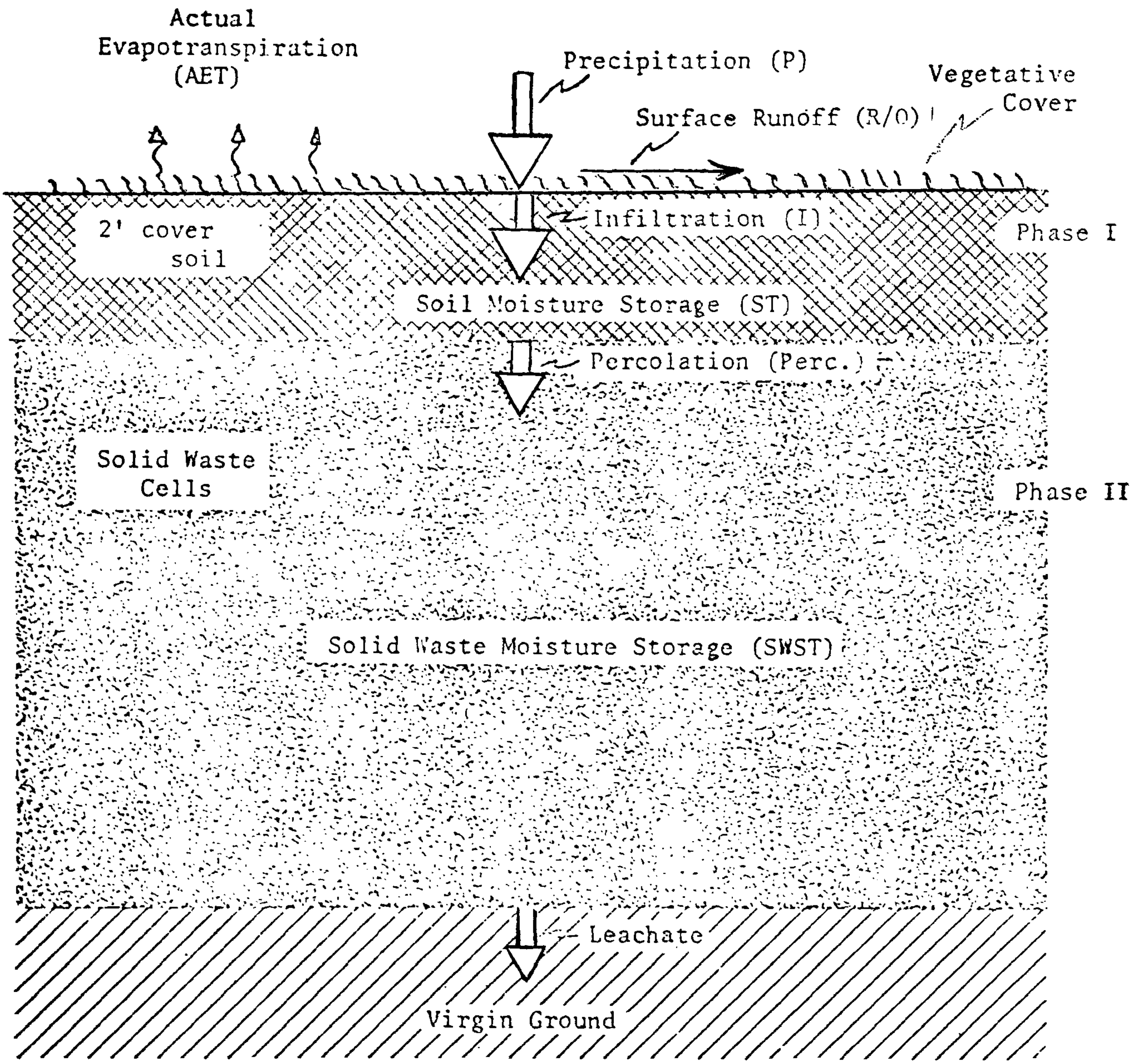


Figure 2. Sanitary Landfill Water Balance

To best illustrate the water balance of a sanitary landfill, three case studies have been selected to reflect various climatic and soil conditions. Cincinnati, Ohio, was selected to represent a humid climate with a sandy type soil; Orlando, Florida, to represent a humid climate with a sandy type soil; and Los Angeles, California, to represent a dry climate with a fine grained soil.

Conditions will vary among sites and among the stages of a given site's life. These conditions must be considered in applying the water balance method. For illustrative purposes, the water balance analysis was simplified by the following basic assumptions:

1. The landfill has been completed with 0.6 meters (2 feet) of final cover and graded with a 2 to 4 percent slope over most of the surface area.

2. The solid waste, cover soil, and vegetative cover were emplaced instantaneously at the beginning of the first month of the computation initiation. Practically speaking, this ignores any percolation that may occur prior to the placement of the final cover soil.

3. The final use of the site is an open green area to be used for recreation or pasture.

4. The surface is fully vegetated with a moderately deep-rooted grass, the roots of which draw water directly from all parts of the soil cover but not from the underlying solid waste.

5. The sole source of infiltration is precipitation falling directly on the landfill's surface. All surface runoff from adjacent drainage areas is diverted around the landfill surface. All ground water infiltration is prevented through proper site selection and design.

6. The hydraulic characteristics of the soil cover and compacted solid waste are uniform in all directions.

7. The depth of the landfill is much less than its horizontal extent. Thus, all water movement is vertically downward.

The water balances for the three case studies are presented and depicted in Tables 4, 5, and 6 and Figures 3, 4, and 5 for Cincinnati, Orlando, and Los Angeles respectively. In order to fully understand the calculations and manipulations involved in the water balance procedure, refer to the Appendix which presents the basic calculations, a discussion of each of the parameters and their manipulations, and copies of the three soil moisture retention tables used in the calculations.

TABLE 4

WATER BALANCE DATA FOR CINCINNATI, OHIO

Parameter*	J	F	M	A	M	J	J	A	S	O	N	D	Annual
PET	0	2	17	50	102	134	155	138	97	51	17	3	766
P	80	76	89	82	100	106	97	90	73	65	83	84	1025
$C_{R/O}$	0.17	0.17	0.17	0.17	0.17	0.13	0.13	0.13	0.13	0.13	0.13	0.17	
R/O	14	13	15	14	17	14	13	12	9	8	11	14	154
I	66	63	75	68	83	92	84	78	64	57	72	70	872
I-PET	+66	+61	+58	+18	-19	-42	-71	-60	-33	+6	+55	+67	+106
Σ NEG (I-PET)				(0)	-19	-61	-132	-192	-225				
ST (Table C)	150	150	150	150	131	99	61	41	33	39	94	150	
Δ ST	0	0	0	0	-19	-32	-38	-20	-8	+6	+55	+56	
AET	0	2	17	50	102	124	122	98	72	51	17	3	658
PERC	+66	+61	+57	+18	0	0	0	0	0	0	0	+11	213

*The parameters are as follows: PET, potential evapotranspiration; P, precipitation; $C_{R/O}$ surface runoff coefficient; R/O, surface runoff; I, infiltration; ST, soil moisture storage; Δ ST, change in storage; AET, actual evapotranspiration; PERC, percolation. All values are in millimeters (1 inch = 25.4 mm). See Appendix for discussion of parameters.

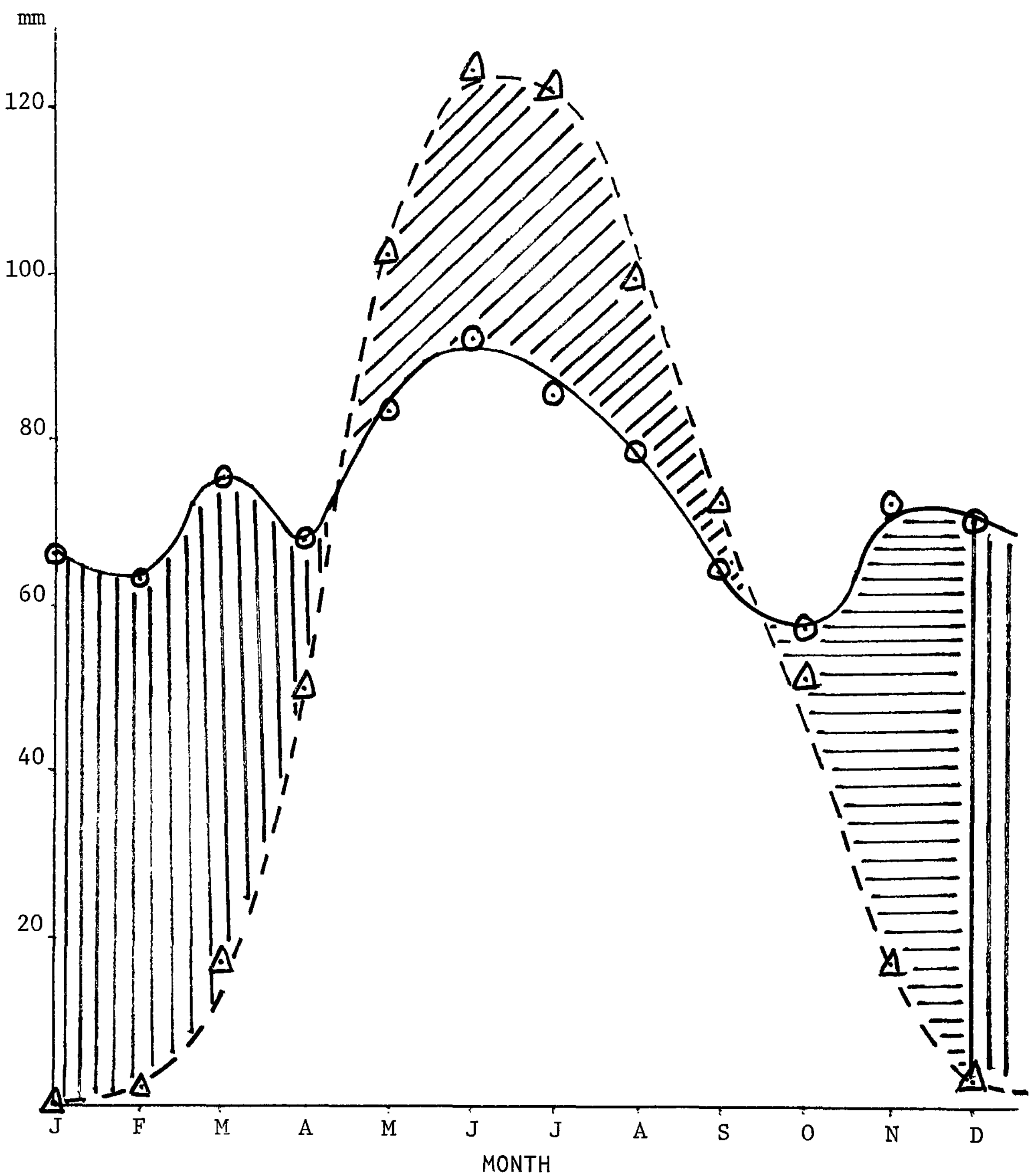


Figure 3. Water Balance for Cincinnati, Ohio

||||||| Percolation

Soil Moisture Recharge

///// Soil Moisture Utilization

Infiltration

Actual Evapotranspiration

TABLE 5

WATER BALANCE DATA FOR ORLANDO, FLORIDA

Parameter*	J	F	M	A	M	J	J	A	S	O	N	D	Annual
PET	33	39	59	90	140	167	175	173	142	100	53	35	1206
P	50	56	91	88	81	161	230	180	200	121	39	45	1342
$C_{R/O}$	.075	.075	.075	.075	.075	.075	.075	.075	.075	.075	.075	.075	
R/O	4	4	7	6	6	13	17	13	15	9	3	3	100
I	46	52	84	82	75	148	213	167	185	112	36	42	1243
I-PET	+13	+13	+25	-8	-65	-19	+38	-6	+43	+12	-17	+7	36
Σ NEG (I-PET)			(0)	-8	-73	-92	-25+	-31			-17		
ST (Table A)	100	100	100	92	47	39	77	73	100	100	84	91	
Δ ST	+9	0	0	-8	-45	-8	+38	-4	+27	0	-16	+7	
AET	33	39	59	90	120	156	175	171	142	100	52	35	1172
PERC	+4	13	25	0	0	0	0	0	16	12	0	0	70

*See footnote, Table 4.

+The situation where a positive I-PET value occurs between two negative values is a special case. Here, ST is found by direct addition of I-PET to the preceding ST. The Σ NEG (I-PET) value is then found from the soil moisture retention table for the ST value.

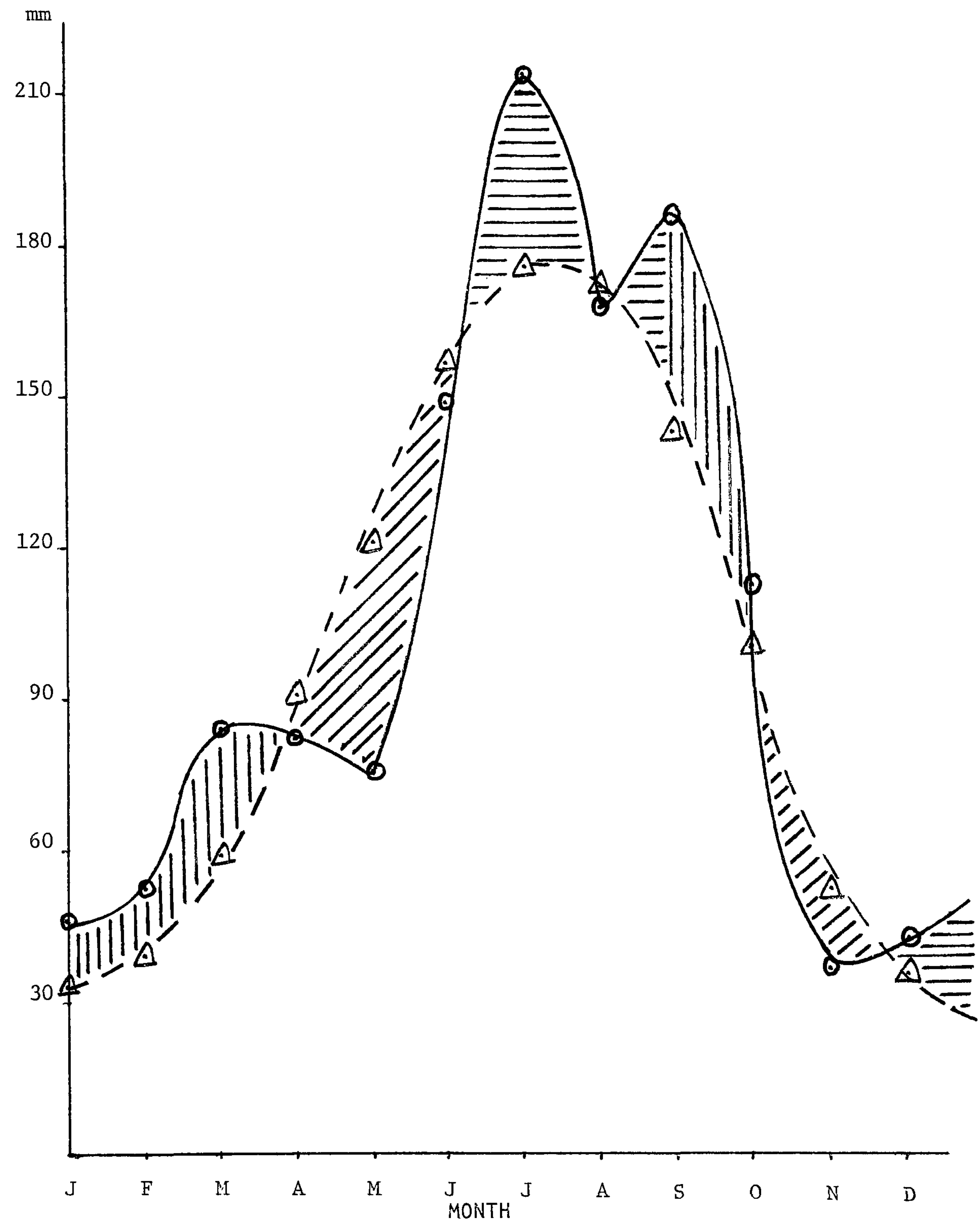


Figure 4. Water Balance for Orlando, Florida

Percolation

Soil Moisture Recharge

Soil Moisture Utilization

Infiltration

Actual Evapotranspiration

TABLE 6

WATER BALANCE DATA FOR LOS ANGELES, CALIFORNIA

Parameter*	J	F	M	A	M	J	J	A	S	O	N	D	Annual
PET	34	36	49	59	76	94	117	115	96	73	52	39	840
P	78	79	66	27	9	2	0	1	5	14	29	68	378
$C_{R/O}$	0.15	0.15	0.15	0	0	0	0	0	0	0	0	0.15	
R/O	12	12	10	0	0	0	0	0	0	0	0	10	44
I	66	67	56	27	9	2	0	1	5	14	29	58	334
I-PET	+32	+31	+7	-32	-67	-92	-117	-114	-91	-59	-23	+19	-506
Σ NEG (I-PET)			-39	-71	-138	-230	-347	-461	-552	-611	-634		
ST (Table B)	52	83	90	70	40	19	7	3	1	1	1	20	
Δ ST	+32	+31	+7	-20	-30	-21	-12	-4	-2	0	0	+19	
AET	34	36	49	47	39	23	12	5	7	14	29	39	334
PERC	0	0	0	0	0	0	0	0	0	0	0	0	0

* See footnote, Table 4.

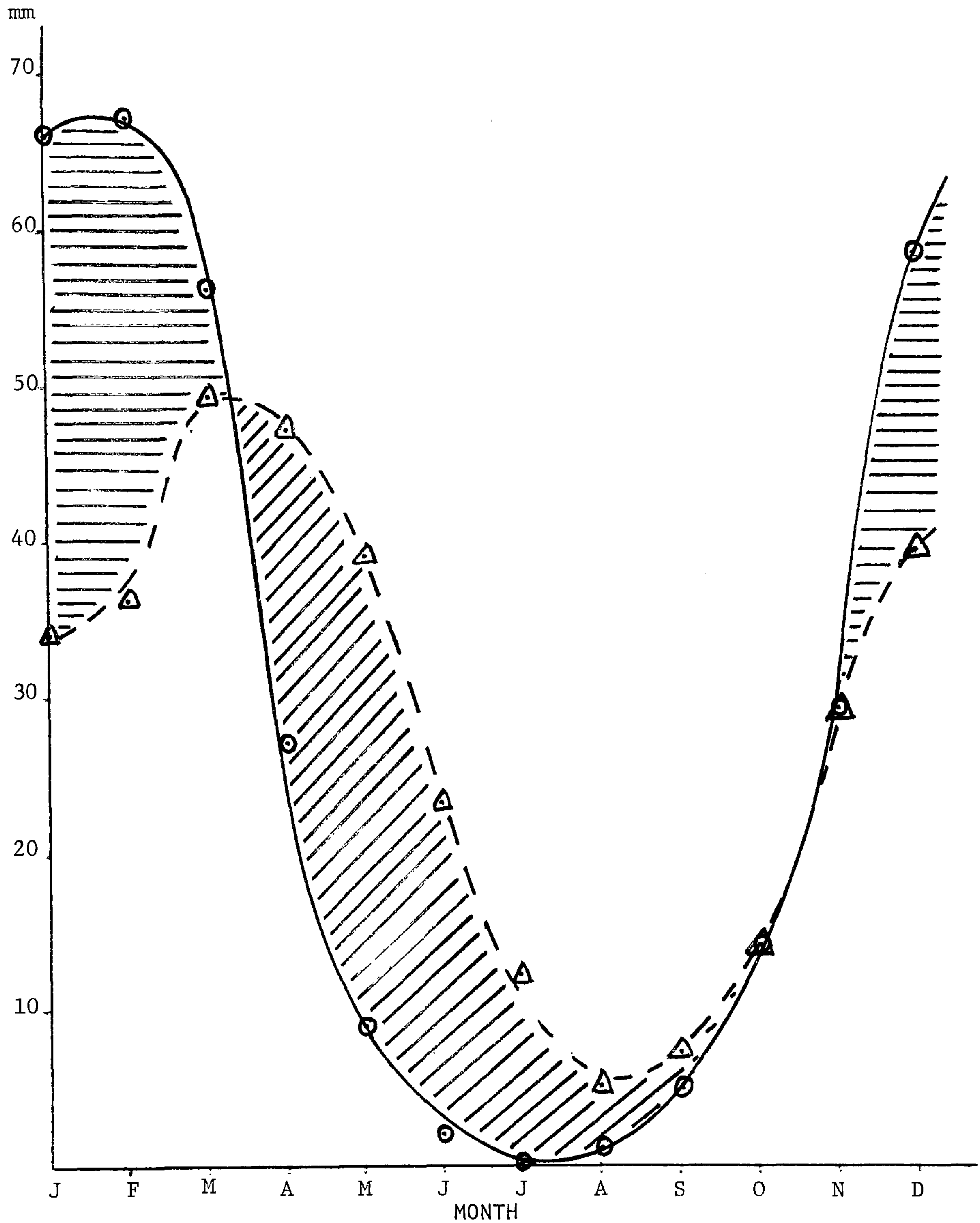


Figure 5. Water Balance for Los Angeles, California

Soil Moisture Recharge

Infiltration

Soil Moisture Utilization

Actual Evapotranspiration

Table 7 presents a summary of the water balances for the three case studies. As expected, the locations in the humid areas experienced percolation while the dry location experienced no significant percolation. It is interesting to note that all three cases are characterized by at least one wet season and one dry season during the one-year cycle. However, only in the humid areas is the precipitation sufficiently greater than the evapotranspiration to exceed the soil moisture storage capacity and produce percolation.

The fluctuating nature of percolation during the one-year cycle is an interesting phenomena to analyze. For example, examine the percolation in Cincinnati. During the dormant season (December to April), little or no evapotranspiration occurs, resulting in a high soil moisture content and significant amounts of percolation. During the growing season (May to September), the large evapotranspiration demand utilizes all of the infiltration moisture. The effect of the soil moisture storage is clearly seen in the fall months of October and November when the infiltration exceeds the potential evapotranspiration. This excess infiltration recharges soil moisture storage, resulting in no significant percolation until December. The fluctuating nature of percolation will cause variations in leachate generation.

Leachate Generation

Knowing the amount of water that percolates through the cover material (phase I), an analysis of the water routing through the solid waste (phase II) can now be performed to determine the magnitude and timing of leachate generation (refer to Figure 2).

Like its cover material, the underlying solid waste cells (including the relatively thin layers of daily cover material) will exhibit a certain capacity to hold water. The field capacity of solid waste has been determined by many investigators to vary from 20 percent to as high as 35 percent by volume.[3,12] In other words, the field capacity would vary from about 200 mm water/meter refuse (2.4 inches/foot) to about 350 mm water/meter refuse (4.2 inches/foot). For present purposes, a value of 300 mm/meter (3.6 inches/foot) will be used.

TABLE 7

SUMMARY OF WATER BALANCE CALCULATIONS

Location	Parameters - mean annual (mm)				
	Precipitation	Runoff	Infiltration	AET	Percolation
Cincinnati, Ohio	1025	154	872	658	213
Orlando, Florida	1342	100	1243	1172	70
Los Angeles, California	378	44	334	334	0

The amount of water which can be added to the solid waste before reaching field capacity depends also on its moisture content when delivered to the landfill site. This value will vary over a wide range depending on the composition of the waste and the climate. Several analyses performed on municipal solid waste show its moisture content to range anywhere from 10 to 20 percent by volume.[3,12,13] A moisture content of 15 percent by volume or about 150 mm/m (1.8 inches/foot) will be used here. Therefore, with a field capacity of 300 mm/m and an initial moisture content of 250 mm/m the compacted waste would have an adsorbtion capacity of about 150 mm of water per meter of solid waste (1.8 inches/foot).

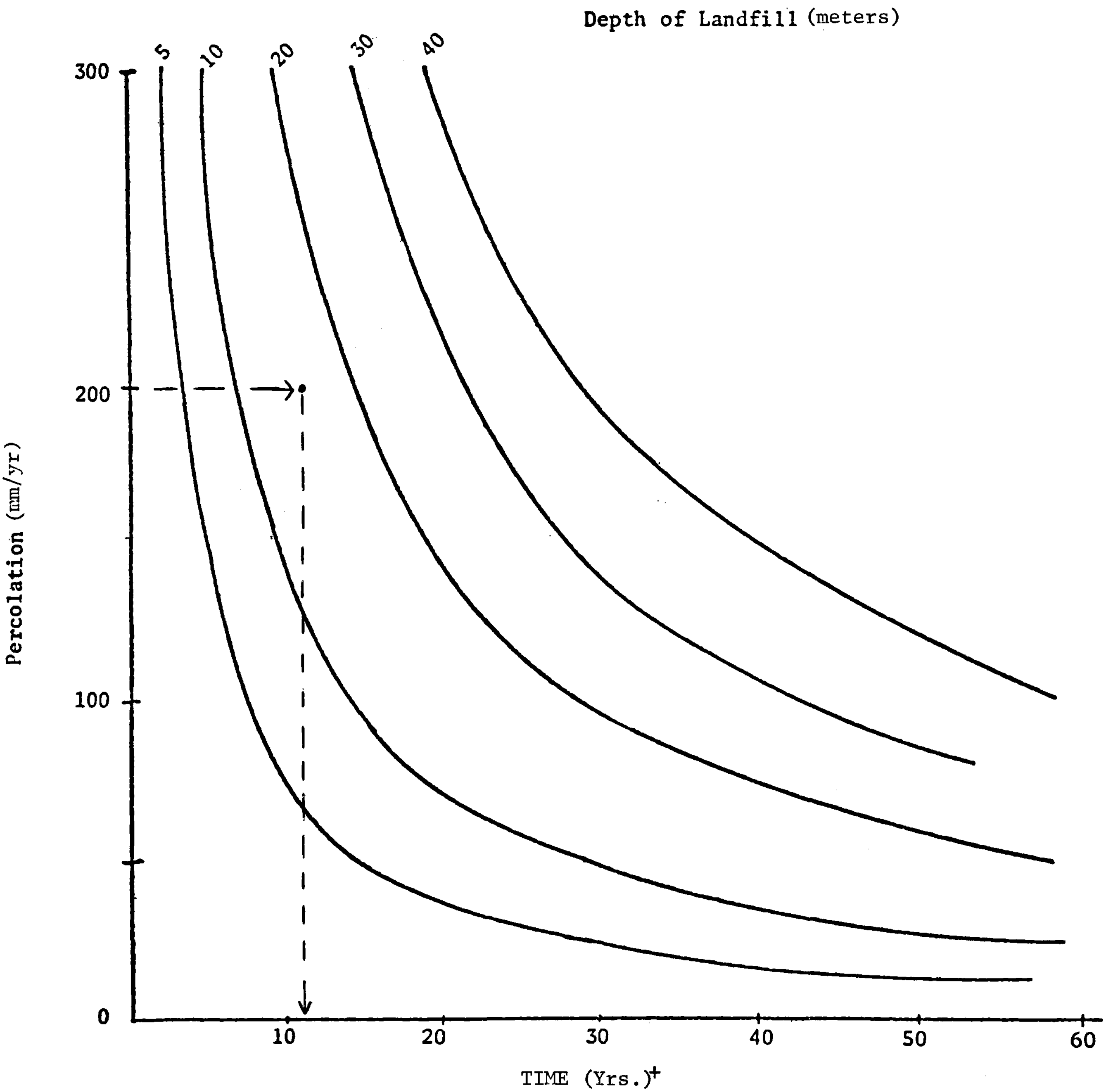
Theoretically, the water movement through a compacted solid waste cell will act like water movement through a soil layer. In other words, the field capacity of a given solid waste level must be exceeded before any significant leachate to a lower level will occur. For the examples, this means that 150 mm of percolation would have to be applied to a municipal solid waste layer one meter deep before any significant leachate would be generated from the bottom of that layer. Practically speaking, due to the heterogeneous nature of the solid waste, some channeling of water will occur causing some leaching to occur prior to attainment of field capacity. However, this amount should be small and certainly not a continuous flow and will be assumed negligible.

Employing the above concepts, one can assess the extent of the leachate problem for a given sanitary landfill site. The time of first appearance of leachate would be influenced by the landfill's depth and the leachate quantities by the landfill surface area (size). Figure 6 shows the relationship between annual percolation amounts and time of first appearance of leachate for various landfill depths. Figure 7 shows the relationship between annual percolation amounts and leachate quantities for various size landfills.

This methodology will be illustrated by application to the three case studies. Equal amounts of solid waste will be assumed for all three cases in determining the relative depths and acreage requirements at the different locations.

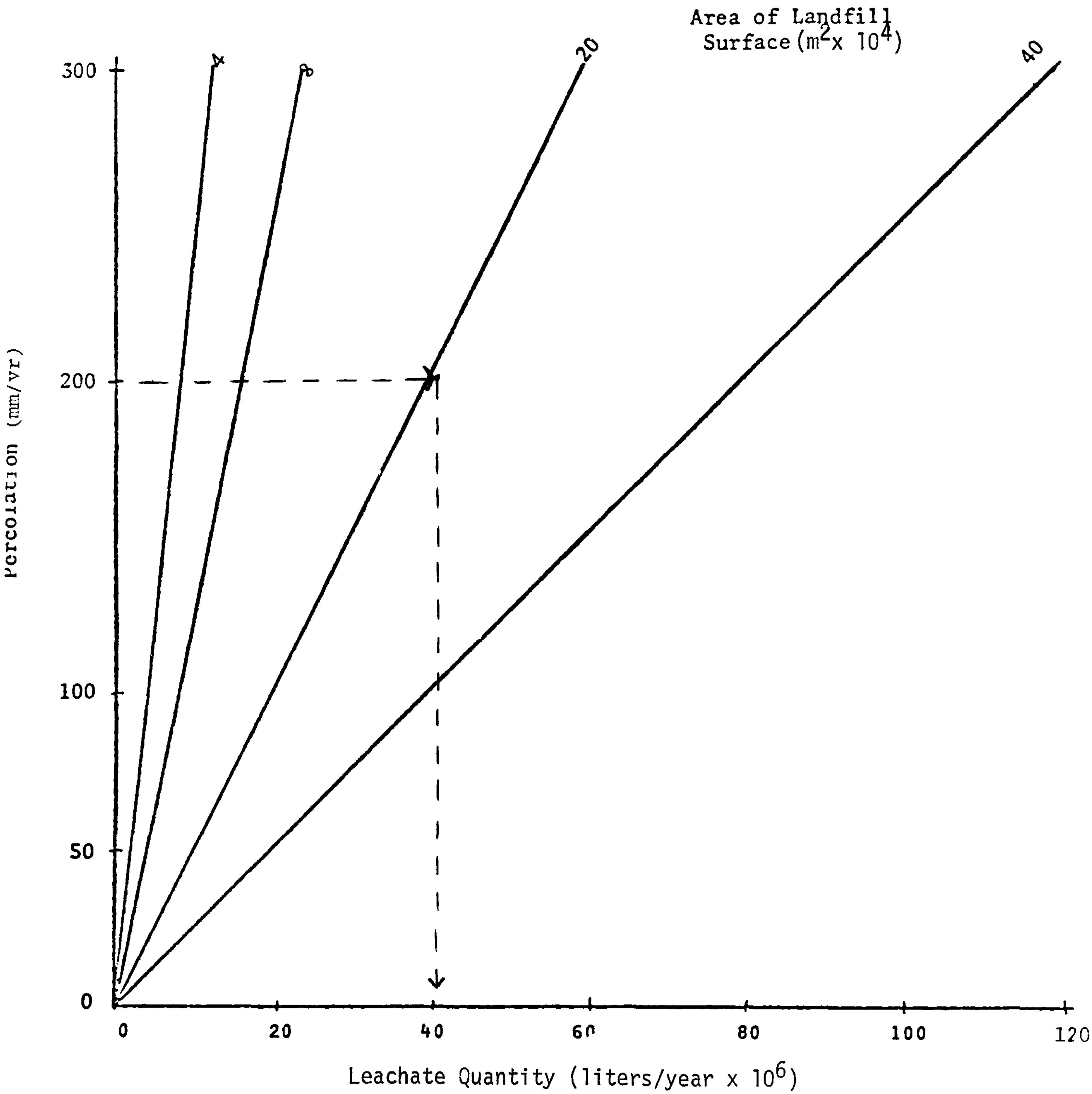
<u>Case 1--Cincinnati, Ohio.</u> The landfills in this location, as in most of the northern part of the country, are generally trench operations or area fills in small ravines. The depth of these operations would be expected to range between 10 and 20 meters, with the surface area usually above 50 acres (ca. $2X10^5 m^2$). A site will be assumed here with an average depth of 15 meters and a surface area of 202,000 m^2 (50 acres). Therefore, with an average annual percolation of slightly more than 200 mm

Figure 6. **Time of First Appearance of Leachate** *



*Based on a solid waste moisture absorption capacity of 150 mm/m.
+Time zero is defined as that time when the field capacity of the soil cover is first exceeded, producing the first amounts of percolation.

Figure 7. Annual Leachate Quantities
After Time of First Appearance



(Table 4), it would take close to 11 years (Figure 6) for significant amounts of leachate to appear at the bottom of the fill, at which time the average annual leachate quantity would be about 40 million liters (Figure 7).

Case 2--Orlando, Florida. The depth of landfills in this location and most of the coastal United States are limited due to proximity of the water table to the ground surface. The regulations of most state agencies prohibit dumping of solid waste directly into the ground water and, in fact, require a few feet of undisturbed soil between the high ground water level and the bottom of the landfill. With these restrictions, most landfills will fill below ground only one or two meters and above ground as high as availability of cover material will allow. Assuming an average depth of 7.5 meters, only half the depth as Case 1, the surface area required would be doubled to 100 acres (ca. $4x10^5 m^2$). Therefore, if the average annual percolation is 70 mm (Table 5), it would take close to 15 years for significant amounts of leachate to appear (Figure 6), at which time the average leachate quantity would be about 30 million liters/year (Figure 7).

Case 3--Los Angeles, California. The landfills in this area are generally area fills in deep canyons with depths ranging between 30 and 60 meters. Assuming an average depth of 40 meters, the surface area required would only be about one-fourth that of case 1, or 12 acres (ca. $5x10^4 m^2$). As noted in Table 6, percolation is negligible and one can easily assess the leachate problem as being insignificant for such a location.

A summary of the results for the three case studies is presented in Table 8.

Analysis of the sanitary landfill water balance calculations presented above points out some very interesting aspects of leachate generation of importance to the design engineer. These aspects should be considered in the overall assessment of the problem and may enter into the selection and design of leachate control measures.

First, in most cases leachate generation presents a potential problem principally in humid (low AET and high precipitation) areas of the country. Therefore, except for those sites where irrigation is utilized (discussed later), leachate problems will be virtually nonexistent at sanitary landfills in arid parts of the country.

TABLE 8

THEORETICAL LEACHATE QUANTITIES
AND TIME OF FIRST APPEARANCE

Location	Leachate	
	Time of first appearance (years)	Average annual quantity (liters/year) x 10
Cincinnati, Ohio	11	40
Orlando, Florida	15	30
Los Angeles, California	--	0

Second, there may not be a continuous flow of leachate throughout the year. Percolation and generation of leachate will most likely follow a pattern similar to that of the precipitation. This will result in the major portion of the leachate being produced during those months of significant percolation, with much lower flows occurring during the rest of the year.

Third, there will be a variation in the leachate generation pattern and amounts from year to year. The water balance calculations presented in this paper use mean monthly climatic values determined over a 25-year period. However, a brief analysis of precipitation data for any given location will indicate significant variations from year to year. So, while the average year might indicate a relatively minor leachate problem requiring little or no leachate control measures, an above average year may result in an entirely different assessment of the problem. Therefore, the engineer may wish to base his design on monthly precipitation values higher than the average values in order to provide a factor of safety in the estimation of leachate flow.

Other Considerations

The above methodology is presented with the intention of being a basic tool for engineers in assessing and designing sanitary landfills. The presentation was purposely kept straightforward since the concern was more to develop a clear understanding of the basic concepts and methods involved rather than a full scale design manual that would assess leachate problems for all conditions in all areas of the country.

Consequently, in an effort to avoid complications and confusion, special field conditions encountered at sanitary landfills sites in various parts of the country were ignored. The following discussion addresses three such special conditions and their effects on the water balance of a sanitary landfill.

1. Shallower cover soil with no vegetation. During the sanitary landfill's operating life, only completed parts of the landfill will be provided with final cover (two feet in thickness) and vegetated. The rest of the landfill surface might only have one foot of cover soil (intermediate cover) with no vegetation. The time to placement of final cover soil and vegetation will vary with the type and size of operation. Two contrasting examples are the deep quarry landfill in Montgomery County, Pennsylvania, and the shallow ravine landfill in Kansas City, Kansas. In the former case, no portion of the landfill surface will have final cover and vegetation until the quarry is completely filled. However, in the latter case the operation is completed in stages with no part of the landfill surface remaining more than one year without final cover and vegetation.[14]

Having different surface characteristics than the final vegetated cover soil, the intermediate cover soil condition will affect the results of the water balance. The shallower depth reduces soil moisture storage, thereby allowing more percolation to occur. The absence of vegetation will tend to have a compensating effect by increasing surface runoff and decreasing the evapotranspiration. Without vegetation, the surface runoff may double or triple for a heavy-type soil and experience only a slight increase for a sandy-type soil. Evaporation from the bare soil surface is quite rapid when the surface is wet but is greatly retarded when the top few millimeters become dry, and practically no evaporation occurs at depths greater than about 200 mm. Because the surface moisture condition is heavily dependent on the distribution of precipitation, any estimate of monthly evaporation from bare soil must be associated with the monthly precipitation. It is estimated that the evaporation from bare soil is roughly half of the precipitation for the heavy soils and about 30 percent of the precipitation for a sandy soil.[15]

Coupled with the above effects, the operational inefficiencies at a landfill, such as lack of adequate drainage, erosion, etc., will also tend to increase percolation. Therefore, it is safe to say that for almost all cases significantly more percolation will occur during the operating life of the landfill. This being the case, it is very likely that leachate may appear sooner and in larger quantities than was predicted by the earlier calculations which considered the completed sanitary landfill condition.

For example, examine the Orlando case study (Table 7), but assume a bare sandy soil. With the runoff doubled to about 22 mm, the infiltration would decrease to about 1150 mm. With evapotranspiration (AET) reduced to about 400 mm (30 percent of the precipitation), the percolation would be greatly increased to about 750 mm per year, or slightly more than ten times as much percolation than was predicted for the completed landfill surface. This would cause leachate to occur in a short period of time (about one year) and in larger quantities. A similar comparison can be done for Cincinnati, with similar but somewhat less severe end results.

2. Irrigation. If the final use of the landfill site is a park or an agricultural area, irrigation is likely to be practiced in semi-arid and arid areas. The amount of water that would be applied to a surface would be equal to the potential evapotranspiration requirements of the vegetative cover. In addition, the irrigation necessary to supply heavy evapotranspiration demands of the growing season is never 100 percent efficient. Some fraction--up to 40 percent--is never absorbed from the soil and eventually percolation will depend on the soil type and will generally be less in finer grained soils.

The effect of irrigation on the results of the water balance is obvious. If the irrigation system is not carefully designed to minimize inefficiencies, it is possible in a dry climate to create a significant amount of leachate which would not have been caused by precipitation alone.

For example, examine the Los Angeles case study. If the final use is a park, irrigation will be required to maintain a good grass cover. It is not uncommon to apply up to 700 mm of water annually. If 25 percent of the irrigation is lost to percolation (less than 40 percent due to the fine grained soil), 175 mm of water will reach the solid waste. Although this is still a relatively minor amount in light of the landfill depth, it should, nevertheless, be considered.

3. Frozen ground and snow accumulation. During the winter months, the northern portion of the country will have frozen ground conditions and snow accumulations. This will reduce the infiltration fraction of the precipitation that falls during the winter months. This is due to the fact that the frozen ground will virtually eliminate percolation during these months, and the spring snow-melt will exhibit higher amounts of surface water runoff than would normally have occurred in a warmer area. Therefore, in general, the net effect on the water balance will be to decrease the amount of percolation and consequently, the amount of leachate generated.

CONCLUSIONS AND RECOMMENDATIONS

The water balance method will serve as a useful engineering tool in conducting environmental assessments of proposed or existing sanitary landfill sites, specifically in regards to leachate generation. However, it should be remembered that the method as presented in this paper is intended only as a basic tool for the engineer, and certain site specific assumptions will be necessary to tailor the method for a particular location. These assumptions will involve the choice of precipitation data and proper methods for predicting evapotranspiration and surface runoff; the accounting for bare soil conditions during the operating life of the landfill; and the accounting for irrigation, frozen ground and snow-melt conditions where applicable.

The water balance method points out the following characteristics of leachate generation:

1. Leachate will be generated in humid areas, while no significant amounts will be generated in dry areas.

2. Leachate generation is not likely to result in a constant flow throughout the year or from year to year but will follow a pattern somewhat similar to that of precipitation.

3. In humid areas where leachate will be generated, the hydrogeology of the site will be carefully evaluated to determine its inherent capability to naturally attenuate leachate contaminants. Where it is determined that water pollution would result, leachate collection and treatment facilities should be employed.

4. Leachate generation can be minimized by proper and efficient covering operations, careful contouring and drainage design of the final surface, proper selection of a vegetative cover, and in some cases the final use selected for the site.

5. Leachate generation will eventually cease if the final use of the landfill prevents percolation.

From the above statements, it is obvious that leachate will be generated for a long period of time unless percolation is prevented by site operating and completion procedures. If percolation is prevented in the final site use, leachate generation will cease shortly after the landfill is completed.

1. The water balance technique should be applied to all existing and proposed sites.

2. If it is determined that leachate generation is significant enough to cause a problem (i.e., the site's hydrogeology does not have the inherent capability to naturally attenuate leachate), then leachate collection and treatment facilities should be provided

3. Recommended operating practices should be followed so as to minimize infiltration, thereby reducing leachate generation during the operating life of the landfill.

4. The final surface of the landfill should be designed to minimize percolation into the solid waste. For example, if the final use is an open green area, an impermeable membrane or clay layer can be placed under the top soil. If the final use is a parking lot, the surface material should by its very nature prevent infiltration. In all cases, surface drainage from adjacent areas should be diverted from the landfill.

APPENDIX

Basic Calculations

Case 1 - Cincinnati, Ohio - Table 4 and Figure 3

a) Soil Moisture Storage at Field Capacity -

For a clay-loam and moderately deep-rooted grass,

available water = 250 mm/m (Table 2)

root zone = .6 m (limited by depth of soil)

Therefore,

soil moisture storage = 250 x .6 = 150 mm at field capacity

Use Soil Moisture Retention Table 11

b) Surface Runoff Coefficient - $C_{R/O}$ - (Table 3)

Grass and heavy soil at 2% slope

$C_{R/O}$ = .17 for wet season

= .13 for dry season

(Note: higher coefficient during wet season to reflect the effect of higher antecedent moisture condition of soil.)

Case 2 - Orlando, Florida - Table 5 and Figure 4

a) Soil Moisture Storage at Field Capacity -

For a sandy-loam and moderately deep-rooted grass,

available water = 150 mm/m (Table 2)

root zone = .6 m (limited by depth of soil)

Therefore,

soil moisture storage = 150 x .6 = 90 mm at field capacity

Since there is no soil moisture retention table for 90 mm, use Soil Moisture Retention Table 9.

b) Surface Runoff Coefficient - $C_{R/O}$ - (Table 3)

Grass and sandy soil at 2% slope

$C_{R/O}$ = .075 for all months

Case 3 - Los Angeles, California - Table 6 and Figure 5

a) Soil Moisture Storage at Field Capacity -

For a silty loam and moderately deep-rooted grass

available water = 200 mm/m (Table 2)

root zone = .6 m (limited by depth of soil)

Therefore,

Soil moisture storage = 200 x .6 = 120 mm at field capacity

Since there is no soil moisture retention table for 120 mm, use Soil Moisture Retention Table 10.

b) Surface Runoff Coefficient - (Table 3)

Grass and silty soil at 2% slope

$C_{R/O}$ = .15 for only those months where P > PET

(Note: Surface runoff is assumed to be negligible for the dry months in an arid climate.)

<u>Parameters and Procedures for the Water Balance</u>

1. Basic equation: $PERC = P \quad R/O - \Delta ST - AET$.

2. Potential Evapotranspiration (PET) - Mean monthly value based on the 25 year period, 1920 to 1944, were used. The values are derived from Thornthwaite's PET equation (Reference 7) and associated tabular data.

3. Precipitation (P) - Mean monthly values based on the 25 year period, 1920 to 1944, were used. These data are available from the U. S. Weather Bureau for any location in the United States.

4. Surface Runoff Coefficients ($C_{R/O}$) - Based on the runoff coefficients for use in the rational runoff calculation method. As strictly defined, the runoff coefficient is the ratio between the maximum rate of runoff from the area and the average rate of rainfall on the area.

5. Surface Runoff (R/O) - The selected runoff coefficient is applied to the mean monthly precipitation to obtain the mean monthly surface runoff value. This represents the amount of precipitation that runs off the landfill surface before it can infiltrate into the cover soil.

6. Infiltration (I) - Represents the amount of precipitation that enters the surface of the cover soil. It is simply the difference between the precipitation and the surface runoff ($I = P - R/O$).

7. Infiltration minus potential evapotranspiration (I - PET) - To determine periods of moisture excess and deficiency in the soil it is necessary to obtain the difference between infiltration and potential evapotranspiration. A negative value of I-PET indicates the amount by which the infiltration fails to supply the potential water need of a vegetated area. A positive value of I-PET indicates the amount of excess water which is

available during certain periods of the year for soil moisture recharge and percolation.

In most locations there is only one so called "wet" season and one "dry" season per year. Thus, there will be only one set of consecutive negative and one set of positive differences. Note that Orlando is an exception to this statement. Cincinnati and Orlando are examples of locations where excess precipitation (positive I-PET) during the year will be greater than the potential water loss (negative I-PET), while Los Angeles is an example of a location where the reverse is true. This latter situation will occur in dry areas where precipitation is not sufficient to bring the soil moisture back up to its maximum value of water holding capacity at any time during the year. At locations with positive annual values of I-PET, the soil moisture at the end of the wet period is always at the maximum value of water holding capacity.

8. Accumulated Potential Water Loss [Σ NEG (I-PET)] - The negative values of I-PET, representing the potential water loss, are summed month by month. In most humid areas (defined as areas where the sum of all the I-PET values is positive), the value of accumulated potential water loss [Σ NEG (I-PET)] with which to start accumulating the negative values of I-PET is 0 (see examples for Cincinnati and Orlando). This value of 0 is assigned to the last month having a positive value of I-PET. The reason for this is that the soil moisture at the end of the wet season is at field capacity. However, for dry areas (defined as areas where the annual total I-PET is negative) such as Los Angeles, soil moisture at the end of the wet season is below field capacity. Therefore, it is necessary to find an initial value of Σ NEG (I-PET) with which to start accumulating the negative values of I-PET. This is done by utilizing Thornthwaite's method of successive approximations (reference 7).

9. Soil Moisture Storage (ST) - This factor represents the soil moisture, or the moisture retained in the soil

after a given amount of accumulated potential water loss or gain has occurred. As shown in the sample calculations for Cincinnati and Orlando (humid areas), the initial value is calculated at field capacity by multiplying available water per unit depth of soil (Table 2) by root zone depth. This initial value of ST is assigned to the last month having a positive value of I-PET, i.e., the last month of the wet season. In dry areas such as Los Angeles, soil moisture at the end of the wet season is below field capacity. Thus, the initial, as well as subsequent, ST values must be determined from the appropriate soil moisture retention table utilizing the values of Σ NEG (I-PET) calculated per item 8, above.

To determine the soil moisture retained each month, Thornthwaite has developed soil moisture retention tables for various water holding capacities. Tables 9, 10, and 11 at the end of this Appendix are the appropriate soil moisture retention tables for Orlando, Los Angeles and Cincinnati, respectively. After the soil moisture storage for each of the months with negative values of I-PET has been found from the table, the positive values of I-PET, representing additions of moisture to the soil, must be added to the previous month's ST value. No ST value can exceed soil moisture storage at field capacity. Thus, any excess of I-PET above this maximum ST value becomes percolation.

10. Change in Soil Moisture Storage (ΔST) - Represents the change in soil moisture from month to month.

11. Actual Evapotranspiration (AET) - Represents the actual amount of water loss during a given month. As soil moisture is depleted, the rate of evapotranspiration decreases below its potential rate, thereby resulting in an AET value less than the corresponding PET value. For those months where I-PET is positive, the rate of evapotranspiration is not limited by moisture availability, and AET is equal to PET. For those months where I-PET is negative, the rate of evapotranspiration is limited by soil moisture availability, and AET =PET + [(I-PET) - ΔST].

12. Percolation (PERC) - After the soil moisture storage reaches its maximum, any excess infiltration becomes percolation through the cover soil and into the underlying solid waste. Therefore, significant percolation will occur only during those months when I exceeds PET (I-PET is positive) and the soil moisture exceeds its maximum. For most humid areas, this will occur during the wet season (see examples for Orlando and Cincinnati). For dry areas, significant percolation may never occur (see example for Los Angeles).

TABLE 9

SOIL MOISTURE RETENTION TABLE - 100 MM

SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF POTENTIAL EVAPOTRANSPIRATION HAVE OCCURRED. SOIL MOISTURE STORAGE AT FIELD CAPACITY IS 100 MM.

ΣNEG(I-PET)	0	1	2	3	4	5	6	7	8	9
					Water Retained in Soil					
0	100	99	98	97	96	95	94	93	92	91
10	90	89	88	88	87	86	85	84	83	82
20	81	81	80	79	78	77	77	76	75	74
30	74	73	72	71	70	70	69	68	68	67
40	65	66	65	64	64	63	62	62	61	60
50	60	59	59	58	58	57	56	56	65	54
60	54	53	53	52	52	51	51	60	50	49
70	49	48	48	47	47	46	46	45	45	44
80	44	44	43	43	42	42	41	41	40	40
90	40	39	39	38	38	38	37	37	36	36
100	36	35	35	35	34	34	34	33	33	33
110	32	32	32	31	31	31	30	30	30	30
120	29	29	29	28	28	28	27	27	27	27
130	26	26	26	26	25	25	25	24	24	24
140	24	24	23	23	23	23	22	22	22	22
150	22	21	21	21	21	20	20	20	20	20
160	19	19	19	19	19	18	18	18	18	18
170	18	17	17	17	17	17	16	16	16	16
180	16	16	15	15	15	15	15	15	14	14
190	14	14	14	14	14	14	13	13	13	13
200	13	13	12	12	12	12	12	12	12	12
210	12	11	11	11	11	11	11	11	11	11
220	10	10	10	10	10	10	10	10	10	10
230	9	9	9	9	9	9	9	9	9	9
240	8	8	8	8	8	8	8	8	8	8
250	8	8	8	7	7	7	7	7	7	7
260	7	7	7	7	7	7	6	6	6	6
270	6	6	6	6	6	6	6	6	6	6
280	6	6	6	6	6	5	5	5	5	5
290	5	5	5	5	5	5	5	5	5	5
300	5	5	4	4	4	4	4	4	4	4
310	4	4	4	4	4	4	4	4	4	4
320	4	4	4	4	4	4	4	4	4	4
330	3	3	3	3	3	3	3	3	3	3
340	3	3	3	3	3	3	3	3	3	3
350	3	3	3	3	3	3	3	3	3	2
360	2	2	2	2	2	2	2	2	2	2
370	2	2	2	2	2	2	2	2	2	2
380	2	2	2	2	2	2	2	2	2	2
390	2	2	2	2	2	2	2	2	2	2
400	2	2	2	2	2	2	2	2	2	2
410	2	2	2	2	2	1	1	1	1	1
420	1	1	1	1	1	1	1	1	1	1
430	1	1	1	1	1	1	1	1	1	1
440	1	1	1	1	1	1	1	1	1	1
450	1	1	1	1	1	1	1	1	1	1
460	1	1	1	1	1	1	1	1	1	1
470	1	1	1	1	1	1	1	1	1	1
480	1	1	1	1	1	1	1	1	1	1
490	1	1	1	1	1	1	1	1	1	1
500	1	1	1	1	1	1	1	1	1	1

SOIL MOISTURE RETENTION TABLE - 150 MM

(CONTINUED)

Σ(I-PET)	0	1	2	3	4	5	6	7	8	9
					WATER RETAINED IN SOIL					
450	7	7	7	7	7	7	7	7	7	7
460	7	7	7	7	6	6	6	6	6	6
470	6	6	6	6	6	6	6	6	6	6
480	6	6	6	6	6	6	6	6	5	5
490	5	5	5	5	5	5	5	5	5	5
500	5	5	5	5	5	5	5	5	5	5
510	5	5	5	5	5	5	5	5	4	4
520	4	4	4	4	4	4	4	4	4	4
530	4	4	4	4	4	4	4	4	4	4
540	4	4	4	4	4	4	4	4	4	4
550	4	4	4	4	4	4	4	3	3	3
560	3	3	3	3	3	3	3	3	3	3
570	3	3	3	3	3	3	3	3	3	3
580	3	3	3	3	3	3	3	3	3	3
590	3	3	3	3	3	3	3	3	3	3
600	3	3	3	3	3	2	2	2	2	2
610	2	2	2	2	2	2	2	2	2	2
620	2	2	2	2	2	2	2	2	2	2
630	2	2	2	2	2	2	2	2	2	2
640	2	2	2	2	2	2	2	2	2	2
650	2	2	2	2	2	2	2	2	2	2
660	2	2	2	2	2	2	2	2	2	2
670	2	2	2	2	2	2	2	2	2	2
680	2	2	1	1	1	1	1	1	1	1
690	1	1	1	1	1	1	1	1	1	1
700	1	1	1	1	1	1	1	1	1	1
710	1	1	1	1	1	1	1	1	1	1
720	1	1	1	1	1	1	1	1	1	1
730	1	1	1	1	1	1	1	1	1	1
740	1	1	1	1	1	1	1	1	1	1

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	0	5		0	5		0	5
750	1	1	790	1	1	830	1	1
760	1	1	800	1	1	840	1	1
770	1	1	810	1	1			
780	1	1	820	1	1			

TABLE 10

SOIL MOISTURE RETENTION TABLE - 125 MM

SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF POTENTIAL EVAPOTRANSPIRATION HAVE OCCURRED. SOIL MOISTURE STORAGE OF FIELD CAPACITY IS 125 MM.

ΣNEG(I-PET)	0	1	2	3	4	5	6	7	8	9
				WATER RETAINED IN SOIL						
0	125	124	123	122	121	120	119	118	117	116
10	115	114	113	112	111	110	109	108	107	106
20	106	105	104	103	102	102	101	100	99	99
30	98	97	96	95	94	94	93	92	91	90
40	90	89	88	87	86	86	85	84	84	83
50	83	82	.82	81	80	80	79	79	78	77
60	76	76	75	74	74	73	73	72	72	71
70	70	70	69	69	68	68	67	67	66	65
80	65	64	64	63	63	62	62	61	61	60
90	60	59	59	58	58	57	57	56	56	55
100	55	55	54	54	53	53	53	52	52	51
110	51	51	50	50	49	49	49	48	48	47
120	47	47	46	46	45	45	45	44	44	43
130	43	43	42	42	41	41	41	41	40	40
140	40	40	39	39	39	38	38	38	38	37
150	37	37	36	36	36	35	35	35	35	34
160	34	34	33	33	33	32	32	32	32	31
170	31	31	31	30	30	30	30	30	30	29
180	29	29	29	29	28	28	28	27	27	27
190	26	26	26	26	26	25	25	25	26	25
200	24	24	24	24	24	23	23	23	23	23
210	22	22	22	22	22	22	22	21	21	21
220	21	21	21	21	20	20	20	20	20	20
230	19	19	19	19	19	18	18	18	18	18
240	18	18	17	17	17	17	17	17	17	17
250	16	16	16	16	16	16	16	16	15	15
260	15	15	15	15	15	14	14	14	14	14
270	14	14	14	14	14	13	13	13	13	13
280	13	13	13	13	13	12	12	12	12	12
290	12	12	12	12	12	11	11	11	11	11
300	11	11	11	11	11	10	10	10	10	10
310	10	10	10	10	10	10	10	10	9	9
320	9	9	9	9	9	9	9	9	9	9
330	8	8	8	8	8	8	8	8	8	8
340	8	8	8	8	8	7	7	7	7	7

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	0	5		0	5		0
350	7	7	450	3	3	550	1
360	7	6	460	3	3	560	1
370	6	6	470	3	3	570	1
380	6	5	480	2	2	580	1
390	5	5	490	2	2	590	1
400	5	5	500	2	2	600	1
410	4	4	510	2	2	610	1
420	4	4	520	2	2	620	1
430	4	4	530	2	2	630	1
440	3	3	540	2	1	640	1

TABLE 11

SOIL MOISTURE RETENTION TABLE - 150 MM

SOIL MOISTURE RETAINED AFTER DIFFERENT AMOUNTS OF POTENTIAL EVAPOTRANSPIRATION HAVE OCCURRED. SOIL MOISTURE STORAGE AT FIELD CAPACITY IS 150 MM.

ΣNEG(I-PET)	0	1	2	3	4	5	6	7	8	9
					WATER RETAINED IN SOIL					
0	150	149	148	147	146	145	144	143	142	141
10	140	139	138	137	136	135	134	133	132	131
20	131	130	129	128	127	127	126	125	124	123
30	122	122	121	120	119	118	117	115	115	114
40	114	113	113	112	111	111	110	109	108	107
50	107	106	106	105	104	103	103	102	101	100
60	100	99	98	97	97	97	96	95	94	93
70	93	92	92	91	90	90	89	89	88	87
80	87	86	86	85	84	84	84	83	83	82
90	82	81	81	80	79	79	78	77	77	76
100	76	75	75	75	74	74	73	72	72	71
110	71	71	70	70	69	69	68	68	67	67
120	66	65	65	65	65	64	64	63	63	62
130	62	62	61	61	60	60	60	59	59	58
140	58	58	57	57	56	56	55	55	54	54
150	54	53	53	53	52	52	52	52	51	51
160	51	51	50	50	50	49	49	48	48	47
170	47	47	47	46	46	46	45	45	45	44
180	44	44	44	43	43	43	42	42	42	41
190	41	41	41	40	40	40	40	39	39	39
200	39	38	38	38	37	37	37	37	36	36
210	36	36	35	35	35	35	35	34	34	34
220	34	34	33	33	33	33	33	32	32	32
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240	30	29	29	29	29	29	28	28	28	28
250	28	27	27	27	27	27	26	26	26	26
260	26	26	25	25	25	25	25	24	24	24
270	24	24	24	23	23	23	23	23	23	23
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290	21	21	21	20	20	20	20	20	20	20
300	20	19	19	19	19	19	19	19	18	18
310	18	18	18	18	18	18	18	17	17	17
320	17	17	17	17	17	17	17	16	16	16
330	16	16	16	15	16	16	16	15	15	15
340	15	15	15	15	15	15	14	14	14	14
350	14	14	14	14	14	14	14	13	13	13
360	13	13	13	13	13	13	13	12	12	12
370	12	12	12	12	12	12	12	12	11	11
380	11	11	11	11	11	11	11	11	11	11
390	11	11	11	10	10	10	10	10	10	10
400	10	10	10	10	10	10	10	10	9	9
410	9	9	9	9	9	9	9	9	9	9
420	9	9	9	8	8	8	8	8	8	8
430	8	8	8	8	8	8	8	8	8	8
440	8	8	8	7	7	7	7	7	7	7

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