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Evaluating Cover Systems for Solid and Hazardous Waste

EVALUATING COVER SYSTEMS FOR SOLID AND HAZARDOUS WASTE

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies; and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research--a vital communications link between the researcher and the user community.

This report is to be used as a tool for evaluating various landfill cover systems. This data information can be used in determining cover design requirements for compliance with the current regulations.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

PREFACE

The land disposal of hazardous waste is subject to the requirements of Subtitle C of the Resource Conservation and Recovery Act of 1976. This Act requires that the treatment, storage, or disposal of hazardous wastes after November 19, 1980 be carried out in accordance with a permit. The one exception to this rule is that facilities in existence as of November 19, 1980 may continue operations until final administrative disposition is made of the permit application (providing that the facility complies with the Interim Status Standards for disposers of hazardous waste in 40 CFR Part 265). Owners or operators of new facilities must apply for and receive a permit before beginning operation of such a facility.

The Interim Status Standards (40 CFR Part 265) and some of the administrative portions of the Permit Standards (40 CFR Part 264) were published by the Environmental Protection Agency in the Federal Register on May 19, 1980. The Environmental Protection Agency published interim final rules in Part 264 for hazardous waste disposal facilities on July 26, 1982. These regulations consist primarily of two sets of performance standards. One is a set of design and operating standards separately tailored to each of the four types of facilities covered by the regulations. The other (Subpart F) is a single set of ground-water monitoring and response requirements applicable to each of these facilities. The permit official must review and evaluate permit applications to determine whether the proposed objectives, design, and operation of a land disposal facility will comply with all applicable provisions of the regulations (40 CFR 264).

The Environmental Protection Agency is preparing two types of documents for permit officials responsible for hazardous waste landfills, surface impoundments, land treatment facilities and piles: Draft RCRA Guidance Documents and Technical Resource Documents. The draft RCRA guidance documents present design and operating specifications which the Agency believes comply with the requirements of Part 264, for the Design and Operating Requirements and the Closure and Post-Closure Requirements contained in these regulations. The Technical Resource Documents support the RCRA Guidance Documents in certain areas (i.e., liners, leachate management, closure, covers, water balance) by describing current technologies and methods for evaluating the performance of the applicant's design. The information and guidance presented in these manuals constitute a suggested approach for review and evaluation based on good engineering practices. There may be alternative and equivalent methods for conducting the review and evaluation. However, if the results of these methods differ from those of the Environmental Protection Agency method, they may have to be validated by the applicant.

In reviewing and evaluating the permit application, the permit official must make all decisions in a well defined and well documented manner. Once an initial decision is made to issue or deny the permit, the Subtitle C regulations (40 CFR 124.6, 124.7 and 124.8) require preparation of either a statement of basis or a fact sheet that discusses the reasons behind the decision. The statement of basis or fact sheet then becomes part of the permit review process specified in 40 CFR 124.6-124.20.

These manuals are intended to assist the permit official in arriving at a logical, well-defined, and well-documented decision. Checklists and logic flow diagrams are provided throughout the manuals to ensure that necessary factors are considered in the decision process. Technical data are presented to enable the permit official to identify proposed designs that may require more detailed analysis because of a deviation from suggested practices. The technical data are not meant to provide rigid guidelines for arriving at a decision. The references are cited throughout the manuals to provide further guidance for the permit officials when necessary.

There was a previous version of this document dated September 1980. The new version supercedes the September 1980 version.

ABSTRACT

A critical part of the sequence of designing, constructing, and maintaining an effective cover over solid and hazardous waste is the evaluation of engineering plans. Such evaluation is an important function of regulating agencies, and accompanying documentation can form one basis for issuing or denying a permit to the owner/operator of the waste disposal facility. This manual describes 39 steps in evaluation of plans submitted for approval. Generally, the evaluator considers available soils, site conditions, details of cover design, and post-closure maintenance and contingencies.

This report was submitted in fulfillment of Phase III of Interagency Agreement No. EPA-IAG-D7-01097 between the U. S. Environmental Protection Agency and the U. S. Army Engineer Waterways Experiment Station (WES). Work for this manual was conducted during the period December 1979 to July 1980, and work was completed in July 1980. Revisions have been made as appropriate following a period of public review. Dr. R. J. Lutton, Geotechnical Laboratory, WES, was principal investigator and author. Director of WES during the work period was COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

METRIC CONVERSION TABLE

Multiply	By	To Obtain
acres	4046.856	square meters
cubic feet per second	0.02831685	cubic meters per second
degrees (angle)	0.01745329	radians
feet	0.3048	meters
feet per second	0.3048	meters per second
gallons (U. S. liquid)	0.003785412	cubic meters
inches	0.0254	meters
pounds (mass)	0.4535924	kilograms
pounds (mass) per acre	0.1120851	grams per square meter
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square feet	0.09290304	square meters
tons (short, mass)	907.1847	kilograms
tons (mass) per acre	0.2241702	kilograms per square meter

SECTION 1

INTRODUCTION

Growing concern for the preservation of a healthful environment, now and in the future, was the major impetus to the enactment of Public Law 94-580, "Resource Conservation and Recovery Act of 1976" (21 October 1976). An important part of solid and hazardous waste management is the regulatory control exercised by the Environmental Protection Agency (EPA) regional offices and corresponding agencies in state governments. In turn, a major facet of this regulatory function is the evaluation of the adequacy of closure covers over the wastes.

PURPOSE AND SCOPE

This manual presents a procedure for evaluating engineering plans for closure covers proposed for solid and hazardous waste land disposal facilities. The manual is written principally for staff members in the Regional EPA offices and/or state offices charged with evaluating applications from owners/operators of solid and hazardous waste disposal areas. All aspects of cover design are addressed in sufficient detail to allow for a complete evaluation of the entire cover system. For more details on the subjects covered in this manual, the reader is referred to a report emphasizing design and construction of covers which serves as the backup document.[1]

PROCEDURES OF EVALUATION

The evaluation of engineering plans should be performed with regard to conformance to applicable regulations. The sequence of procedures is outlined as follows:

1. Examine soil test data
2. Examine topography
3. Examine climate data
4. Evaluate composition
5. Evaluate thickness
6. Evaluate placement
7. Evaluate configuration

8. Evaluate drainage

9. Evaluate vegetation

10. Evaluate post-closure maintenance

11. Evaluate contingencies plan

The first three procedures in the evaluation process (presented in SECTION 2) constitute a careful review of materials and conditions at the proposed or existing site under consideration. Procedures 4-9 outline evaluations of the characteristics of the cover system within the constraints offered by review procedures 1-3. Procedures 10 and 11 evaluate the adequacy of the cover system and post-closure plan for future conditions, both expected and unexpected.

Opportunity will be provided in the evaluation scheme in Section 2 for consideration of departures from more or less conventional designs. Such an option is specifically intended for instances where the owner/operator, for one reason or another, proposes a design based on a special engineering study or calculations. In evaluating such departures in design, the permitting authority will find useful the additional technical guidance in Reference 1 or may enlist an experienced consulting firm or other source of technical assistance to conduct the evaluation.

CHARACTERIZATION OF WASTE

Individual emphases among the procedures for examining and evaluating covers are predicated to some degree on the characteristics of the waste to be covered. Although not identified as such in this manual, the review of waste characteristics can be considered a preliminary step from which the examination proceeds. Accordingly, the reviewer may want to request documentation in the application. Some important characteristics of the waste are composition (including water content), thickness, unit weight (in place), prior compaction, gas-forming potential, and hazardous components.

The characterization of waste helps to identify the important functions of the cover. Control of percolation often predominates as a cover function but, even then, other functions should be recognized also and ranked accordingly. Elsewhere, the control of percolation will be subordinate to another function, e.g. control of gas migration. Reference 1 addresses each of the numerous functions of cover and should be helpful in reviewing this background for a specific site.

SECTION 2

EXAMINATION OF DATA

TEST DATA REVIEW PROCEDURE

Sampling and testing are intended to characterize and delineate all important soil types, and therefore should be under the direction of an experienced engineer or geologist having competence in the field of soil mechanics. Field sampling data and laboratory test results should be thorough and according to widely accepted procedures. Table 1 summarizes the tests that may be necessary.

Review Field Sampling of Soils — Step 1

The objective of Step 1* is to establish that the applicant has satisfactorily documented the physical characteristics, volume, and spatial distribution of each of the major, distinguishable soil types to be used as cover. These data, obtained from test pits or borings in the borrow area, must be accurate since the adequacy of the cover system and the feasibility of the covering operation are directly affected.

The evaluation is accomplished by examining a map of soil sampling locations along with some graphical or tabular presentation of the depths and nature of the soils at each location. Soil types collected at each location should be classified as described under Step 2. Soil type should be identified at regular depth intervals even where the soil is obviously uniform to the depth of interest. Changes in soil types should be located. Much of the delineation of soil types is accomplished on the basis of characteristics observed and used in the field, e.g., color and feel when rubbed between fingers. Such field characteristics should be explained and related to the traditional U. S. Department of Agriculture (USDA) soil classes based on grain size (Figures 1 and 2) where reasonable. Characterization in terms of the Unified Soil Classification System (USCS) (Figure 3) is confirmed subsequently in laboratory testing (Step 2).

The owner/operator application should include a brief description of the field sampling methods besides the observations. The traditional manner of exploring soil to depths of more than a few feet is by soil boring, but trenching below ground surface or cleaning an existing bluff face or pit

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* Step 1 may be unnecessary where the plan is to contract for the required volumes of certain soil types delivered to the waste disposal site.

TABLE 1. LABORATORY TEST METHODS FOR SOIL

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
		Index and Classification Tests	
Gradation Analysis	ASTM D421 D422 D2217	Particle size distribution	
Percent Fines	ASTM D1140	Percent of weight of material finer than No. 200 sieve	
Atterberg Limits	ASTM D423 D424 D427	Plastic limit, liquid limit, plasticity index, shrinkage factors	
Specific Gravity	ASTM D854	Specific gravity or apparent specific gravity of soil solids	Can usually be estimated closely
Soil Description	ASTM D2488	Description of soil from visual-manual examination	
Soil Classification	ASTM D2487	Unified soil classification	
		Moisture-Density Relations	
Dry Unit Weight	Reference 3	Dry unit weight (dry density)	Both undisturbed and remolded samples
Water Content	ASTM D2216 D2974	Water content as percent of dry weight	
Relative Density†	Reference 3	Maximum and minimum density of cohesionless soils	Modified test may be substituted for test with vibratory table
Compaction	ASTM D698 (or 5- to 15-blow modification)	Optimum water and maximum density	Method for earth and rock mixtures is given in Reference 3

(continued)

TABLE 1. (continued)

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
		Consolidation and Permeability	
Consolidation†	ASTM D2435	One-dimensional compressibility, permeability of cohesive soil	
Permeability	ASTM D2434	Permeability	
		Physical and Chemical Properties	
Mineralogy†	Reference 4	Identification of minerals	Requires X-ray diffraction apparatus. Differential thermal analysis apparatus may also be used
Organic Content	Reference 5 ASTM D2974	Organic and inorganic carbon content as percent of dry weight	Where organic matter content is critical, D2974 results should be verified by wet combustion tests (Reference 5)
Soluble salts†	Reference 6	Concentration of soluble salts in soil pore water	
Pinhole Test†	Reference 7	Dispersion tendency in cohesive soils	Significant in evaluation of potential erosion or piping
		Shear Strength and Deformability	
Unconfined Compression†	ASTM D2166	Undrained shear strength	Applicable to cohesive soil only

(continued)

TABLE 1. (continued)

Name of Test	Standard or Preferred Method*	Properties or Parameters Determined	Remarks/Special Equipment Requirements
Direct Shear, Consolidated-Drained†	ASTM D3080	Effective shear strength parameters, cohesion and angle of internal friction	
Triaxial Compression, Unconsolidated-Undrained†	ASTM D2850	Undrained shear strength parameters, cohesion and angle of internal friction	
Triaxial Compression, Consolidated-Undrained†	Reference 3	Undrained shear strength parameters, cohesion and angle of internal friction	Effective shear strength parameters obtained if pore pressure is measured

* ASTM standard methods are given in Reference 2.

† Specialized test assigned only to obtain input for special engineering analysis and design.

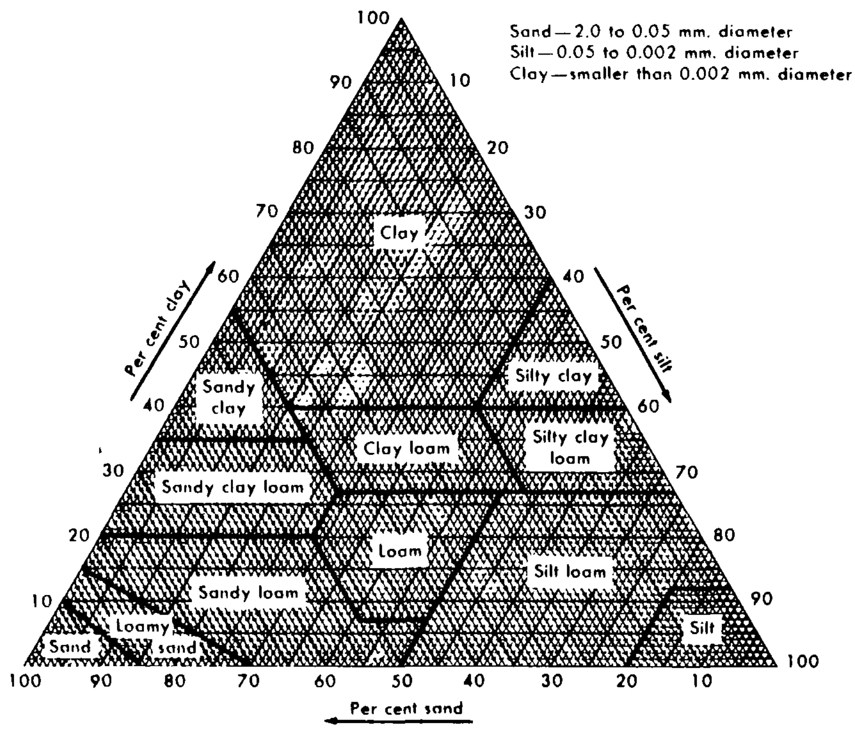


Figure 1. USDA textural classification chart.

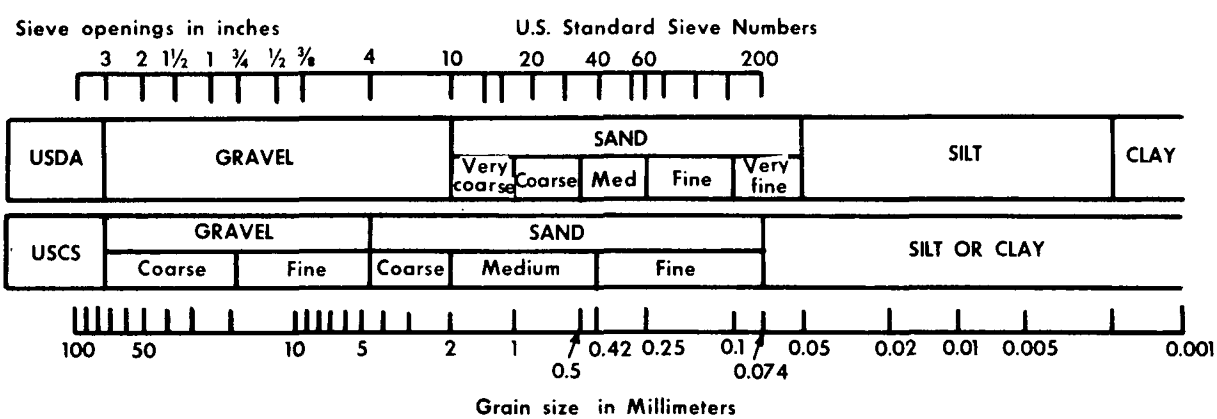


Figure 2. Comparison of USCS and USDA particle-size scales.

Major Divisions			Group Symbols	Typical Names	Field Identification Procedures (Excluding particles larger than 3 in. and basing fractions on estimated weights)		
1	2		3	4	5		
Coarse-grained Soils More than half of material is larger than No. 200 sieve size. The No. 200 sieve size is about the smallest particle visible to the naked eye.	Gravels More than half of coarse fraction is larger than No. 4 sieve size. (For visual classification, the 1/4-in. size may be used as equivalent to the No. 4 sieve size)	Clean Gravels (Little or no fines)	GW	Well-graded gravels, gravel-sand mixtures, little or no fines.	Wide range in grain sizes and substantial amounts of all intermediate particle sizes.		
			GP	Poorly graded gravels or gravel-sand mixtures, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Gravels with Fines (Appreciable amount of fines)	GM	Silty gravels, gravel-sand-silt mixture.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			GC	Clayey gravels, gravel-sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
	Sands More than half of coarse fraction is smaller than No. 4 sieve size.	Clean Sands (Little or no fines)	SW	Well-graded sands, gravelly sands, little or no fines.	Wide range in grain size and substantial amounts of all intermediate particle sizes.		
			SP	Poorly graded sands or gravelly sands, little or no fines.	Predominantly one size or a range of sizes with some intermediate sizes missing.		
		Sands with Fines (Appreciable amount of fines)	SM	Silty sands, sand-silt mixtures.	Nonplastic fines or fines with low plasticity (for identification procedures see ML below).		
			SC	Clayey sands, sand-clay mixtures.	Plastic fines (for identification procedures see CL below).		
Fine-grained Soils More than half of material is smaller than No. 200 sieve size.					Identification Procedures on Fraction Smaller than No. 40 Sieve Size		
					Dry Strength (Crushing characteristics)	Dilatancy (Reaction to shaking)	Toughness (Consistency near PL)
	Silts and Clays Liquid limit is less than 50		ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands or clayey silts with slight plasticity.	None to slight	Quick to slow	None
			CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.	Medium to high	None to very slow	Medium
			OL	Organic silts and organic silty clays of low plasticity.	Slight to medium	Slow	Slight
	Silts and Clays Liquid limit is greater than 50		MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	Slight to medium	Slow to none	Slight to medium
			CH	Inorganic clays of high plasticity, fat clays.	High to very high	None	High
			OH	Organic clays of medium to high plasticity, organic silts.	Medium to high	None to very slow	Slight to medium
Highly Organic Soils			Pt	Peat and other highly organic soils.	Readily identified by color, odor, spongy feel and frequently by fibrous texture.		

(1) Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well-graded gravel-sand mixture with clay binder. (2) All sieve sizes on this chart are U. S. standard.

FIELD IDENTIFICATION PROCEDURES FOR FINE-GRAINED SOILS OR FRACTIONS (MINUS NO. 40 SIEVE)

Screening is not intended; simply remove by hand the coarse particles that interfere with tests.

Dilatancy (reaction to shaking). After removing particles larger than No. 40 sieve size, prepare a pat of moist soil with a volume of about one-half cubic inch. Add enough water if necessary to make the soil soft but not sticky.

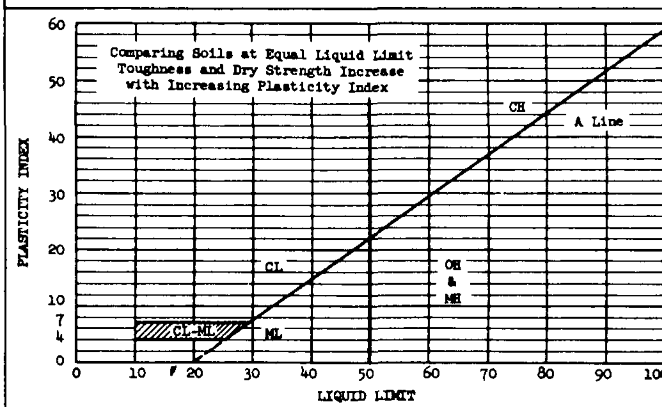
Place the pat in the open palm of one hand and shake horizontally, striking vigorously against the other hand several times. A positive reaction consists of the appearance of water on the surface of the pat which changes to a livery consistency and becomes glossy. When the sample is squeezed between the fingers, the water and gloss disappear from the surface, the pat stiffens, and finally it cracks or crumbles. The rapidity of appearance of water during shaking and of its disappearance during squeezing assist in identifying the character of the fines in a soil.

Very fine clean sands give the quickest and most distinct reaction whereas a plastic clay has no reaction. Inorganic silts, such as a typical rock flour, show a moderately quick reaction.

Dry Strength (crushing characteristics). After removing particles larger than No. 40 sieve size, mold a pat of soil to the consistency of putty, adding water if necessary. Allow the pat to dry completely by oven, sun, or air-drying, and then test its

Figure 3. Summary of the USC system.

(continued)

Information Required for Describing Soils	Laboratory Classification Criteria		
6	7		
For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions, and drainage characteristics. Give typical name; indicate approximate percentages of sand and gravel, maximum size; angularity, surface condition, and hardness of the coarse grains; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Silty sand, gravelly; about 20% hard, angular gravel particles 1/2-in. maximum size; rounded and subangular sand grains, coarse to fine; about 15% nonplastic fines with low dry strength; well compacted and moist in place; alluvial sand; (SM).	Use grain-size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain-size curve. Depending on percentage of fines (fraction smaller than No. 200 sieve size) coarse-grained soils are classified as follows: Less than 5% = GW, GP, SW, SP, More than 12% = GM, GC, SM, SC. 5% to 12% = Borderline cases requiring use of dual symbols.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		Not meeting all gradation requirements for GW	
		Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
		Atterberg limits above "A" line with PI greater than 7	
		$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6 $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		Not meeting all gradation requirements for SW	
		Atterberg limits below "A" line or PI less than 4	Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.
		Atterberg limits above "A" line with PI greater than 7	
For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions. Give typical name; indicate degree and character of plasticity; amount and maximum size of coarse grains; color in wet condition; odor, if any; local or geologic name and other pertinent descriptive information; and symbol in parentheses. Example: Clayey silt, brown; slightly plastic; small percentage of fine sand; numerous vertical root holes; firm and dry in place; loess; (ML).	 PLASTICITY CHART For laboratory classification of fine-grained soils		

strength by breaking and crumbling between the fingers. This strength is a measure of the character and quality of the colloidal fraction contained in the soil. The dry strength increases with increasing plasticity.
High dry strength is characteristic of clays of the CH group. A typical inorganic silt possesses only very slight dry strength. Silty fine sands and silts have about the same slight dry strength, but can be distinguished by the feel when powdering the dried specimen. Fine sand feels gritty whereas a typical silt has the smooth feel of flour.

Toughness (consistency near plastic limit). After particles larger than the No. 40 sieve size are removed, a specimen of soil about one-half inch cube in size is molded to the consistency of putty. If too dry, water must be added and if sticky, the specimen should be spread out in a thin layer and allowed to lose some moisture by evaporation. Then the specimen is rolled out by hand on a smooth surface or between the palms into a thread about one-eighth inch in diameter. The thread is then folded and rerolled repeatedly. During this manipulation the moisture content is gradually reduced and the specimen stiffens, finally loses its plasticity, and crumbles when the plastic limit is reached.
After the thread crumbles, the pieces should be limped together and a slight kneading action continued until the lump crumbles.
The tougher the thread near the plastic limit and the stiffer the lump when it finally crumbles, the more potent is the colloidal clay fraction in the soil. Weakness of the thread at the plastic limit and quick loss of coherence of the lump below the plastic limit indicate either inorganic clay of low plasticity, or materials such as kaolin-type clays and organic clays which occur below the A-line.
Highly organic clays have a very weak and spongy feel at the plastic limit.

Figure 3. (continued)

wall may be as effective and less costly where on-site equipment is sufficient. Whatever the method, it should be documented in the application.

The evaluator must decide whether the arrangement and spacing of samples have been adequate to delineate the vertical and lateral extent of the major soil types. Where the evaluation indicates that sampling intervals are too large, it may be necessary to require additional samples at intermediate positions. One effective technique is to sample at fairly close spacing along a single line across the borrow area. Elsewhere in the area there may be a need for only a few additional borings to confirm that the stratification (including thicknesses) along the cross section apply elsewhere also. A grid pattern may also be definitive. The following example helps to clarify Step 1.

> Example: Suppose an application presents as an inclosure the plan map in Figure 4. The sampling methods at the three locations have been reviewed and found to be satisfactory; a drilling inspector made depth measurements and identified and sampled the soil types. The evaluator observes that one of the three sampling locations is distinct from the other two. The evaluator therefore recommends that new boring locations be added to delineate the extent of the CL soil more confidently since this soil type is important in design of the particular cover.

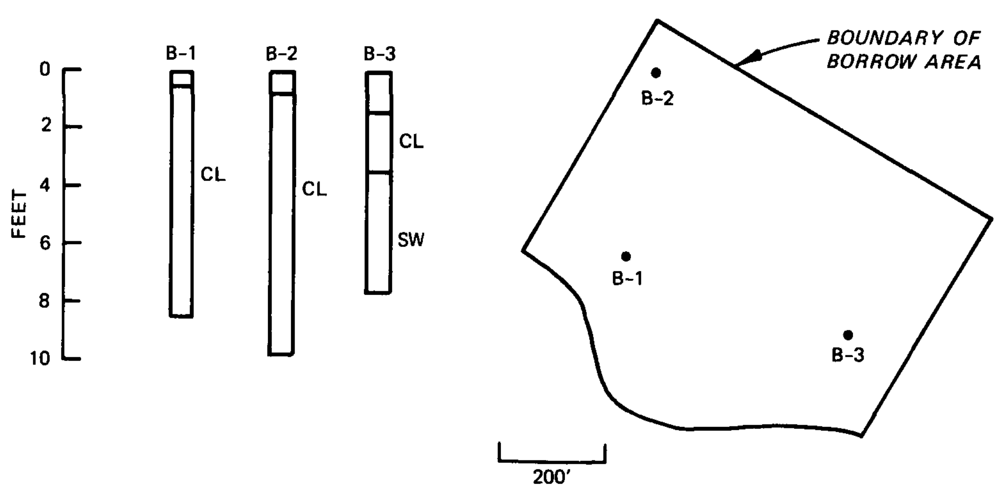


Figure 4. Hypothetical cover soil source.

<u>Check Adequacy of Soil Testing Program</u> <u>Step 2</u>

Two major aspects of the testing program that need to be evaluated are the selection of tests and the adequacy of testing facilities and personnel. Tests that might be expected or perhaps even specified as minimum requirements for all diagnostic samples are as follows:

Grain-Size Distribution (Figure 5)

Percent Fines

Atterberg Limits

Soil Classification

Water Content

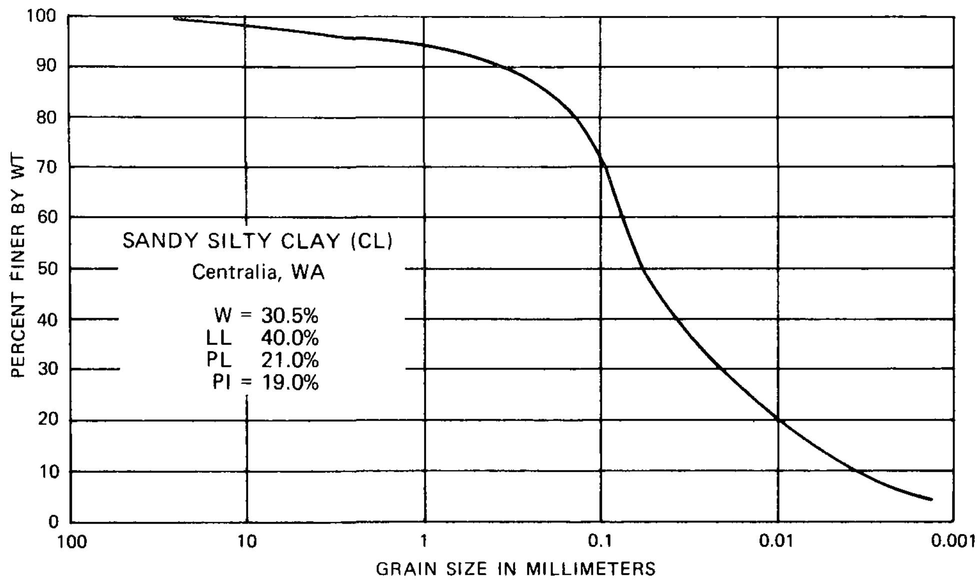


Figure 5. Gradation of a landfill cover soil.

The tests may be required in duplicate (or more) for better representation and checking. These tests are basically indexing tests but also useful for establishing the uniformity or variability within individual soil types. Other important tests are compaction (Figure 6) and permeability. Even one of these additional tests or test series may be adequate to establish characteristics of the unit as a whole provided that unit is relatively uniform in its index properties.

The remaining soil tests (Table 1) are assigned only where special problems of slope stability, consolidation, etc., are anticipated. The need for these tests may not become apparent until after most of the routine index testing has been accomplished, sometimes not until the critical review by the evaluator. Nevertheless, the lack of information from special tests may occasionally constitute a basis for delaying a permit application.

> Example: In reviewing a permit application an evaluator finds that a county soil survey report has been used as the basis for characterizing the soil at the proposed

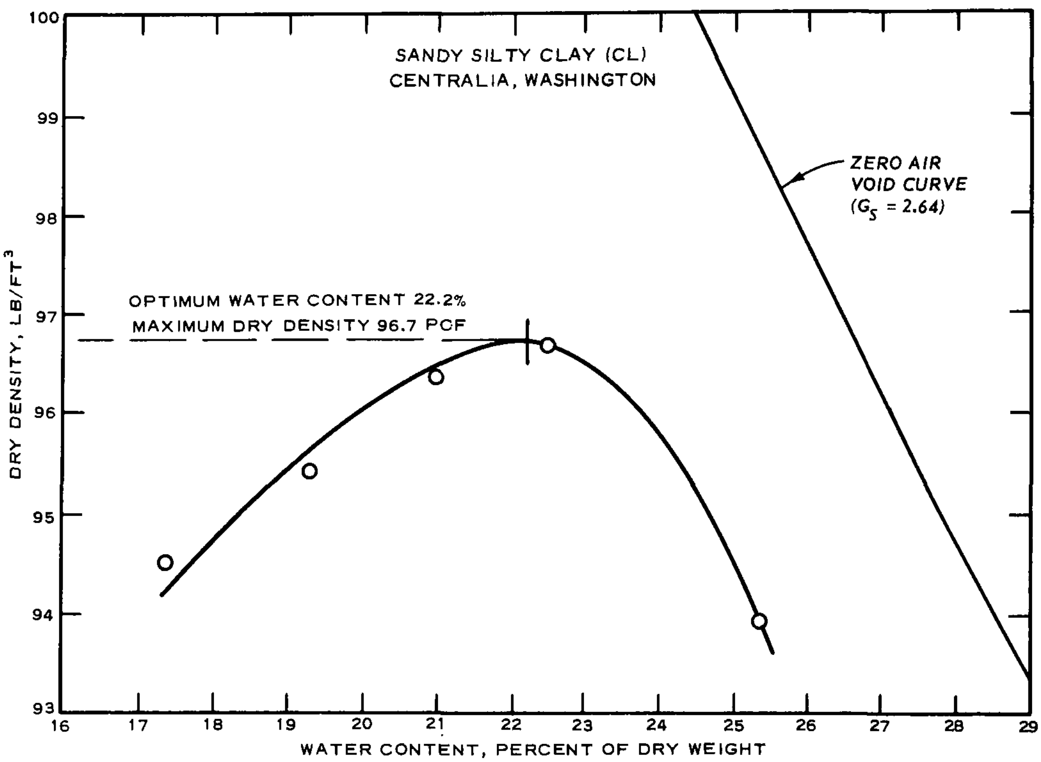


Figure 6. Standard compaction test results with landfill cover soil.[1]

borrow area. The applicant has used Atterberg limits, classification, and grain-size distribution data from the report for type Grenada 6 soil which has been mapped over 36 percent of the county and specifically is shown as underlying the borrow area. After careful consideration, the evaluator requests that several deep soil boring samples from the borrow area be tested at a qualified testing laboratory to verify or reject the suitability of the data from the general county report for cover design. These samples will also serve to show how well the county survey of surficial agricultural soils represents the soils at depths below a few feet which, of necessity, will contribute to total cover soil volume.

Check Soil Volumes Available — Step 3

At some stage, not necessarily when the site or borrow area is sampled and tested, the sufficiency of cover soil volume should be evaluated. Accurate volume calculations depend upon accurate measurements of soil thicknesses and areas. Accordingly, the evaluator may recommend additional sampling locations, not only for a better fix on soil indices and properties but to allow a better calculation of the volumes. Where the data in the application have shown a uniformity of soil type, it may only be necessary to check thicknesses rather than to sample and test also. The following example illustrates the situation, but also see the example under Step 1.

> Example: An applicant has submitted the information shown in Figure 7 as a basis for his estimates of volumes of soil types available for use as cover. The evaluator reasons that there is a possibility of a sizable overestimation of suitable soils available to complete the closure since variations of layer thicknesses between the existing sample locations are a distinct possibility (shown by dashed line in the figure). In this hypothetical case, the evaluator chooses to accept the estimated volumes on the basis of observations he has made in a field inspection and after consultation with a staff geologist.

An important factor in checking volumes available can be the bulking factor. Some natural soils, particularly those at depth, have a relatively high unit weight in situ. After excavation, working, and placement as cover over solid waste, these soils will have experienced a reduction in unit weight, i.e., a bulking effect, and available volumes tend to be underestimated. In contrast, other soils, particularly those near the surface, have a relatively low unit weight in situ so that available volumes are easily overestimated. The evaluator should carefully check the basis for any bulking factor where soil is in short supply.

TOPOGRAPHICAL DATA REVIEW PROCEDURE

Examine Configuration and Topography — Step 4

Next the surface configuration of the cover is examined to assure that evaluations can be made in regard to slope stability, water erosion, and wind erosion. Most engineered fills for highways, foundations, and so forth are designed on the basis of accurate topography or multiple cross sections, and the evaluator may reasonably expect some such basic data to accompany the closure plan. Otherwise, the justification for omitting such basic data should be convincingly presented in the application or be self-evident.

One basic form of data presentation is with cross sections through the cover extending across the site (see Step 1). Cross sections should show thickness of the closure cover and solid waste and the limits of natural soil previously excavated for use as cover. Besides being useful for engineering design and for evaluation of the design, cross sections are potentially useful for monitoring changes in configuration that may take place as a result of settlement in the long term. Preparation of cross sections is well within the capability of most organizations engaged in construction and can reasonably be expected as a part of an application.

A set of cross sections, often parallel to one another, can be highly useful. Ordinarily the line of section (the surface trace of the cross section) should trend downslope. Since many solid waste landfills will be completed with a somewhat irregular surface configuration approaching natural

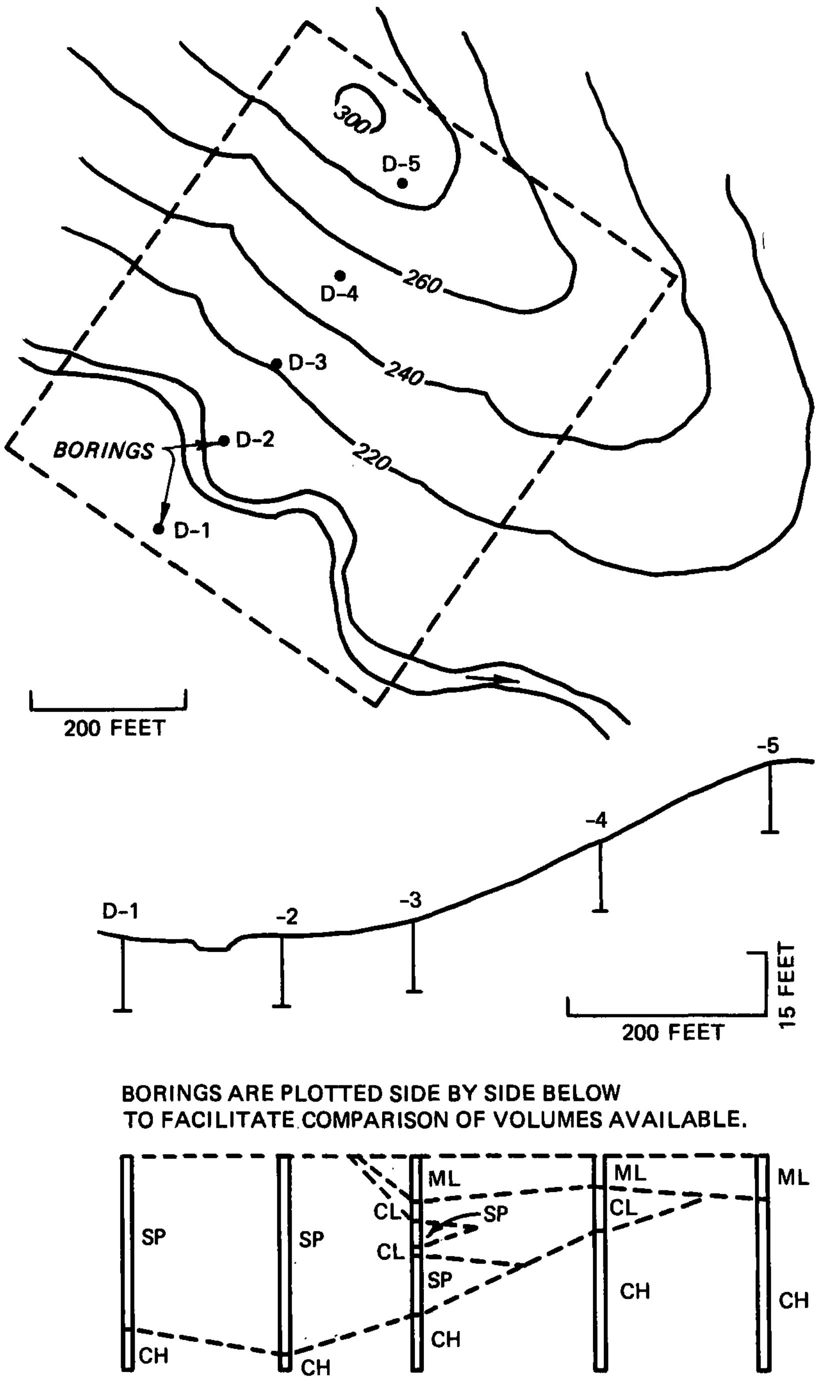


Figure 7. Hypothetical cover soil volume data.

hills and swales, it may be necessary for the cross sections to be oblique to one another rather than parallel. About the only criterion for evaluating sufficiency in the number of cross sections is whether they present the important aspects of the surface form, closure cover, and underlying solid waste.

> Example: Suppose that the configuration of a solid waste landfill is as shown in Figure 8. The owner/operator of the landfill is seeking permission to place final cover and move his current operations to an adjacent site. He has supplied the sketch of the site and the surveyed cross section as the only graphical information of the actual layout at the site. In his evaluation, the staff member of the permitting authority feels there are insufficient data on the existing configuration, i.e., the base on which cover will be placed, and he requires the applicant to provide another cross section based on field measurements across the west side. The evaluator has reasoned that the west edge of the landfill near the drainageway is steeper and otherwise distinct from the large open side on the south and therefore should be represented accurately and separately in cross section for special examination.

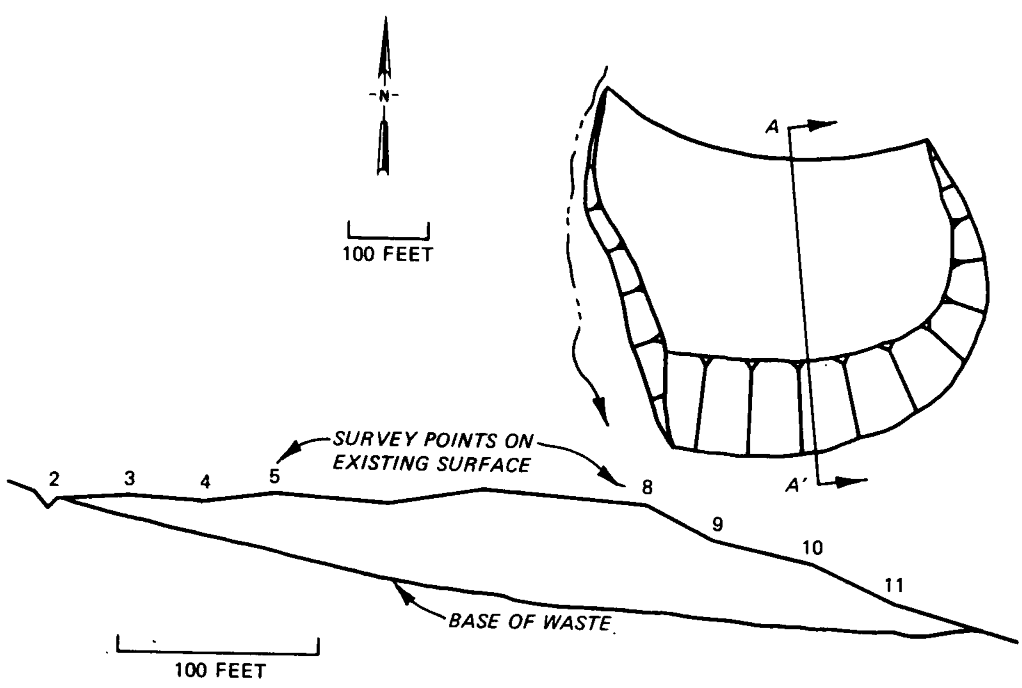


Figure 8. Hypothetical landfill configuration.

Examine Precipitation Records — Step 5

The application should include data on the precipitation to be expected at the site. A useful record typically gives average amounts for a period of at least several years in the past, e.g. the average monthly precipitations from the last 20 years or thereabout. Average data can be supplemented with typical records of rainfall on a daily or even hourly basis for a better picture of rainfall distribution in detail. The source of all climatological data should be given also so that verifications can be made. Figure 9 is a map of average annual precipitation that the evaluator can use to check roughly the expected annual precipitation provided by the applicant. Similar information is available for Alaska and Hawaii. In some mountainous or coastal regions the average rainfall can vary over short distances, and special care must be exercised in evaluation as illustrated by the following example.

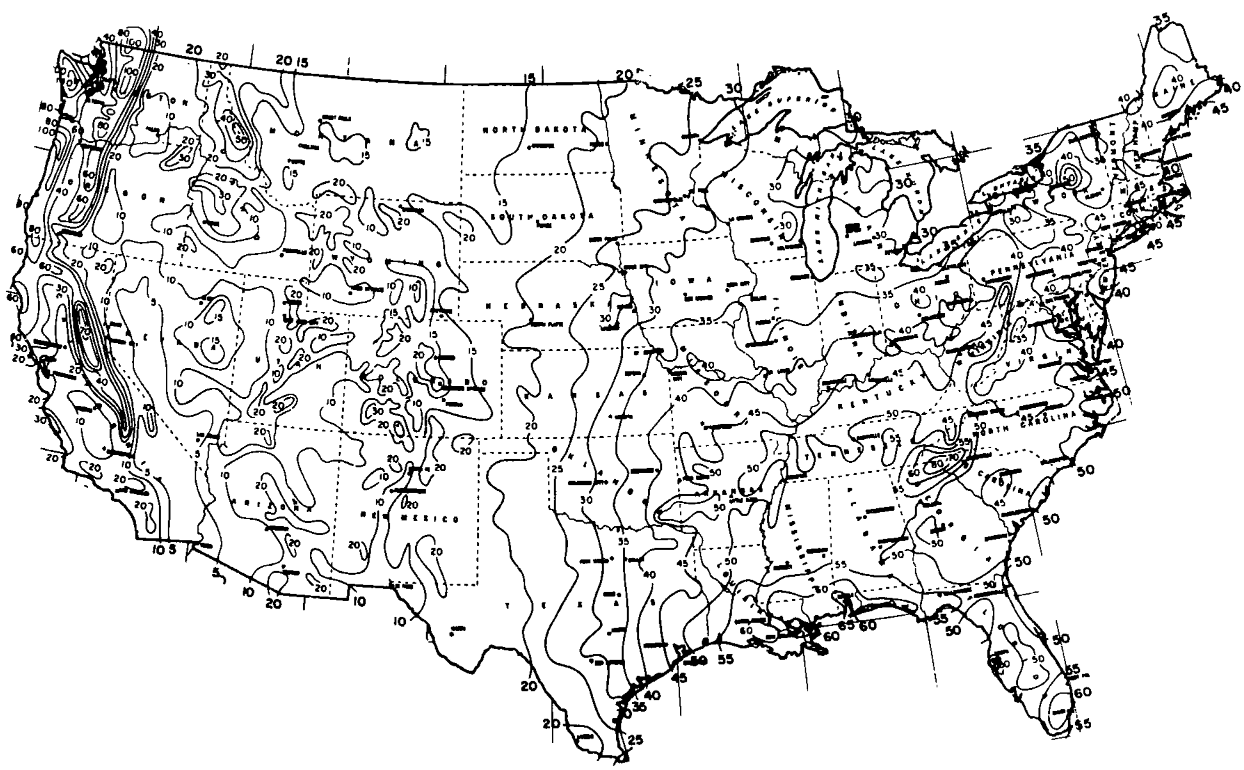


Figure 9. Average annual precipitation in inches (US Dept of Agriculture)

> Example: Precipitation records provided in the permit application concerning a landfill for a city in the Pacific Northwest are those compiled from the downtown weather station. The evaluator recognizes that there is a difference in the weather at the downtown location (near sea level) and the weather at the landfill which

is located in foothills at the far end of the same county. Therefore, he requests more representative data or conclusive evidence that any departures will be on the conservative side.

<u>Examine Evapotranspiration Estimates</u> <u>Step 6</u>

Since evapotranspiration operates in an important manner to remove moisture from the cover, it must be regarded as a major factor in cover design. Therefore, an applicant should include in documentation an accurate estimate of monthly evapotranspiration as evidence that this factor has been included in the design. The source of information should be included also. Where the evapotranspiration data have been derived through calculations from other parameters, the calculations should be included and explained, and references should be made to original sources. Figure 10 is a map of average annual lake evaporation over the contiguous United States which the evaluator can use to check roughly the expected annual evapotranspiration. Evapotranspiration approximately equals lake evaporation which is about 0.7 x pan evaporation.

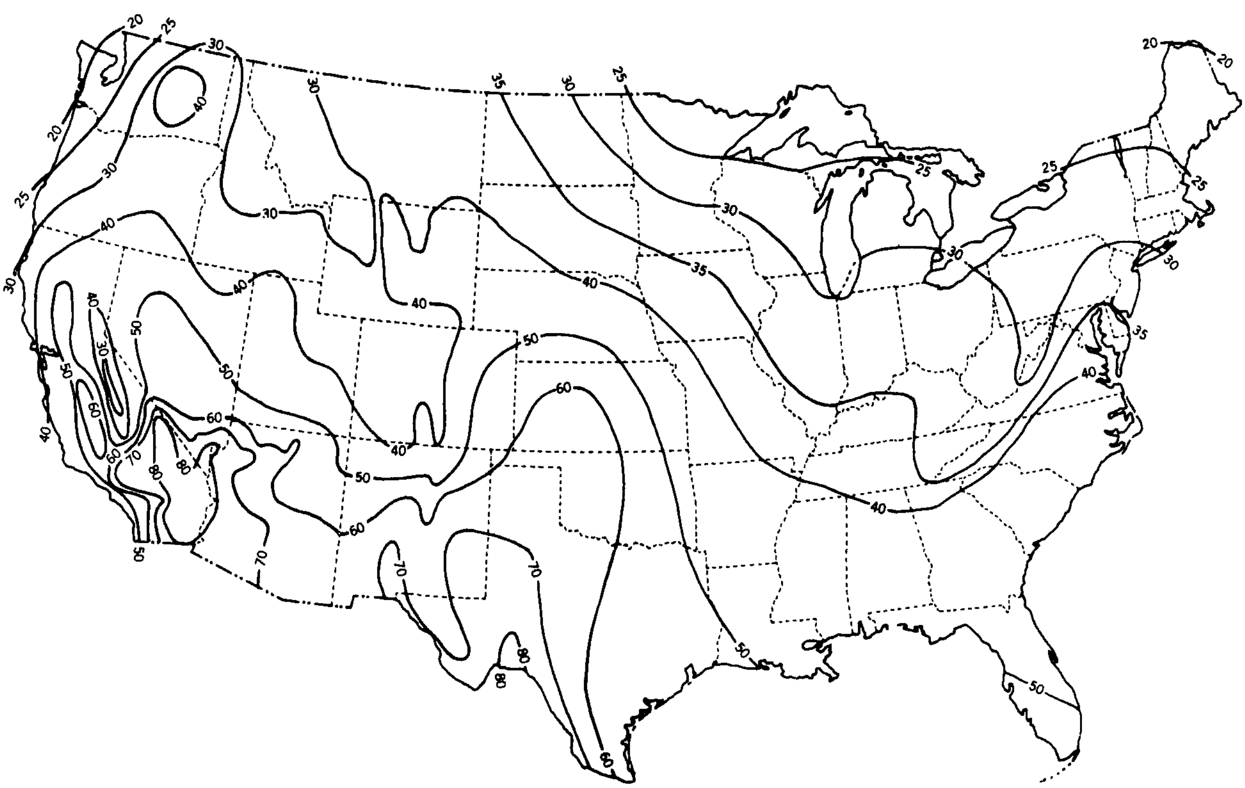


Figure 10. Average annual lake evaporation in inches, according to the National Weather Service.

<u>Examine Design Storms</u> <u>Step 7</u>

Closure covers should be designed not only for average precipitation but also for high rates over short durations. Such information is readily available in the form of design storms for any locality, and it is reasonable to expect that the documentation accompanying an application recognize several extreme rainfalls for recurrence intervals of possible interest. For an average size landfill a 1-hour storm and storms of longer duration are of typical interest. The recurrence interval would likely be 10 or 20 years, but the applicant should present reasons for choosing specific intervals and storm durations. Figure 11 is an example of summary information available to the evaluator for checking design storm amounts supplied in an application.

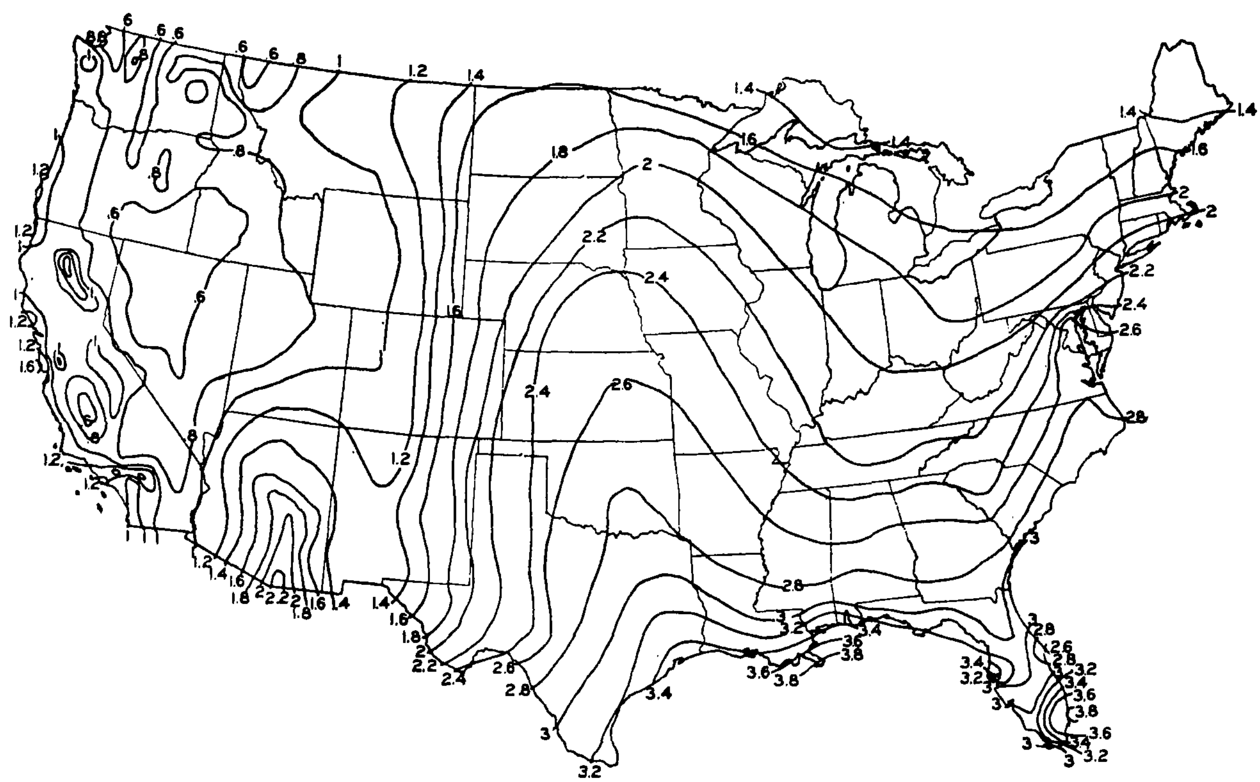


Figure 11. Ten-year 1-hour rainfall in inches (US Weather Bureau)

A sequel to the presentation of design storm data is the calculation of flood discharges for ditches and other elements of the drainage system. The calculation in simplest form utilizes the rational equation:

$$Q = C_{RO}\ i\ A$$

where Q = peak discharge, cubic feet/second
C_{RO} = runoff coefficient
i = rainfall intensity, inches/hour
A = area of basin, acres

The formula above incorporates the approximation that 1 inch/hour/acre = 1 cubic foot/second. Roughly approximated, the C_{RO} values for vegetated clayey soils on flats and slopes are about 0.5 and 0.7, respectively, and for vegetated sandy soils on flats and slopes are about 0.2 and 0.4.

SECTION 3

STEPS IN EVALUATION

Steps in this section differ from those in Section 2 by involving actual evaluation of the designs and judgments submitted by the applicant rather than just the examination and ordering of basic data.

COVER COMPOSITION EVALUATION PROCEDURE

The basis for evaluating the composition of the cover is the collection of data on quantities and descriptions supplied with the application.

<u>Evaluate Composition</u> <u>Step 8</u>

Referring to Table 2,[1] the evaluator should check the soil composition for suitability as cover by establishing the soil's strengths and deficiencies in a general way. Where a soil is rated IV or higher, look for special design features to compensate for deficiencies (e.g., multilayering to supplement a vulnerable soil with other types). Higher rating numbers tend to indicate greater need for special features. There is need, of course, to exercise good judgment when applying a somewhat subjective ranking as that in the table.

In the particularly important function of minimizing infiltration, it may be necessary to reject a simple cover design of one layer and require inclusion of a clay soil layer or other barrier. This necessity may arise where the dominant soil proposed as cover is:

a. Designated GW, GP, or SP by testing (see Figure 3)

b. Dispersive and therefore possibly subject to internal erosion (see Reference 1)

c. Insufficient in volume for cover design

Other options may be to import a more suitable soil type or in some way to improve characteristics by additional treatments.

> Example: According to the testing results accompanying the permit application, cover at a solid waste disposal site will consist of gravelly sand classified SW according to the USCS. The permitting authority has previously assigned a high priority to impeding water percolation into the solid waste. The evaluator, therefore, notifies

TABLE 2. RANKING OF USCS TYPES ACCORDING TO PERFORMANCE OF COVER FUNCTIONS

USCS Symbol	Typical Soils	Trafficability: Go-No Go (RCI Value)*	Trafficability: Stickiness (Clay, %)	Trafficability: Slipperiness (Sand-Gravel, %)	Water Percolation: Impede (k, cm/s)*	Water Percolation: Assist (k, cm/s)*	Gas Migration: Impede (H_c, cm)*	Gas Migration: Assist (H_c, cm)*
GW	Well-graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	X (10^{-2})	III	X (6)	I
GP	Poorly graded gravels, gravel-sand mixtures, little or no fines	I (>200)	I (0-5)	I (95-100)	XII (10^{-1})	I	IX ---	II
GM	Silty gravels, gravel-sand-silt mixtures	III (177)	III (0-20)	III (60-95)	VII (5×10^{-4})	VI	VII (68)	IV
GC	Clayey gravels, gravel-sand-clay mixtures	V (150)	VI (10-50)	V (50-90)	V (10^{-4})	VIII	IV ---	VII
SW	Well-graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	IX (10^{-3})	IV	VIII (60)	III
SP	Poorly graded sands, gravelly sands, little or no fines	I (>200)	II (0-10)	II (95-100)	XI (5×10^{-2})	II	VII ---	IV
SM	Silty sands, sand-silt mixtures	II (179)	IV (0-20)	IV (60-95)	VIII (10^{-3})	V	VI (112)	V
SC	Clayey sands, sand-clay mixtures	IV (157)	VII (10-50)	VI (50-90)	VI (2×10^{-4})	VII	V ---	VI
ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity	IX (104)	V (0-20)	VII (0-60)	IV (10^{-5})	IX	III (180)	VIII
CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	VII (111)	VIII (10-50)	VIII (0-55)	II (3×10^{-8})	XI	II (180)	IX
OL	Organic silts and organic silty clays of low plasticity	X (64)	V (0-20)	VII (0-60)	---	---	---	---
MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	VIII (107)	IX (50-100)	IX (0-50)	III (10^{-7})	X	---	---
CH	Inorganic clays of high plasticity, fat clays	VI (145)	X (50-100)	X (0-50)	I (10^{-9})	XII	I (200-400+)	X
OH	Organic clays of medium to high plasticity, organic silts	XI (62)	---	---	---	---	---	---
Pt	Peat and other highly organic soils	XII (46)	---	---	---	---	---	---

Same k values as for Impede Water Percolation

Same H_c values as for Impede Gas Migration

(continued)

TABLE 2. (continued)

USCS Symbol	Fire Resistance	Erosion Control: Water (K-Factor)*	Erosion Control: Wind (Sand-Gravel, %)	Dust Control	Reduce Freeze Action: Fast Freeze (H_c, cm)*	Reduce Freeze Action: Saturation (Heave, mm/day)	Crack Resistance (Expansion, %)
GW	Same as Impede Gas Migration	I (< .05)	I (95-100)	Same ranking and values as for Wind Erosion Control	X	I (0.1-3)	I (0)
GP		I ---	I (95-100)		IX	I (0.1-3)	I (0)
GM		IV ---	III (60-95)		VII	IV (0.4-4)	III ---
GC		III ---	V (50-90)		IV	VII (1-8)	V ---
SW		II (.05)	II (95-100)		VIII	II (0.2-2)	I (0)
SP		II ---	II (95-100)		VII	II (0.2-2)	I (0)
SM		VI (.12-.27)	IV (60-95)		VI	V (0.2-7)	II ---
SC		VII (.14-.27)	VI (50-90)		V	VI (1-7)	IV ---
ML		XIII (.60)	VII (0-60)		III	X (2-27)	VI ---
CL		XII (.28-.48)	VIII (0-55)		II	VIII (1-6)	VIII (1-10)
OL		XI (.21-.29)	VII (0-60)		---	VIII ---	VII ---
MH		X (.25)	IX (0-50)		---	IX ---	IX ---
CH		IX (.13-.29)	X (0-50)		I	III (0.8)	X (>10)
OH		VIII ---	---		---	---	IX ---
Pt		V (.13)	---		---	---	---

(continued)

TABLE 2. (continued)

USCS Symbol	Side Slope: Stability	Side Slope: Seepage	Side Slope: Drainage	Discourage Burrowing	Impede Vector Emergence	Discourage Birds	Support Vegetation	Future Use: Natural	Future Use: Foundation
GW	Determine on basis of laboratory testing	Same ranking and values as for Impede Water Percolation	Same ranking and values as for Assist Water Percolation	Same ranking and values as for Slipperiness Trafficability	X	All soils are suitable	X	Same ranking as for Support Vegetation	Same ranking and values as for Go-No Go Trafficability
GP					X		X		
GM					VIII		VI		
GC					V		V		
SW					IX		IX		
SP					IX		IX		
SM					VII		II		
SC					IV		I		
ML					VI		III		
CL					III		VII		
OL					VI		IV		
MH					II		IV		
CH					I		VIII		
OH					---		VIII		
Pt					---		III		

* RCI is rating cone index, k is coefficient of permeability, H_c is capillary head, and K-Factor is the soil erodibility factor. The ratings I to XIII are for best through poorest in performing the specified cover function.

the applicant that the SW soil (well-graded sand) is unacceptable (ranked IX in Table 2) in a single-layer configuration and that it will be rejected unless a layered system with a barrier layer is incorporated.

Example: The applicant at a site has proposed to use a clayey silt for closure cover. The applicant had previously been asked to obtain at his own expense a series of tests on the soil to determine its tendency towards dispersion. The area has a high rainfall, and its low topography can conceivably cause a detention of runoff with increased opportunity for infiltration. Internal erosion that can affect dispersive soils would conceivably lead to a deterioration of the cover by migration of soil particles into the solid waste below. The laboratory test report in the second submittal of the application confirms that the silty soil has a modest tendency for dispersion. The evaluator concludes that inclusion of a clay barrier is advisable. However, the evaluator goes on to explain that other solutions to the potential problem may be investigated also since the applicant has indicated an interest in treating the dispersive soils with lime in order to flocculate clay particles and reduce their tendency towards dispersion.

The susceptibility of particular soil types to surface erosion by running water can also be evaluated according to a useful erosion loss equation (see Step 19).

THICKNESS EVALUATION PROCEDURE

The evaluation of closure cover thickness is often of primary importance and the evaluator should devote considerable attention to it. Thickness in excess of a certain established minimum* may be governed by one or more of the following factors:

a. Coverage

b. Infiltration

c. Gas migration

d. Trafficability and support requirements

e. Freeze/thaw or dry/soak effects

This list may be extended by addition of other factors of possible concern such as:

* Minimum cover thickness requirements vary from state to state according to experience.

f. Cracking (factors f, g, h, and i are discussed in Reference 1)

g. Differential settlement and offset

h. Membrane protection

i. Vegetative requirements

Evaluate Coverage — Step 9

The closure cover functions basically to cover solid waste completely; therefore, some guidance is in order to evaluate for factor _a._ above. A reasonable criterion of adequacy for coverage over irregular solid waste can be offered as follows:

$$T \geq 2R$$

where T is cover thickness and R is relief. The relief is defined for this criterion as the vertical distance from high point to low point of irregularities on the top surface of the solid waste. The size of the area over which this vertical distance should be measured corresponds roughly to the size of the equipment used for placing closure cover. Where intermediate size dozers are to be used, the area within which the relief is measured would be on the order of 20 by 20 feet. In large covering operations where pans or other large pieces of equipment are to be used, the area size could be on the order of 50 feet across.

The applicant may choose to circumvent the requirement of increasing thickness above the established minimum to compensate for relief by smoothing the upper surface of solid waste. Where sand fill is available, it can be placed alone or mixed with heterogenous solid waste in roughly equal proportions for a more workable material to achieve a smoother top surface. The sand or the mixture thus forms a buffer[1] that generally improves the performance and longevity of the cover. This buffer also serves specifically as a base for more effective compaction of layers placed above.

Evaluate Thickness for Infiltration — Step 10

Logically, the next criterion to be examined in the evaluation concerns infiltration, _b._ above. Adequacy against infiltration can be evaluated by use of a water balance technique in which input of water on a monthly or daily basis is compared with expected losses from surface runoff and evapotranspiration. Excesses beyond storage capacity of the cover soil are considered to pass through the cover as percolation. The evaluator is referred to another manual[8] in which the details of a recommended computerized procedure are outlined step by step.

For purposes of evaluating the thickness of the cover, a somewhat abbreviated water balance technique may be useful also. This method has been suggested for predicting percolation by the EPA,[9] and its utility in evaluating or designing cover has been reviewed.[1] The water balance technique serves to check the effect of increased thickness for providing increased water storage in the cover soil and consequent decrease in percolation. The example below illustrates the technique and its use.

> Example: Using a 30-year climate record, the evaluator analyzes the effectiveness of a 2-foot silty sand cover with grass at Chippewa Falls, Wisconsin. Table 3 shows the water balance tabulation. The average annual percolation is calculated to be 3.88 inches. The evaluator next expands this analysis to explore the effects of a much thicker cover on percolation. The result is shown in Table 4. A storage capacity of 8 inches (representing greatly increased thickness) is substituted for the storage of 1.05 inches used in Table 3. The overall effect on cumulative percolation is small, with a reduction by only about 20 percent to an annual percolation of 3.13 inches. His analysis indicates to the evaluator that increasing cover thickness is not an efficient way of reducing percolation in this area.

<u>Evaluate Thickness for Gas Migration</u> <u>Step 11</u>

Thickening the cover is sometimes a direct and effective procedure along with choice of soil (Step 8) for reducing gas migration through the cover, especially to the extent that increased thickness reduces evaporation and preserves a high moisture content. The technique is particularly attractive for remedial work where problems are localized. Increasing the thickness of coarse-grained soils decreases gas discharge directly when diffusion is the mechanism. Where gas is driven through coarse soil by a difference in total pressure, however, thickening the cover may be ineffective. In fine-grained soils the open pore space necessary for migration by either diffusion or pressure difference is at least intermittently blocked by the included pore water, and the evaluator must consider this complication critically in arriving at his recommendations. Finally, there is the potential problem of excessive lateral migration as a result of effective blockage of vertical migration. For this condition, the evaluator will need to address gas drainage in considerable detail (Step 24).

The generation of methane and carbon dioxide from wastes, followed by migration driven by pressure difference, provides the opportunity for any relatively minor but toxic gaseous components to be moved along as well. 10
Therefore, any capacity for generating gases in abundance greatly compounds the problem of retaining hazardous gaseous chemicals and may make gas drainage imperative (Steps 15 and 24).

> Example: The cover proposed for a solid waste disposal site in a high-rainfall area consists of a fine-grained soil that basically functions to exclude most percolation. Anticipating eventual problems with gas migration through this cover, the evaluator considers recommending thickening of the cover design. However, after careful consideration, the evaluator concludes that adjustments of the thickness will not have a dramatic effect because

TABLE 3. MONTHLY WATER BALANCE ANALYSIS IN INCHES FOR CHIPPEWA FALLS, WISCONSIN[1]

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
Average Precipitation (P)	0.89†	0.71†	0.77‡ 0.77‡	2.55	3.73	4.19	3.65	3.56	3.37	2.04	0.67‡ 0.67‡	1.00†	4.04 24.53
Runoff (RO)			0.05	0.17	0.24	0.27	0.24	0.23	0.22	0.13	0.04		1.59
Moisture available for infiltration (I)	0.00	0.00	0.72	2.38	3.49	3.92	3.41	3.33	3.15	1.91	0.63	0.00	22.94
Potential evapotranspiration (PET)	0.00	0.00	0.00	1.10	2.50	3.90	4.60	4.00	2.70	1.20	0.00	0.00	20.00
(I - PET)	0.00	0.00	0.72	1.28	0.99	0.02	-1.19	-0.67	0.45	0.71	0.63	0.00	
(Σ neg (I - PET))						(0)	-1.19	-1.86					
Soil moisture storage (ST)	1.05	1.05	1.05§	1.05	1.05	1.05	0.27	0.13	0.58	1.05	1.05	0.05	
(ΔST)	0.00	0.00	0.00	0.00	0.00	0.00	-0.78	-0.14	+0.45	+0.47	0.00	0.00	
Actual evapotranspiration (AET)	0.00	0.00	0.00	1.10	2.50	3.90	4.19	3.47	2.70	1.20	0.00	0.00	19.06
Percolation (PRC)	0.00	0.00	0.72	1.28	0.99	0.02	0.00	0.00	0.00	0.24	0.63	0.00	3.88

† Precipitation between November 16 and March 15 is listed as snow but is changed to runoff at spring thaw.

‡ Precipitation in November and March is divided into half rain, half snow.

§ Water-holding capacity is assumed to be at maximum in March when snow melts.

TABLE 4. MONTHLY WATER BALANCE ANALYSIS IN INCHES WITH THICK COVER*

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann.
Average Precipitation (P)	0.89†	0.71†	0.77‡ 0.77‡	2.55	3.73	4.19	3.65	3.56	3.37	2.04	0.67‡ 0.67‡	1.00†	4.04 24.53
Runoff (RO)			0.05	0.17	0.24	0.27	0.24	0.23	0.22	0.13	0.04		1.59
Moisture available for infiltration (I)	0.00	0.00	0.72	2.38	3.49	3.92	3.41	3.33	3.15	1.91	0.63	0.00	22.94
Potential evapotranspiration (PET)	0.00	0.00	0.00	1.10	2.50	3.90	4.60	4.00	2.70	1.20	0.00	0.00	20.00
(I - PET)	0.00	0.00	0.72	1.28	0.99	0.02	-1.19	-0.67	0.45	0.71	0.63	0.00	
(Σ neg (I - PET))						(0)	-1.19	-1.86					
Soil moisture storage (ST)	8.00	8.00	8.00§	8.00	8.00	8.00	6.89	6.33	6.78	7.49	8.00	8.00	
(ΔST)	0.00	0.00	0.00	0.00	0.00	0.00	-1.11	-0.56	+0.45	+0.71	+0.51	0.00	
Actual evapotranspiration (AET)	0.00	0.00	0.00	1.10	2.50	3.90	4.52	3.89	2.70	1.20	0.00	0.00	19.81
Percolation (PRC)	0.00	0.00	0.72	1.28	0.99	0.02	0.00	0.00	0.00	0.00	0.12	0.00	3.13

* Compare with Table 3.

† Precipitation between November 16 and March 15 is listed as snow but is changed to runoff at spring thaw.

‡ Precipitation in November and March is divided into half rain, half snow.

§ Water-holding capacity is assumed to be at maximum in March when snow melts.

> the soil usually retains considerable moisture (depending on the complications of rainfall history and evapotranspiration[1]) and is already blocking most of the gas movement. The evaluator learns that the applicant believes that thickening the cover to reduce the remaining intermittent, uncontrolled gas discharge will also not be cost-effective and, therefore, thickening is not favored by the applicant. He then concentrates his immediate attention on considering other options such as gas vents though it may be necessary to return later to the thickening technique despite its low cost-effectiveness.

Evaluate Support Requirements — Step 12

The low bearing capacity of some solid waste landfills can be circumvented by increasing soil thickness above waste. In this way, the relatively strong soil resists punching and rotational shear. The thickness of soil should be at least 1.5 x the width of footings. However, any proposal to superimpose buildings on the cover should receive particularly critical reviews and would ordinarily be rejected for a hazardous waste site. Past experience with buildings on landfills is replete with cases of structural damage from differential settlement and unnecessary hazard from accumulation of methane and other gases.

Consider Freeze/Thaw and Dry/Soak Effects — Step 13

In cold regions of the country, special attention may need to be directed to disturbing effects of freezing. Similarly in semiarid areas subject to periods of sustained drying conditions, equal concern may be warranted in regard to excessive drying and cracking. The reasons for concern have been summarized elsewhere[1] but largely involve substantial decreases in effectiveness of cover in impeding water and gas migration.

The evaluator may check for adequacy of the cover thickness by use of Figure 12 or similar summary. In case of a need for greater detail or in locations of mountainous terrain where the depth of freezing can vary over short distances, the evaluator should seek information on depth of freezing from a local agricultural agency. The depth of drying to be expected over extended droughty periods can similarly be estimated on the basis of experience in the region.

> Example: An applicant has proposed to use 3 feet of soil in the northern Great Plains where the average annual maximum depth of freezing is 3 feet. To avoid disturbance of the cover to its full thickness the evaluator recommends that cover thickness be increased to 4 feet.

Before requiring substantial modification by thickening the cover, the evaluator would ordinarily obtain the opinion of one or more local geotechnical engineers regarding the disturbance of the cover.

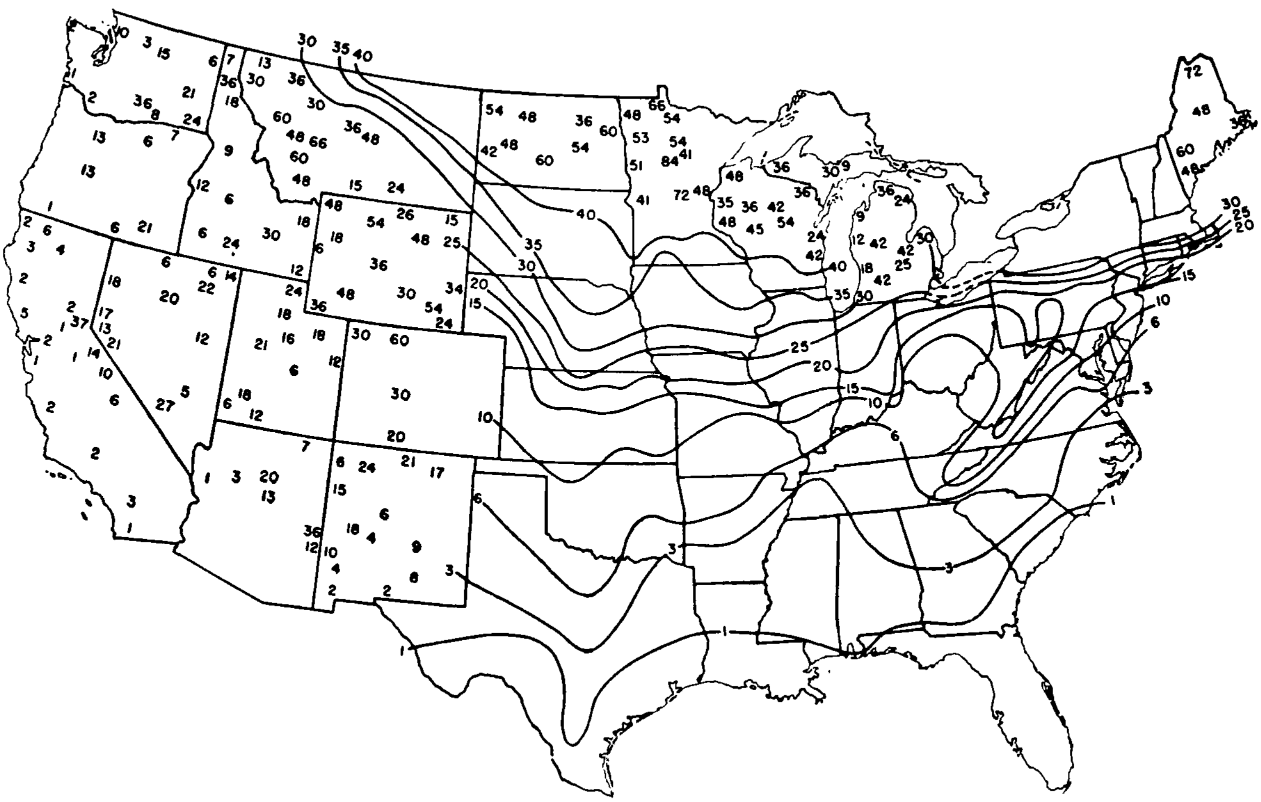


Figure 12. Regional depth of frost penetration in inches.[11]

PLACEMENT EVALUATION PROCEDURE

After selection of the material and appropriate thickness for cover, efforts should be directed to the most effective placement and treatment. Cover can be improved in several ways as it is constructed. Materials may be added for better gradation, hauling and spreading equipment can be operated beneficially, and certain layering can be introduced.[1]

Evaluate Cover Compaction — Step 14

Some compaction is almost always accomplished during the spreading of cover soil; and this densification is highly effective in producing benefits, principally increasing strength and reducing permeability. Figures 13 and 14 illustrate these effects and provide the evaluator some guidance on what can be achieved. The laboratory compaction test provides a useful data base on which the evaluator can judge the effects of compaction of the cover under consideration. It has been found[1] that soil compacted routinely over soft waste (municipal wastes) falls below standard compaction curves such as obtained in ASTM D698 (Table 1). The differences in field compaction results over spongy solid waste versus those over a hard base can be compensated approximately by using laboratory test procedures with fewer than the

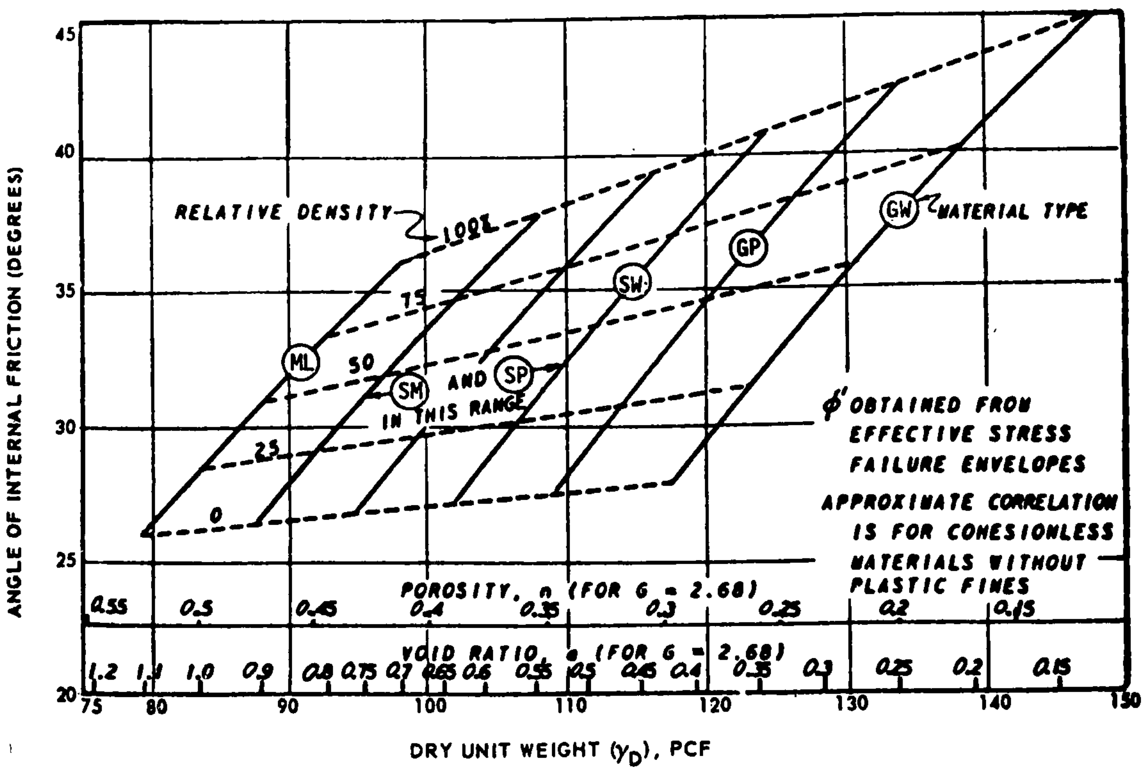


Figure 13. Relation of effective angle of internal friction to dry unit weight for cohesionless soils (US Navy).

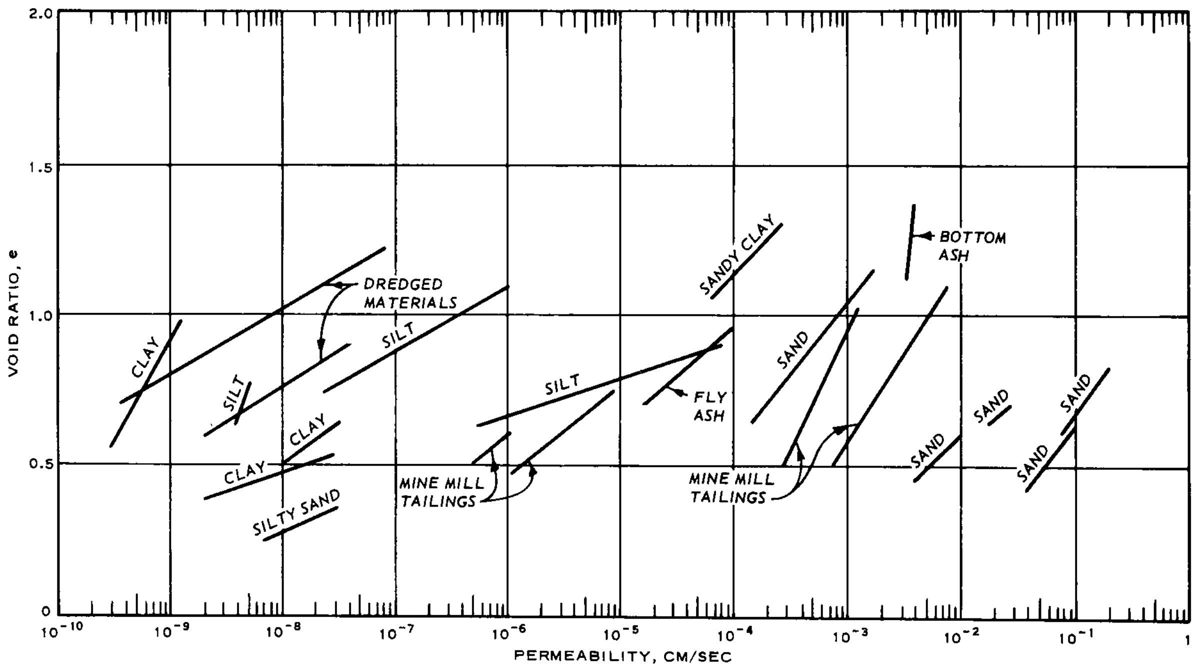


Figure 14. Coefficient of permeability of materials as affected by degree of compaction.

"standard" 25 blows of the compacting hammer. Keep in mind that the objective of the laboratory tests is to model actual field compaction of cover soil with dozers and other compacting equipment.

Approximate general guidance (Figure 15) has been derived regarding the field compaction effort necessary in 6 to 12 inches of soil cover on municipal solid waste. Field dry density of the cover can be predicted from measured placement water contents by using laboratory compaction curves at appropriately light compaction effort. For example, where a dozer makes four passes on the average, a 5-blow compaction curve should be determined by laboratory testing and be used for predictions. The curves shown in Figure 15 appear generally valid, but relations between field compaction and laboratory curves should be determined site-specifically if cover density data are deemed necessary;[1] the evaluator may need to make this judgment under Step 2. A reasonable goal for which one might strive, particularly in the compaction of barrier layers, is 90 percent of maximum dry density according to 5- or 15-blow compaction tests. On the other hand, when

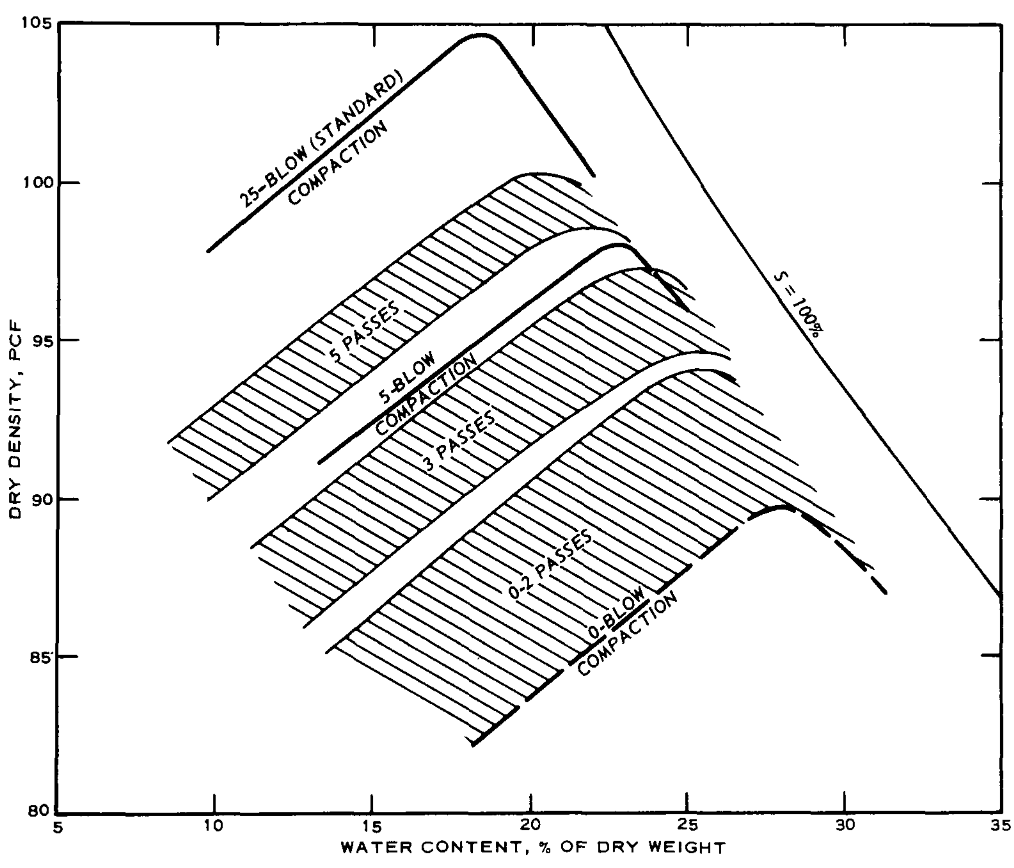


Figure 15. Schematic guidance for predicting cover compaction results with intermediate-size dozers on municipal solid waste using laboratory test results.

compacting on a solid base, e.g., on a granular soil-like solid waste, one might strive for 90 percent of maximum dry density by standard 25-blow tests.

Example: In his second submission of an application, an owner/operator has included results of 15-blow compaction tests conducted on the cover soil by a certified testing laboratory (Figure 16). It is claimed later that approximately 90 percent of maximum dry density will be achieved with six passes of the compacting equipment. The natural water content is approximately 10 percent. The evaluator notes that the cover soil is to be excavated and hauled and placed directly. Therefore, he asks the applicant to expand on his intentions as far as manipulating the water content of the soil closer to optimum in order to reasonably expect 90 percent of maximum dry density.

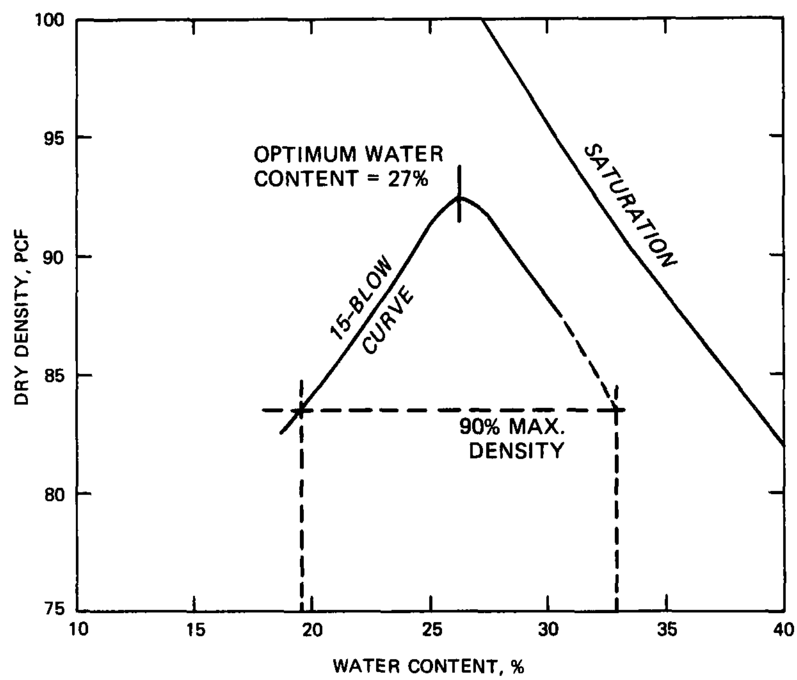


Figure 16. Hypothetical cover soil compaction.

Evaluate Internal Layering — Step 15

Layering is a promising technique for final solid waste cover. By combining two or three distinct materials in layers (Figure 17) the designer may mobilize favorable characteristics of each together at little extra expense. The following descriptions[1] should help to guide the evaluation of layered cover designs.

The primary feature in layered systems is usually the barrier. This layer functions to restrict passage of water or gas. Barrier layers are

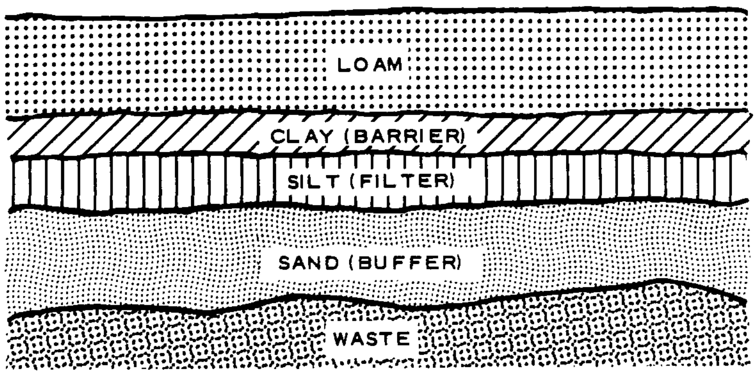


Figure 17. Typical layered cover system.

almost always composed of clayey soil that has inherently low permeability; USCS types CH, CL, and SC (Figure 3) are recommended. Soil barriers are susceptible to deterioration by cracking when exposed at the surface, so that a buffer layer above is recommended to protect the clayey soil from excessive drying. Similarly, where a synthetic membrane is used as the barrier, buffer soils are needed above and below the membrane for its protection.

Synthetic membranes of butyl or neoprene rubber, hypalon, polyolefin, polyvinyl chloride, etc., may be considered in place of soil barriers.[1] Usually a sheet thickness of at least 20 mils is required. Some membranes should be spread carefully over a smooth base to lie in a relaxed state or a 5-percent slack may be necessary; usually the manufacturers provide directions. Soils immediately above and below a membrane can constitute critical components of the layered cover since irregularities and hard pieces impinging on the membrane can cause damage, particularly during subsequent compaction. Therefore, the application should address thoroughly the question of preserving the integrity of the impermeable membrane during construction. Manufacturer's recommendations for splicing the membrane in the field or in the shop should be followed and should be detailed in the application. Provide a trench at least 8 inches deep or other anchorage at the top of any slope. The evaluation of synthetic membranes in layered cover systems may benefit from related guidance on basal liner systems presented in another manual;[12] particularly in regard to reactivity between waste and membrane.

Experience in using membrane liners within cover has emphasized the need for special attention to lateral drainage of the water that accumulates. Water trapped by the liner may saturate the protective soil above and make it vulnerable to erosion. On slopes over about 10 percent, a few heavy rainstorms may erode such soil and expose the liner in channels. A further consequence of saturation is damage to the roots of vegetative cover after a few days of submergence. Consequently, the evaluator should check for attention to these concerns where a membrane is planned for incorporation in the cover. A system of pipe drains buried along lines of drainage convergence is one possible solution to potential saturation problems.

Barrier layers may also be constructed by adding certain additives or cements to the available soil. Addition of bentonite clay is a proven means of reducing permeability, but homogenizing the mixture can present difficulties and may need to be confirmed by laboratory tests, post-placement examination, or other means identified in the permit application. Other additions to soil, such as lime, portland cement, and bituminous cement, may require an even more conservative stance on the part of the evaluator since experiences with these materials in layered covers are quite limited.

Layered cover systems should include buffer soil layers[1] where a buffer layer may be described as a random layer having a subordinate covering function. Buffers serve to protect the barrier layer or membrane sheet from tears, cracks, offsets, punctures, and other deterioration. Below a barrier or the main cover soil a buffer also provides a smooth, regular base. Any soil type will serve as a buffer ordinarily, but it should be free of clods. A properly placed buffer filling voids around barrels of waste serves to minimize settlement and disruption of the final capping cover.

Where soils of widely different grain size are in contact, there may be a tendency for fine particles to penetrate the coarser layer. As a result, the effectiveness of coarse layers that may be used for water drainage can be reduced by clogging of the pores. Removals from the fine layer may promote additional undesirable effects, such as internal erosion and settlement. Similar problems can develop around pipe drains buried in the cover system. Such problems can be eliminated by selecting the proper size gradation of one or both of the soil layers. The coarser soil layer is commonly termed as the filter. A widely used criterion is written

$$\frac{D_{15}\text{(filter soil)}}{D_{85}\text{(finer soil)}} < 4 \text{ to } 5$$

where D_{15} and D_{85} refer to the grain sizes for which 15 and 85 percent by weight of the soils are finer, respectively. Common filter soils are SP, SM, SW, and GW (Figure 3); filter fabric or cloth may be considered in place of a soil filter layer.

> Example: Suppose that grain-size distribution curves have been submitted with the application to represent soils to be used in a layered system. The evaluator locates the D_{15} and D_{85} grain sizes at the points shown in Figure 18. Since the ratio of these sizes does not meet the criterion, the application is returned for modification of design.

A water drainage layer, blanket, or channel may be designed into cover in numerous ways to provide a path for water to exit rapidly. Well-sorted (poorly graded) sand and gravel are recommended as effective drainage materials, i.e., soils classified GP and SP. Drainage channels and layers may be associated with a system of buried pipe drains, but the expense of this combined system ordinarily limits its applicability to high-priority disposal areas.

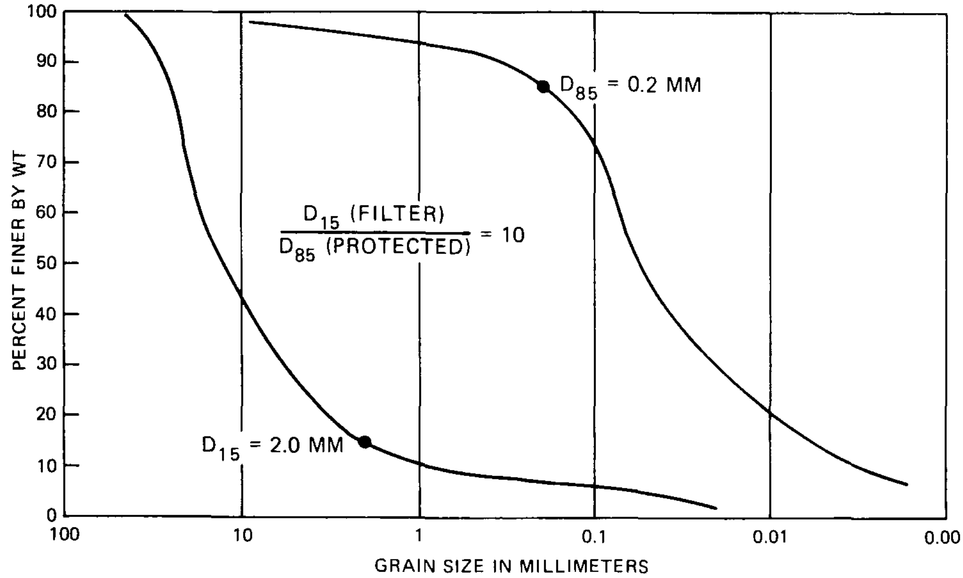


Figure 18. Hypothetical size gradation of ineffective filter soil.

Gas drainage layers and channels may have granular consistency and interconnections and general configuration similar to those of the water drainage layer or channel. Both layer types function to transmit preferentially. The position in the cover system is a main distinction. The gas drainage layer is placed on the lower side (Figure 19) to intercept gases rising from waste cells, whereas the drain for water is positioned on the upper side to intercept water percolating from the surface.

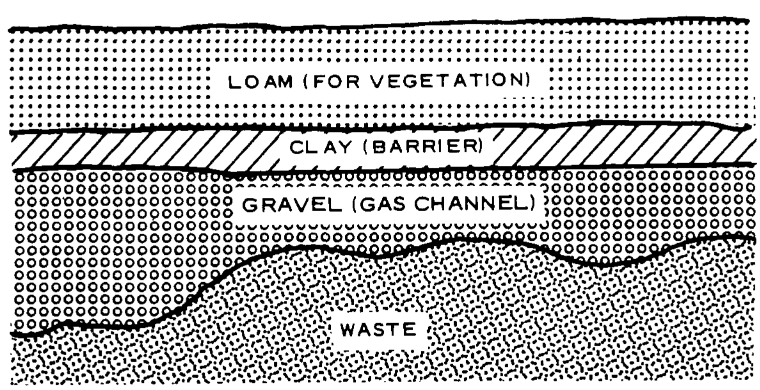


Figure 19. Cover layering suitable for conveying gases to vents.

Evaluate Topsoil Step 16

A topsoil or a subsoil made amenable to supporting vegetation frequently forms the top of a layered cover system. Untreated subsoils are seldom suitable directly, so it has been necessary frequently to supplement subsoil with fertilizers, conditioners, etc., as explained elsewhere (Steps 26-28), to obtain the desired result. Loams or USCS types GM, GC, SM, SC, ML, and CL (Figure 3) are recommended, but agronomic considerations usually prevail. The upper lift should be placed in a loose condition and not compacted.

Evaluate Time of Construction — Step 17

Better results in placement of cover can often be achieved at certain times (seasons) of the year. For this reason, the permit application may need to have the time of cover construction bracketed. The dominant consideration is commonly the season appropriate to establishing vegetation, and the subject is discussed in more detail in Steps 31 and 32. The presence of snow or a condition of frozen soil and waste interferes with proper placement in many northern states. Later, the spring thaw can produce temporary problems in handling and control of wet soil. On the other hand, hot, dry summer weather can create construction problems of excessive drying and cracking, wind erosion, and dust generation. As general guidance, it is usually preferable to place cover in the spring or early fall (and to a lesser degree through the summer). Departures from the two preferred intervals should be justified in the application.

Review Proposed Construction Techniques — Step 18

The application should be carefully reviewed for conformance to the following general recommendations for layering (from the bottom up):

a. Make buffer layer below barrier thick and dense enough to provide smooth, stable base for compacting in c below.

b. Compact all layers except topsoil and top lift of upper buffer.

c. In barrier layer, consider striving for 90 percent of maximum dry density according to 5- or 15-blow compaction test where solid waste is soft or according to standard 25-blow compaction test where solid waste is granular and soil-like.

d. Cover barrier layer soon enough to prevent excessive drying and cracking.

e. Provide sufficient design thickness to assure performance of layer function; specifying a 6- to 12-inch minimum should prevent excessively thin spots resulting from poor spreading techniques.

f. Construct in plots small enough to allow rapid completion.

g. Consider seeding topsoil at time of spreading.

CONFIGURATION EVALUATION PROCEDURE

The concern for the configuration of the cover surface is driven mostly by a desire to avoid excessive erosion or excessive infiltration.

Not only is erosion objectionable in itself but erosion can degrade the cover and seriously reduce its effectiveness.

<u>Evaluate Erosion Potential</u> <u>Step 19</u>

The USDA universal soil loss equation (USLE) is a convenient tool for use in evaluating erosion potential. The USLE predicts average annual soil loss as the product of six quantifiable factors. The equation is:

$$A = R\ K\ L\ S\ C\ P$$

where A = average annual soil loss, in tons/acre
R = rainfall and runoff erosivity index
K = soil erodibility factor, tons/acre
L = slope-length factor
S = slope-steepness factor
C = cover-management factor
P = practice factor

The data necessary as input to this equation are available to the evaluator in a figure and tables included below. Note that the evaluations in Step 8 on soil composition and Steps 25-32 on vegetation all impact on the evaluation of erosion also.

Factor R in the USLE can be calculated empirically from climatological data. For average annual soil loss determinations, however, R can be obtained directly from Figure 20. Factor K, the average soil loss for a given

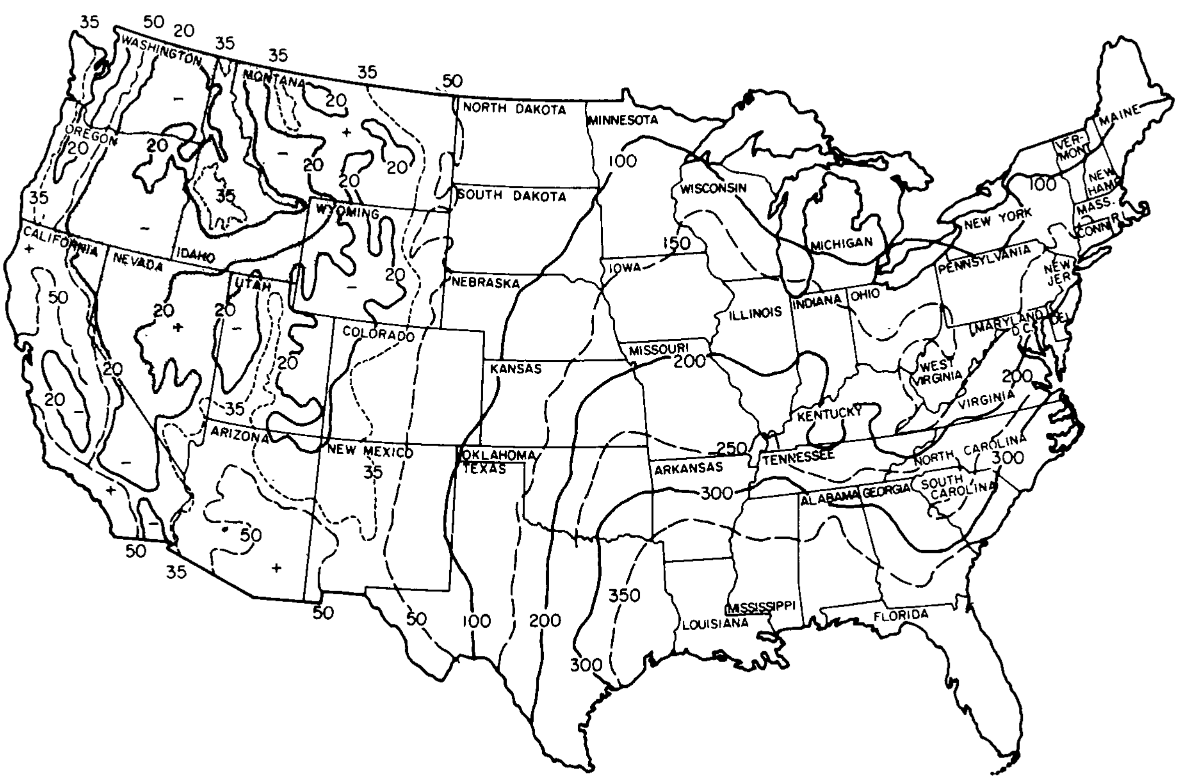


Figure 20. Average annual values of rainfall-erosivity factor R.[11]

soil in a unit plot, pinpoints differences in erosion according to differences in soil type. Long-term plot studies under natural rainfall have produced K values generalized in Table 5 for the USDA soil types.

TABLE 5. APPROXIMATE VALUES OF FACTOR K FOR USDA TEXTURAL CLASSES[11]

Texture class	Organic matter content <0.5% K	2% K	4% K
Sand	0.05	0.03	0.02
Fine sand	.16	.14	.10
Very fine sand	.42	.36	.28
Loamy sand	.12	.10	.08
Loamy fine sand	.24	.20	.16
Loamy very fine sand	.44	.38	.30
Sandy loam	.27	.24	.19
Fine sandy loam	.35	.30	.24
Very fine sandy loam	.47	.41	.33
Loam	.38	.34	.29
Silt loam	.48	.42	.33
Silt	.60	.52	.42
Sandy clay loam	.27	.25	.21
Clay loam	.28	.25	.21
Silty clay loam	.37	.32	.26
Sandy clay	.14	.13	.12
Silty clay	.25	.23	.19
Clay		0.13-0.29	

The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values.

The evaluator must next consider the shape of the slope in terms of length and inclination. The appropriate LS factor is obtained from Table 6. A nonlinear slope may have to be evaluated as a series of segments, each with uniform gradient. Two or three segments should be sufficient for most engineered landfills, provided the segments are selected so that they are also of equal length (Table 6 can be used, with certain adjustments). Enter Table 6 with the total slope length and read LS values corresponding to the percent slope of each segment. For three segments, multiply the chart LS values for the upper, middle, and lower segments by 0.58, 1.06, and 1.37, respectively. The average of the three products is a good estimate of the

TABLE 6. VALUES OF THE FACTOR LS FOR SPECIFIC COMBINATIONS OF SLOPE LENGTH AND STEEPNESS[11]

% Slope	Slope length (feet)											
	25	50	75	100	150	200	300	400	500	600	800	1000
0.5	0.07	0.08	0.09	0.10	0.11	0.12	0.14	0.15	0.16	0.17	0.19	0.20
1	0.09	0.10	0.12	0.13	0.15	0.16	0.18	0.20	0.21	0.22	0.24	0.26
2	0.13	0.16	0.19	0.20	0.23	0.25	0.28	0.31	0.33	0.34	0.38	0.40
3	0.19	0.23	0.26	0.29	0.33	0.35	0.40	0.44	0.47	0.49	0.54	0.57
4	0.23	0.30	0.36	0.40	0.47	0.53	0.62	0.70	0.76	0.82	0.92	1.0
5	0.27	0.38	0.46	0.54	0.66	0.76	0.93	1.1	1.2	1.3	1.5	1.7
6	0.34	0.48	0.58	0.67	0.82	0.95	1.2	1.4	1.5	1.7	1.9	2.1
8	0.50	0.70	0.86	0.99	1.2	1.4	1.7	2.0	2.2	2.4	2.8	3.1
10	0.69	0.97	1.2	1.4	1.7	1.9	2.4	2.7	3.1	3.4	3.9	4.3
12	0.90	1.3	1.6	1.8	2.2	2.6	3.1	3.6	4.0	4.4	5.1	5.7
14	1.2	1.6	2.0	2.3	2.8	3.3	4.0	4.6	5.1	5.6	6.5	7.3
16	1.4	2.0	2.5	2.8	3.5	4.0	4.9	5.7	6.4	7.0	8.0	9.0
18	1.7	2.4	3.0	3.4	4.2	4.9	6.0	6.9	7.7	8.4	9.7	11.0
20	2.0	2.9	3.5	4.1	5.0	5.8	7.1	8.2	9.1	10.0	12.0	13.0
25	3.0	4.2	5.1	5.9	7.2	8.3	10.0	12.0	13.0	14.0	17.0	19.0
30	4.0	5.6	6.9	8.0	9.7	11.0	14.0	16.0	18.0	20.0	23.0	25.0
40	6.3	9.0	11.0	13.0	16.0	18.0	22.0	25.0	28.0	31.0	--	--
50	8.9	13.0	15.0	18.0	22.0	25.0	31.0	--	--	--	--	--
60	12.0	16.0	20.0	23.0	28.0	--	--	--	--	--	--	--

Values given for slopes longer than 300 feet or steeper than 18% are extrapolations beyond the range of the research data and, therefore, less certain than the others.

overall effective LS value. If two segments are sufficient, multiply by 0.71 and 1.29.

Factor C in the USLE is the ratio of soil loss from land cropped under specified conditions to that from clean-tilled, continuous fallow. Therefore, C combines effects of vegetation, crop sequence, management, and agricultural (as opposed to engineering) erosion-control practices. On landfills, freshly covered and without vegetation or special erosion-reducing procedures of cover placement, C will usually be about unity. Where there is vegetative cover or significant amounts of gravel, roots, or plant residues or where cultural practices increase infiltration and reduce runoff velocity, C is much less than unity. Estimate C by reference to Table 7 for anticipated cover management, but also consider changes that may take place in time. Meadow values are usually most appropriate. See Reference 1 for additional guidance.

Factor P in the USLE is similar to C except that it accounts for additional erosion-reducing effects of land management practices that are superimposed on the cultural practices, e.g., contouring, terracing, and contour strip-cropping. Approximate values of P, related only to slope steepness,

TABLE 7. GENERALIZED VALUES OF FACTOR C FOR STATES EAST OF THE ROCKY MOUNTAINS[11]

Crop, rotation, and management	Productivity level	
	High	Mod.
	C value	
Base value: continuous fallow, tilled up and down slope	1.00	1.00
CORN		
C, RdR, fall TP, conv	0.54	0.62
C, RdR, spring TP, conv	.50	.59
C, RdL, fall TP, conv	.42	.52
C, RdR, wc seeding, spring TP, conv	.40	.49
C, RdL, standing, spring TP, conv	.38	.48
C-W-M-M, RdL, TP for C, disk for W	.039	.074
C-W-M-M-M, RdL, TP for C, disk for W	.032	.061
C, no-till pl in c-k sod, 95-80% rc	.017	.053
COTTON		
Cot, conv (Western Plains)	0.42	0.49
Cot, conv (South)	.34	.40
MEADOW		
Grass & Legume mix	0.004	0.01
Alfalfa, lespedeza or Sericia	.020	
Sweet clover	.025	
SORGHUM, GRAIN (Western Plains)		
RdL, spring TP, conv	0.43	0.53
No-till pl in shredded 70-50% rc	.11	.18
SOYBEANS		
B, RdL, spring TP, conv	0.48	0.54
C-B, TP annually, conv	.43	.51
B, no-till pl	.22	.28
C-B, no-till pl, fall shred C stalks	.18	.22
WHEAT		
W-F, fall TP after W	0.38	
W-F, stubble mulch, 500 lbs rc	.32	
W-F, stubble mulch, 1000 lbs rc	.21	

Abbreviations defined:

B - soybeans
C - corn
c-k - chemically killed
conv - conventional
cot - cotton
F - fallow
M - grass & legume hay
pl - plant
W - wheat
wc - winter cover

lbs rc - pounds of crop residue per acre remaining on surface after new crop seeding
% rc - percentage of soil surface covered by residue mulch after new crop seeding
70-50% rc - 70% cover for C values in first column; 50% for second column
RdR - residues (corn stover, straw, etc.) removed or burned
RdL - all residues left on field (on surface or incorporated)
TP - turn plowed (upper 5 or more inches of soil inverted, covering residues)

are listed in Table 8. These values are based on rather limited field data, but P has a narrower range of possible values than the other five factors.

TABLE 8. VALUES OF FACTOR P[11]

Practice	Land slope (percent)				
	1.1-2	2.1-7	7.1-12	12.1-18	18.1-24
	(Factor P)				
Contouring (P_c)	0.60	0.50	0.60	0.80	0.90
Contour strip cropping (P_{sc})					
R-R-M-M[1]	0.30	0.25	0.30	0.40	0.45
R-W-M-M	0.30	0.25	0.30	0.40	0.45
R-R-W-M	0.45	0.38	0.45	0.60	0.68
R-W	0.52	0.44	0.52	0.70	0.90
R-O	0.60	0.50	0.60	0.80	0.90
Contour listing or ridge planting (P_{cl})	0.30	0.25	0.30	0.40	0.45
Contour terracing (P_t)[2]	[3] $0.6/\sqrt{n}$	$0.5/\sqrt{n}$	$0.6/\sqrt{n}$	$0.8/\sqrt{n}$	$0.9/\sqrt{n}$
No support practice	1.0	1.0	1.0	1.0	1.0

[1] R = rowcrop, W = fall-seeded grain, O = spring-seeded grain, M = meadow. The crops are grown in rotation and so arranged on the field that rowcrop strips are always separated by a meadow or winter-grain strip.

[2] These P_t values estimate the amount of soil eroded to the terrace channels and are used for conservation planning. For prediction of off-field sediment, the P_t values are multiplied by 0.2.

[3] n = number of approximately equal-length intervals into which the field slope is divided by the terraces. Tillage operations must be parallel to the terraces.

Example: An owner/operator proposes to close one section of his small landfill with a sandy clay subsoil cover having the surface configuration shown in Figure 21. The factor R has been established as 200 for this locality. The evaluator questions anticipated erosion along the steep side and assigns the following values to the other factors in the USLE after inspecting Tables 5 through 8:

$$K = 0.14 \quad LS = 8.3 \quad C = 1.00 \quad P = 0.90$$

The rate of erosion for the steep slope of the landfill is calculated as follows:

$$A = 200\ (0.14\ \text{tons/acre})\ (8.3)\ (1.00)\ (0.90) = 209\ \text{tons/acre}$$

This erosion not only exceeds a limit recommended by the permitting authority but also indicates a potential exposure of solid waste in that side of the landfill. The evaluator therefore recommends that the owner/operator review his plan of closure to reduce the potential erosion. One way that the operator might accomplish this reduction in erosion is by placing additional solid waste along the steep slope in an overlapping wedge as indicated in the figure. Although the new cover would have a greater slope length, the overall effect is to reduce the factor LS and the amount of erosion.

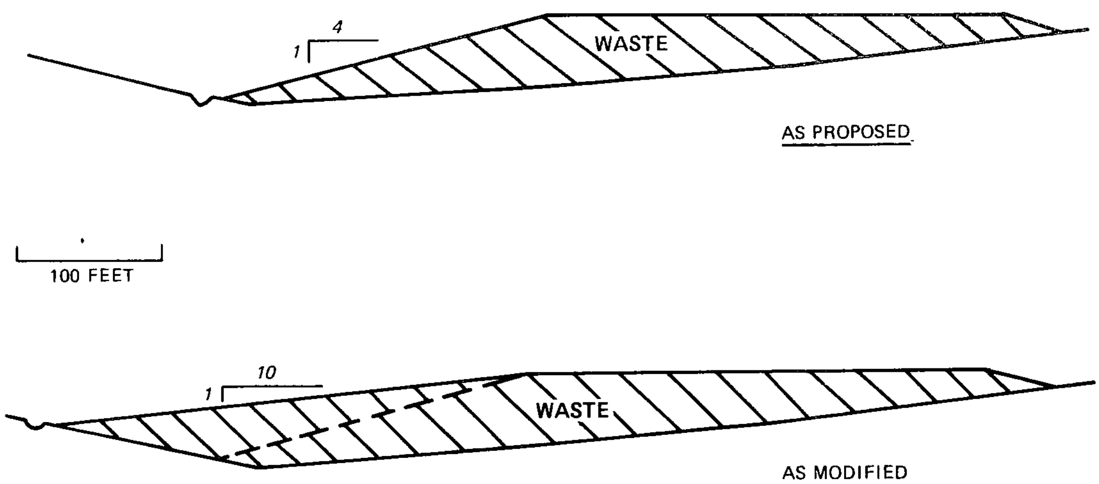


Figure 21. Hypothetical landfill configuration and modification.

Evaluate Surface Slope Inclination — Step 20

Rainfall runoff is increased by increases in inclination of the surface, and accordingly, infiltration is decreased. Since erosion also increases with increasing inclination (Step 19), the balance between these opposing considerations often must be carefully evaluated. On slopes of less than 3 percent, the irregularities of the surface and vegetation commonly act as traps for detention of runoff. The value 5 percent has been suggested and used in grounds maintenance[13] as an approximation of an inclination sufficient to facilitate runoff without risking excessive erosion. A quantitative evaluation of the erosional effect of inclination is outlined for factor LS under Step 19.

Not only is erosion more serious as inclination is increased, but slope mass stability can become a factor on relatively steep side slopes of landfills and surface impoundments. Usually the evaluator will do well to seek assistance from technical agencies experienced in analyzing slope stability since varied strength properties and seepage conditions can greatly complicate the mass stability. As a rough guide, however, the evaluator can usually count on the rule of thumb that not exceeding 1V (vertical) on 4H (horizontal) or other inclination shown by experience or analysis to be relatively stable would assure satisfactory slope performance in most cases.

The vulnerability of knoll-like configurations to wind erosion can be evaluated by the use of Figure 22. An adjustment factor is obtained as an erosion loss percentage of 100 or more in comparison with erosion loss from a similar flat surface. This factor should be used to estimate the effects of sides of landfills that may present a knoll-like configuration toward the prevailing winds.

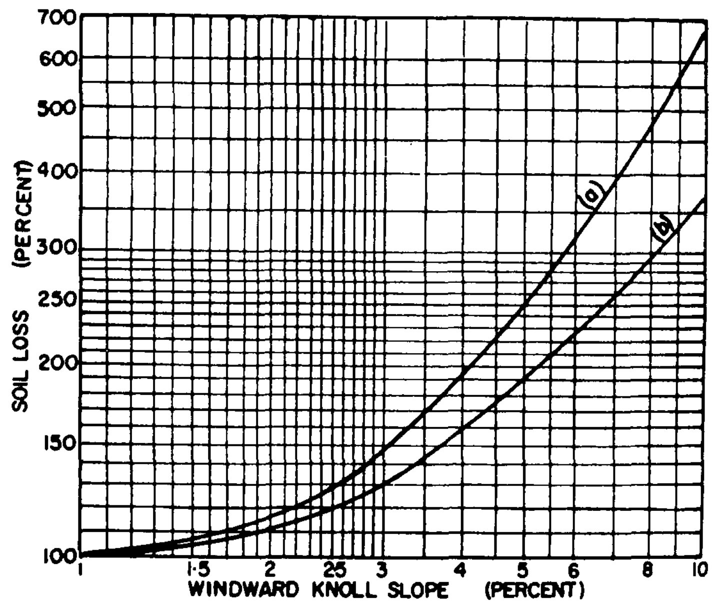


Figure 22. Knoll adjustment (a) from top of knoll and (b) from upper third of slope.[14] (Reproduced by permission of Soil Science Society of America.)

Another general rule of thumb[15] provides that 1V on 2H is the maximum slope on which vegetation can be established and maintained, assuming ideal soil with low erodibility and adequate moisture-holding capacity. In soils less than ideal, maximum vegetative stability cannot be attained on slopes steeper than about 1V on 3H. Optimum vegetative stability generally requires slopes of 1V on 4H or flatter. Similarly, there are limits to the inclination where mowing maintenance is planned. The limit can be as low as IV on 6H for grassed ditches where two slopes meet at the bottom, but more commonly the limit is about IV on 3H.

DRAINAGE EVALUATION PROCEDURE

Check Overall Surface Drainage System — Step 21

Examine the documentation to establish that drainage of surface runoff from the covered area and surroundings has been thoroughly addressed. Maps presenting topography or other descriptions of surface configuration should be carefully reviewed to see that rainfall or snow melt on any part of the site is free to move downslope without encountering obstacles that might lead to ponding or excessive erosion. At the same time, a check should be made to see that the slope is not anywhere in excess of the slopes for flat surfaces and for ditches provided in the regulations. In those places such as the edge of the landfill where slopes may of necessity be relatively steep, a check for adverse effects in the form of excessive erosion should be made as explained elsewhere (Step 19).

<u>Evaluate Ditch Design</u> <u>Step 22</u>

To confirm the adequacy of drainage ditches, the evaluator should formally check the hydraulic calculations on which design for ditch cross sections are based. This step can be important but for many landfills may only be necessary where diversion ditches convey runoff from beyond the site around its edge. Calculation should not usually be necessary on the landfill cover itself unless an overflow situation would have serious consequences.

Design (and evaluation) of a ditch is routinely accomplished using the Rational equation (Step 7) and Manning's equation. It was explained in Section 2 that calculations of discharge Q for design storm or storms should be included with the documentation supplied with the application for closure. Q in cubic feet/second is used to calculate ditch cross sections in Manning's equation:

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

where n = coefficient of roughness
A = area, square feet
R = hydraulic radius, feet
S = energy gradient, feet/foot

The Manning's n value is usually obtained from a table and that authoritative reference should be cited in the application to facilitate checking. For a rough check, use n = 0.02. The S in the equation is simply the longitudinal inclination of the ditch.

The design amounts to a manipulation of the remaining unknowns A and R within certain constraints. Numerous tables have been developed and are available for assistance in design; again these references should be identified when used. The cross-sectional area A of the waterfilled ditch is affected by the choice of shape, e.g., between triangular and trapezoidal. The hydraulic radius R is also affected since it is by definition the area divided by the wetted perimeter formed by the ditch. A final constraint is the requirement that erosion in the ditch be limited by limiting discharge velocity Q/A to an appropriate maximum from among those determined as critical for the range of soil types (Table 9).

<u>Evaluate Culvert Design</u> <u>Step 23</u>

Evaluations of culverts and other closed structures that may occasionally be used as a part of the surface drainage system are approached in approximately the same way as Step 22. An added complication is the capacity

TABLE 9. THRESHOLD VELOCITY FOR EROSION IN DITCHES

Soil	V_{max}, feet/second
GP	7-8
GW, GC	5-7
GM	2-5
SC	3-4
SM	2-3
SW, SP	1-2
CL, CH	2-3
ML, MH	3-5

of the structure to transmit the water. Where the capacity is too small, water will back up and form a pond, at least temporarily.

Check Gas Drainage — Step 24

Municipal waste usually generates methane and carbon dioxide. Industrial and hazardous wastes may also produce these gases and may contain sufficient other volatile components to be of concern (see Step 11). Depending on location, land use, and the proximity of buildings, there may be a need for a careful review of the routes of gas drainage.* Methane leakage occasionally threatens human life by potential for explosion. Volatile compounds such as HCB and PCB may present a health or environmental problem. More commonly landfill gases pose a serious threat to the success of vegetation in the long-term.[16] Guidance on the best soils for blocking gas or, at the other extreme, for conveying gas is given in Step 8. The effects of water content, thickness, and layering of cover are discussed in Steps 11 and 15. What remains is commonly to connect the broad collecting layers to surface vents, sometimes through linear drainage features consisting of gravel-filled trenches in which perforated collector pipes are embedded. See Step 15 for criteria on gravelly drains. Details of the system should be submitted with the permit application and should include the features for venting. Reference 17 reviews the passive and induced (pumped) venting systems.

VEGETATION EVALUATION PROCEDURE

Rapid establishment and maintenance of vegetation can be accomplished on soil covering solid waste only by carefully addressing soil type,

* Step 24 is unnecessary for wastes containing no garbage or volatile chemicals.

nutrient and pH levels, climate, species selection, mulching, and seeding time.[1] Fertile soils, if available at all for landfill cover, are usually cost-prohibitive, so that nonproductive soils or subsoils often have to be used. County agricultural agents can provide guidance based on local conditions.

Evaluate Soil Suitability for Vegetation — Step 25

Soil composed of a mixture of clay, silt, and sand such that none of the components dominates is called a loam. The stickiness of the clay and the floury nature of the silt are balanced by the nonsticky and mealy or gritty characteristics contributed by the sand. A loam is rated overall best for supporting vegetation as it is easily kept in good physical condition and is conducive to good seed germination and easy penetration by roots.

Clay-rich soils may be productive when in a granular condition, but they require special management methods to prevent puddling or breaking down of the clay granules. Silt-rich soils lack the cohesive properties of clay and the grittiness of sand, are water retentive, and usually are easily kept in good condition. Soils made up largely of sand can be productive if sufficient organic matter is present internally or as a surface mulch to hold nutrients and moisture; sandy soils tend to dry out very rapidly and lose nutrients by leaching.

Remember that worthwhile provisions in establishing vegetation may be to stockpile and then to reuse the original topsoil. The less fertile underlying soil will be available as daily or intermediate cover. As the operation nears completion, the stockpiled topsoil can be used in the final cover to facilitate growth of grasses and/or shrubbery. The original topsoil must be significantly more fertile than underlying soil strata; otherwise, stockpiling is not practical or economical.

Evaluate pH Level — Step 26

Tests should be made to determine pH and buffering capacity (usually stated as tons/acre of lime necessary to adjust the soil pH to around 6.5). The amount of lime necessary to neutralize a given soil depends upon soil pore-water pH and "reserve acidity." The reserve acidity is a single factor which incorporates several variables; soils with high levels of organic matter and/or clay require higher amounts of lime for pH adjustment. The pH of subsoil (where appreciable in the cover) also influences lime requirements; acidic subsoils require higher levels and repetitive applications of lime. Some buried landfill wastes act much like acid subsoils making higher lime application levels or more frequent liming intervals necessary for adequate pH control.

Evaluate Nitrogen and Organic Matter — Step 27

Nitrogen is of special importance in establishing vegetation because it is needed in relatively large amounts during vigorous growth but is easily lost from the soil. Nitrogen fertilizer requirements depend upon the amount of organic matter present (higher organic matter levels requiring higher application rates), the soil texture (more is required on sandy soils), and the seed mixture chosen (more is required for grasses than legumes). Generally, 50 to 85 pounds/acre of nitrogen are recommended. Fertilizers are rated by the amount of nitrogen they contain per weight of fertilizer (e.g. 6 percent nitrogen). To calculate the amount of fertilizer necessary to furnish the recommended amount of nitrogen, simply divide the recommended application by the fractional amount of nitrogen the fertilizer to be used contains. For example, to apply 50 pounds/acre of nitrogen using fertilizer which is 6 percent nitrogen, divide 50 by 0.06 to get 833 pounds/acre of fertilizer required. Table 10 indicates typical ranges of organic matter in different soil types and a rough range of nitrogen levels present in a typical loam with moderate levels of organic matter.

Evaluate Other Nutrients — Step 28

Necessary levels of phosphorus in soil are shown in Table 10. Unlike

TABLE 10. RELATIVE LEVELS OF ORGANIC MATTER AND MAJOR NITRIENTS IN SOILS[18]

	Organic Matter, percent					
Relative Level*	Sand, Loamy Sand	Sandy Loam, Loam, Silt Loam	Clay Loam, Sandy Clay, Clay	Nitrogen lb/acre	Phosphorus lb/acre	Potassium lb/acre
Very low	<0.6	<1.6	<2.6	<20	<6	<60
Low	0.6-1.5	1.6-3.0	2.6-4.5	20-50	6-10	60-90
Medium	1.6-2.5	3.1-4.5	4.6-6.5	50-85	11-20	91-220
High	2.6-3.5	4.6-5.5	6.6-7.5	85-125	21-30	221-260
Very high	>3.5	>5.5	>7.5	>125	>30	>260

* Medium level is typical of agricultural loam soil. Low levels need supplemental fertilization; high levels need no fertilization under normal circumstances.

nitrogen, phosphorus is not mobile in the soil and thus is lost very slowly to leaching. It is possible to give enough phosphorus in one application to last several growing seasons. Generally at least 15 pounds/acre of phosphorus* is recommended as a starter. The availability of phosphorus to the plant is quite dependent on pH. At optimum pH values (6.2-6.8), amounts of 50 pounds/acre are usually adequate; at pH values below 6.2 or between 6.9 and 7.5, about 80 pounds/acre is needed for optimum growth. Under very alkaline conditions (pH greater than 7.5), phosphorus levels of 110 pounds/acre are required. These recommendations are for raw subsoils, or for sandy or high clay soils of low organic material content.

* In calculating on the basis of P_2O_5, remember that percent P_2O_5 is 2.3 times an equivalent percent phosphorus.

Potassium is much less important in grass establishment than in legume establishment and maintenance; thus the rate of application depends upon both test results and species to be seeded. A minimum potassium application of 26 pounds/acre (32 pounds/acre of K_2O) as a starter is recommended under any circumstances. Potassium applications can run as high as 230 pounds/acre (277 pounds/acre of K_2O) on impoverished soils where legumes are to be seeded. Potassium is moderately mobile in the soil and is slowly leached out, but one heavy application should be adequate for several growing seasons.

Evaluate Species Selection — Step 29

Each species of grass, legume, shrub, or tree has its own environmental and biological strengths and limitations. Moisture, light, temperature, elevation, aspect, balance and level of nutrients, and competitive cohabitants are all parameters which favor or restrict plant species. The selection of the best plant species for a particular site depends upon knowledge of adapted plants that have the desired characteristics. Table 11 gives the major parameters usually important to species selection and examples of grasses and legumes exhibiting the parameters. Characteristics which almost universally should be given precedence are: low growing and spreading from rhizomes or stolons; rapid germination and development; and resistance to fire, insects, and disease. Plants which are poisonous or are likely to escape the site and become noxious should be avoided.

A very large number of species of grasses and legumes are available for reclamation use. Species that find wide and frequent application are described in Tables 12 and 13. A local agronomist should be consulted for recommendation of locally adapted plant varieties.

Evaluate Shrubs and Trees — Step 30

Volunteer and native species of shrubs and trees tend to invade landfill cover systems[16] much as they will any disturbed land. The extreme environment of the cover may be less restrictive to certain strong species of shrubs and trees, and the astute planner or reviewer should allow for or even take advantage of such relative strengths that would appear in the future. One planning strategy is to specify the planting of the preferred volunteer species at the start. Otherwise, more control of species taking root in the future may be necessary (Step 34). Actually, the growth of shrubs and trees may be an unfavorable development because of the effects of their deep roots on the integrity of the cover. Besides its importance to planning for post-closure care this development also needs to be considered in assessing risks posed by the facility after the extended care terminates.

The special conditions of greatest concern in maintaining healthy shrubs and trees are often the thinness and intermittent dryness of the cover soil.[16] The adverse consequence of thinness is that only small, shallow-rooted species may survive, and even some of these will become unstable and will topple during winds. Where planted shrubs and trees warrant high priority, it may be necessary to assure success by providing a wide, deep pocket of soil around each plant.

TABLE 11. IMPORTANT CHARACTERISTICS OF GRASSES AND LEGUMES

Characteristic	Degree *	Common Examples
Texture	Fine	Kentucky bluegrass, bentgrass, red fescue
	Coarse	Smooth bromegrass, reed canarygrass, timothy
Growth height	Short	Kentucky bluegrass, buffalograss, red fescue
	Medium	Redtop, perennial ryegrass
	Tall	Smooth bromegrass, timothy, switchgrass
Growth habit	Bunch	Timothy, big bluestem, sand dropseed, perennial ryegrass
	Sod former	Quackgrass, smooth bromegrass, Kentucky bluegrass, switch grass
Reproduction	Seed	Red and alsike clover, sand dropseed, rye, perennial ryegrass, field bromegrass
	Vegetative	Prairie cordgrass, some bentgrasses
	Seed and vegetative	White clover, crownvetch, quackgrass, Kentucky bluegrass, smooth bromegrass
Annual	Summer	Rabbit clover, oats, soybeans, corn, sorghum
	Winter	Rye, hairy vetch, field bromegrass
Perennials	Short-lived	Timothy, perennial ryegrass, red and white clover
	Long-lived	Birdsfoot trefoil, crownvetch, Kentucky bluegrass, smooth bromegrass
Maintenance	Difficult	Tall fescue, reed canarygrass, timothy, alfalfa
	Moderate	Kentucky bluegrass, smooth bromegrass
	Easy	Crownvetch, white clover, birdsfoot trefoil, big bluestem
Shallow rooted	Weak	Sand dropseed, crabgrass, foxtail, white clover
	Strong	Timothy, Kentucky bluegrass
Deep rooted	Weak	Many weeds
	Strong	Big bluestem, switchgrass, alfalfa, reed canarygrass
Moisture	Dry	Sheep fescue, sand dropseed, smooth bromegrass
	Moderate	Crested wheatgrass, red clover
	Wet	Reed canarygrass, bentgrass
Temperature	Hot	Lehman lovegrass, fourwing saltbush, ryegrass
	Moderate	Orchard grass, Kentucky bluegrass, white clover
	Cold	Alfalfa, hairy vetch, smooth bromegrass, slender wheatgrass

* Variety, specific characteristic, subcharacteristic, or favored condition.

Example: A local agronomist has recommended that gray birch (a volunteer species) be planted on the cover for a landfill in New England. The reviewer asks for clarification in the plan on the development of roots for the expected tree density. This information will help the reviewer to evaluate the likely changes in effectiveness of the cover for impeding percolation.

Evaluate Time of Seeding — Step 31

Probably the most critical of all decisions in the successful establishment of vegetative cover on poor soils is the time of seeding. The optimum time of seeding depends on the species selected and the local climate. Best seeding time under normal circumstances is presented in Tables 12 and 13 for the recommended grasses and legumes. A local county agent or seed house should be consulted for more specific local information. Note the interrelationship with Step 17.

Most perennials require a period of cool, moist weather to become established to the extent that they can withstand a cold winter freeze or hot summer drought. Early fall (late August in the north through October in the south) usually allows enough time for the plants to develop to the stage that they can withstand a hard winter. Plants then have a good start for

TABLE 12. GRASSES COMMONLY USED FOR REVEGETATION*

Variety	Best Seeding Time	Seed Density† seeds/ft²	Important Characteristics	Areas/Conditions of Adaptation
Redtop bentgrass	Fall	14	Strong, rhizomatous roots, perennial	Wet, acid soils, warm season
Smooth bromegrass	Spring	2.9	Long-lived perennial	Damp, cool summers, drought resistant
Field bromegrass	Spring	6.4	Annual, fibrous roots, winter rapid growth	Cornbelt eastward
Kentucky bluegrass	Fall	50	Alkaline soils, rapid grower, perennial	North, humid U.S. south to Tennessee
Tall fescue	Fall	5.5	Slow to establish, long-lived perennial, good seeder	Widely adapted, damp soils
Meadow fescue	Fall	5.3	Smaller than tall, susceptible to leaf rust	Cool to warm regions, widely adapted
Orchard grass	Spring	12	More heat tolerant but less cold resistant than smooth bromegrass or Kentucky bluegrass	Temperate U.S.
Annual ryegrass	Fall	5.6	Not winter hardy, poor dry land grass	Moist southern U.S.
Timothy	Fall	30	Shallow roots, bunch grass	Northern U.S., cool, humid areas
Reed canarygrass	Late summer	13	Tall coarse, sod former, perennial, resists flooding and drought	Northern U.S., wet, cool areas

* Taken from many sources, but especially References 18 and 19.

† Number of seeds per square foot when applied at 1 pound/acre.

TABLE 13. LEGUMES COMMONLY USED FOR REVEGETATION*

Variety	Best Seeding Time	Seed Density† seeds/ft^2	Important Characteristics	Areas/Conditions of Adaptation
Alfalfa (many varieties)	Late summer	5.2	Good on alkaline loam, requires good management	Widely adapted
Birdsfoot trefoil	Spring	9.6	Good on infertile soils, tolerant to acid soils	Moist, temperate U.S.
Sweet clover	Spring	6.0	Good pioneer on non-acid soils	Widely adapted
Red clover	Early spring	6.3	Not drought resistant, tolerant to acid soils	Cool, moist areas
Alsike clover	Early spring	16	Similar to red clover	Cool, moist areas
Korean lespedeza	Early spring	5.2	Annual, widely adapted	Southern U.S.
Sericea lespedeza	Early spring	8.0	Perennial, tall erect plant, widely adapted	Southern U.S.
Hairy vetch	Fall	0.5	Winter annual, survives below 0°F, widely adapted	All of U.S.
White clover	Early fall	18	World-wide, many varieties, does well on moist, acid soils	All of U.S.
Crownvetch	Early fall	2.7	Perennial, creeping stems and rhizomes, acid tolerant	Northern U.S.

* Taken from many sources, but mainly from References 18 and 19.

† Number of seeds per square foot when applied at 1 pound/acre.

early spring growth and can reach full development before any summer drought. Spring planting is usually second choice for all but a few of the more rapidly developing perennials. Germination and early development are slowed due to the cool early spring weather. Late frosts often severely damage the young plants. Late spring planting does not allow enough time for most perennials to mature before summer, and annuals will usually outcompete the preferred perennials.

Annuals generally are best planted in spring and early summer. Growth is completed quickly prior to the summer heat and before the soil moisture is used up. During this period annuals easily outcompete the perennials. Annuals can, however, be planted any time the soil is damp and warm when a quick plant cover is desired and often will provide an acceptable mulch for fall-seeded perennials.

Evaluate Seed and Surface Protection — Step 32

Bare soil as a seeding medium suffers from large temperature and moisture fluctuations and from rapid degeneration due to wind and water erosion. Mulches provide temporary protection against these influences; therefore, the use of mulch should be expected in the plan for closure cover.

Almost any material spread, formed, or simply left on the soil surface will act as a mulch, e.g., straw and other crop residues, sawdust, wood chips, wood fiber, bark, manure, brush, jute or burlap, gravel, stones, peat, paper, leaves, plastic film, and various organic and inorganic liquids. For straw used where erosion is not anticipated, an application of 1.5 tons/acre is recommended. On slopes or elsewhere where erosion threatens, 2 tons/acre produces better results. Application rates over 2.5 tons/acre often result in reduced germination and emergence and such high rates should be avoided.

Rapid growing, summer cover crops can be used to advantage as living mulches if final grade work is finished in late spring or early summer when chances of successful perennial grass-legume seedings are low. Coarse grasses such as Sudan grass or a local equivalent are good choices as they are widely adaptable, and the tall, stiff stalks are most effective as a mulch.

Petroleum-based products such as asphalt and resins are often suitable and are frequently used as mulching materials. Specially formulated emulsions of asphalt under various trade names have been used throughout the world to prevent erosion, reduce evaporation, promote seed germination, and warm the soil to advance the seeding date. The film clings to but does not deeply penetrate the soil; it is not readily destroyed by wind and rain and remains effective from 4 to 10 weeks. Application rates of 1000-1200 gallons/acre are usually required to control erosion. Asphalt mulches cost about twice the applied cost of a straw mulch.

SECTION 4

POST-CLOSURE PLAN

Provisions for maintenance and for contingencies after site closure should follow a logical plan.

MAINTENANCE EVALUATION PROCEDURE

Some cover deterioration like erosion can be tolerated where the post-closure plan has provisions for frequent, regular maintenance. Elsewhere regular maintenance of the cover may be planned on a less frequent interval, in which case a more conservative cover design is necessary at the start.

Evaluate Design/Maintenance Balance — Step 33

Check to see that the plan for closure covering generally achieves a reasonable balance between initial design and plans for monitoring, maintenance, and repair. So many specific factors (climate, waste type, soil, vegetation, etc.) are involved in evaluating this balance that little detailed guidance can be offered; nevertheless, the assessment is important and should be performed with care and diligence. The following example helps clarify the general nature of the problem and the recommended philosophy.

> Example: In a late modification, the applicant formally proposes to reduce the frequency of post-closure monitoring inspection visits to a remote hazardous waste site by overdesigning the closure cover at the start. A certain period between inspection visits has become more or less standard in the region on the basis of experience, but the applicant now proposes to double this period. The overdesign amounts to prescribing a thicker cover than might ordinarily be considered sufficient. In this case the evaluator rejects the proposed modification of less frequent inspections. He reasons that emergency conditions, such as from wind or water erosion or from cover cracking, can compound and intensify the problem in a short period in this region; therefore, frequent inspections are imperative and necessary.

Evaluate Maintenance of Vegetation — Step 34

After vegetation is established on a landfill, maintenance is necessary to keep less desirable, native species from taking over and weak areas in the cover from developing. In most areas judicious, twice-yearly mowing will keep down weed and brush species. Annual fertilization (and liming if necessary) will generally allow desirable species to outcompete the weedy species of lower quality. Occasional use of selective herbicides usually controls noxious invaders, but care must be taken to avoid injuring or weakening the desirable species, lest more harm than benefit results in the long run. In rare circumstances, large insect populations may threaten the stand of vegetation so that insecticide application becomes desirable. The evaluator should review the intermediate and long-range plans for maintaining vegetation with cognizance of plant needs in establishment (and reestablishment) as outlined in Steps 26-32.

Landfill cover soils are usually shallow and of low quality for growing high-quality vegetation. This problem is greatly compounded if an impervious clay or plastic barrier is incorporated in the cover. Such a barrier makes the plant-root zone susceptible to swamping after moderate rains since vertical drainage is impeded. Upon saturation, the soil becomes anaerobic and roots in the system are threatened. Short periods of swamping will weaken the vegetation; longer periods may cause a complete loss. Swamping tolerant species (such as reed canarygrass) and surface drainage will lessen these problems.

On the other extreme, thin layers dry excessively during droughty periods. No deep soil moisture is available to tide the plants over even moderate droughts. Plants which have been weakened by prior waterlogging or that are not drought-tolerant are especially vulnerable. Irrigation may be necessary during prolonged dry spells to preclude complete loss of plant cover.

Landfills may continue to produce gases and soluble organic decomposition products for years after closure, and vegetation can be damaged. An impervious cover keeps the landfill dry so that gas production is low or nonexistent and also may shield the plant roots from these products. Deep-rooted shrubs or trees are usually not recommended on landfills since roots will tend to penetrate into the waste zone.

Evaluate Provisions for Condition Surveys — Step 35

Applications for closures should include plans for monitoring the site in the future. An annual site visit by a technical person qualified to evaluate the condition of the cover may be considered sufficient by the permitting authority for some sites. Elsewhere, however, it may be judged that more frequent inspections are necessary. Provisions should be made in the application for collecting documentation during the site visit. The documentation and inspection reports should be kept on site by the owner/operator or at some other location where it can be examined conveniently. Copies of the reports including all significant observations or conclusions should be kept in the applicant's file for review on request by the overseeing agency.

> Example: The evaluator has reviewed an application for closing a site and found that there is sufficient

> planning to monitor site conditions over an extended period. He notes, however, that the site visits are to be made by a representative of the owner/operator with no provision for a state or EPA representative to accompany the inspector. Among changes he requires in this application, therefore, is the stipulation in the post-closure plan that the state agency (or EPA) will be notified five days before the site visit so that they may send a representative.

CONTINGENCY PLAN EVALUATION PROCEDURE

Evaluate Plan for Erosion Damage Repair — Step 36

Long-term maintenance helps to avoid erosion problems. However, unusual climate conditions and shortcomings in the design occasionally cause excessive erosion by wind or water even on well-maintained covers.

Factors that need to be considered in the plan include the future source of supply of fill soil for repair and the ability of someone to undertake the repair work. The extent of repair work should be detailed in words to the effect that repair work will bring lines and grades at least to their original configuration. It is also appropriate to expect that the remedial work will involve redesign where excessive erosion indicates that the original design was deficient. Some of the many options that might be mentioned for consideration in the case of a necessity for repair would include construction of berms, protection of slopes and channels by riprap, and the use of other special energy dissipators such as check dams.

In anticipation of major problems of sheet erosion across entire surfaces such methods as terracing might be identified, provided their effect on infiltration is not excessively adverse.

In those regions where wind erosion can present a serious problem, the post-closure plan should include specific statements on correcting wind erosion problems. The following example is illustrative of the recommended attitude.

> Example: Consider a site in the southern Great Plains. An applicant proposes to dispose of waste in a trench operation in which soil excavated from the trench will be used as final cover. Since a considerable mound will have been formed upon closure, the evaluator foresees the possibility of eventual wind erosion. No provision with specifics for timely repair addresses this possible erosion problem, so the evaluator recommends that the applicant develop contingencies accordingly. The evaluator offers for consideration the use of snow fences as one quick response technique.

Evaluate Plan for Vegetation Repair — Step 37

Waste disposal areas have long-lived potential for negative impact, and permanent vegetative cover should be maintained. Once a cover of vegetation is started and stabilized, extensive root systems develop and decomposition processes form a layer of humus capable of perpetuating the cover of vegetation. However, erosion forces, burrowing animals, etc., may damage parts of this cover of soil, humus, and vegetation. Provisions should be made for repairing such damage, specifically for transplanting grass sod, planting the new seeds or shrubs, and replacing eroded soil during the inactive life of the area.

The principal part of the application documents that the evaluator should carefully review is that part dealing with measures to return damaged vegetation to a state such as originally planned (see VEGETATION EVALUATION PROCEDURE, SECTION 3). One additional concern of the plan for maintenance of vegetation is that any deterioration of the vegetative cover is often widespread; swampiness or droughtiness, nutrient starvation, or methane migration once appearing in the cover may quickly affect the entire vegetation system. Exceptions are problems induced by erosion, and repair in this case should be of less concern. Because of this potential widespread impact the applicant's plans for maintaining or for repairing the vegetation should be closely tied to the monitoring plan and should be adequate to respond quickly to the early stages of a developing problem.

Evaluate Plan for Drainage Renovation — Step 38

The principal part of the applicant's plan for drainage renovation should include sufficient details to assure that the drainage system for the site as designed will be restored quickly to its original condition. Furthermore, the plan for repair should provide for such additional work as becomes necessary after a period of operations. Such additional work might include repair of gullies and placement of riprap along a slope subjected to more erosive action than anticipated in the original drainage design. Except for such unexpected problems, the maintenance of drainage should amount to fairly straightforward cleaning of ditches and cutting of brush.

Evaluate Provisions for Other Cover Deterioration — Step 39

Contingency planning should include making provisions for all forms of cover deterioration other than erosion and distress of the vegetation covered elsewhere. The relatively high unit weights of some freshly compacted cover soils will be reduced substantially in a few years. This bulking (brought on partly by penetration of countless fine roots) benefits vegetation but negatively affects the cover as a barrier to percolation. Other deterioration might result from deep root penetration, cracking, disturbance by cold weather, seepage, and slope instability. The evaluator should consider the likely effectiveness of post-closure plans to addressing such problems in a timely manner. His evaluation should, of course, be made in the context of policies established by state agencies and EPA. Such policies need not necessarily assign responsibility for correcting such unanticipated problems to the owner/operator.

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