# TESTS FOR EVALUATING SITES FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

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# ABSTRACT

This report, the second of a series, identifies the tests and other means of evaluating or documenting the important characteristics of sites for disposal of low-level radioactive waste. The specific parameters were identified and explained in regard to their importance in characterizing disposal facilities in the previous report. More than half of the tests and procedures are standard methods recognized and used nationwide, most conspicuously the numerous chemical tests. Other tests are commonly used methods recognized widely as state of the art, e.g., geological and geophysical methods. The basis for choosing these state-of-the-art methods is discussed, and the concepts and procedures themselves are reviewed in the absence of standards for ready reference. Besides standards and state-of-the-art practices a third category of methods involves the use of existing data sources or recognized correlations in place of new testing or documentation. It is particularly important that mapping, logging, sampling, testing, interpretation, and analysis be conducted by technically qualified and professionally motivated personnel using appropriate equipment and facilities, and general guidance is provided in this direction.

There will be cases where site-specific testing and measurement are indicated to be unnecessary on a technical basis. This report calls attention to the usual subordinate role of such parameters and their only infrequent need for testing.

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# PREFACE

This report was prepared by personnel of the Geotechnical Laboratory (GL) and the Environmental Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES) during the period November 1981 to July 1982. The investigation was sponsored by the U. S. Nuclear Regulatory Commission. The authors of the report were R. J. Lutton, D. K. Butler, R. B. Meade, D. M. Patrick, A. B. Strong, and H. M. Taylor, Jr. The work was conducted under the direct supervision of D. C. Banks, Chief, Engineering Geology and Rock Mechanics Division, GL, and the general supervision of W. F. Marcuson III, Chief, GL.

COL Tilford C. Creel, CE, was Commander and Director of the WES during preparation of the report. Fred R. Brown was the Technical Director.

Cut exposure of Borden formation on Interstate Highway 64, 8 miles east of Maxey Flats LLW disposal facility. This shale interval with included thin, siltstone beds is representative of the stratigraphic interval trenched at the facility. Such exposures can be invaluable in characterization of LLW sites.

# TESTS FOR EVALUATING SITES FOR DISPOSAL OF LOW-LEVEL RADIOACTIVE WASTE

## PART I: INTRODUCTION

This report presents the results of an investigation for the Nuclear Regulatory Commission (NRC) on the second of three tasks on the general subject of characterizing and monitoring sites for near-surface disposal of low-level radioactive waste (LLW). Efforts were focused in Task 1* on the identification of parameters. The present report continues the study by identifying those tests or means of documentation for evaluation of the parameters identified in Task 1. Task 3 will concentrate on site monitoring and provide recommendations on appropriate monitoring programs. The three reports together are intended to provide background useful to developers and operators at disposal facilities and to agencies responsible for licensing, regulating, and controlling these operations according to the proposed rule Title 10 Code of Federal Regulations Part 61 (10 CFR 61).

### Purpose of Study

The purpose of this task study was to identify recommended laboratory and field tests and documentational techniques for investigating the parameters previously identified as important to LLW siting.

This report is intended for use in combination with the Task 1 report in which the background as well as the importance of parameters for determining suitability of a site were established. Previous discussions are not repeated in this report.

### Scope of Report

This report follows as a sequel to the Task 1 report (NUREG/CR-2700) in which parameters were identified and explained. The testing procedure or means of documentation for each of those parameters are given in this report. The methods and techniques have been referenced to published standards (e.g., American Society for Testing and Materials) or to appropriate technical publications to the extent practical. Where a standard test is not available, the state-of-the-art procedure for the most appropriate technique has been described. In those cases where no state-of-the-art or standard procedure has been identified, research needs may exist. The values or ranges of values of parameters for LLW siting are addressed only to the extent that they affect the choice of

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* "Parameters for Characterizing Sites for Disposal of Low-Level Radioactive Waste," NUREG/CR-2700, U. S. Nuclear Regulatory Commission, May 1982.

test method. Table 1 lists the 67 parameters and parameter groups identified as important in Task 1. One previous parameter has been upgraded in potential importance so that the list now totals 68.

This task report also provides the basis for selecting certain tests, field methods, and equipment over other options that are available. The acceptance of a test as a recognized standard method is the unstated basis for the choice in many cases. In numerous other cases, where no basis of choice is given, there is the expectation that the method will receive wide recognition (standardization) in the future. In view of the multiplicity of parameters, tests, and methods of documentation presented in this report, it is appropriate to repeat from the Task 1 report that many special parameters have been included for completeness and some of these will need evaluation by testing only on a site-specific basis when their relevance has been substantiated technically. The subject areas covered are horizontal and vertical controls, field mapping, meteorological observations, surface water analysis, ground water analysis, soil sampling and testing, rock sampling and testing, geophysical techniques, and geological studies.

Parts II and III review the general concepts of field and laboratory investigations as well as the use of existing data sources. This short text is intended, along with Table 1, to provide the reader with an overview of possible technical investigations. These parts also review the important preliminaries involved in collecting and recording data and in gathering samples for testing.

Specific tests for each of the parameters and parameter groups are listed in alphabetical order in the Appendix. Groups of parameters are further subdivided as appropriate.

Table 1

Parameters and Parameter Groups for Characterizing LLW Sites

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Stratigraphy
Lithology and soils
Structure
Geomorphology
Ground water system and boundaries
Surface water system and boundaries
Recharge and discharge areas
Visual description
Soil classification
Rock classification
Material zone boundaries
Water zone boundaries
Immediate site boundary
Extended site boundary
Color (material color)
Grain-size distribution or parameter (grain-size distribution)
Material densities
Water content
Soil water pH and acidity (soil pH and acidity)
Electrical conductivity or resistivity (electrical resistivity)
Penetration parameter
Material variability parameter
Hydraulic conductivities
Permeability function
Transmissivity
Storativity
Anisotropy

Porosities and void ratio
Hydraulic potentials and pressures
Seepage velocity
Apparent velocity
Flow direction
Dispersion
Pore water age
Suction pressures
Suction pressure function
Water-holding parameters
Infiltration capacity
Evapotranspiration
Precipitation
Runoff coefficients (runoff)
Air temperature
Air pressure
Wind speeds and directions
Partition coefficients
Mineralogy and clay mineralogy
Ion exchange capacities
Oxidation-reduction potential
Natural gamma and spectra (material radioactivity)
Soil solubles
Soil organics
Gaseous constituents
Ground water chemistry
Surface water chemistry
Atterberg limits
Specific gravity
Seismic velocity

(Continued)

Table 1, Concluded

Collapse susceptibility
Shrinking-swelling parameter
Strength
Consolidation relation
Compaction relation
Rebound index
Heaving susceptibility (frost heaving)
Erodibility parameters (erodibility)
Monument and point positions
Burial unit boundaries
Material temperature*

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* Temperature was previously included (Task 1) only under Ground water chemistry.

# PART II: FIELD INVESTIGATIONS

The field investigations for characterization and monitoring of LLW sites are conducted for three specific purposes:

a. Direct field evaluation of the characterizing parameters.

b. Installation of equipment and collection of data for evaluation of parameters.

c. Collection of samples for examination and testing in the laboratory.

Accordingly the field investigations must be carefully planned to coordinate field and laboratory parameter evaluation, sample collection, and installation of monitoring devices. This careful planning should permit optimum collection of data using multiple techniques in each boring or measurement point.

## Surface Exploration

Surface exploration primarily uses geological techniques and inferences to characterize the site in regard to stratigraphy, lithology and soils, structure, geomorphology, and hydrogeology. The specific techniques are reviewed in the Appendix under those or related headings. Surface exploration starts during the site selection stage in the LLW facility life cycle, but it is during the evaluation stage that investigation of parameters must be completed in detail. The primary means of surface exploration is through geological mapping. The coverage of geological mapping should extend well beyond the extended site to make a clear connection between features found at the site and those in the surrounding area. The mapping should be accomplished by plotting significant geological features on a topographic map of appropriate scale (commonly about 1:1000).* Where a considerable amount of the surface is underlain by material classified as soil, the limits of rock outcrops should be indicated. Consideration should also be given to mapping the intervening soil types (in both engineering and agricultural context). Where a soil map such as a Department of Agriculture county soil survey is available, it may be used but the accuracy of boundaries and classification of soil units should be verified and if necessary refined to the degree appropriate for LLW sites.

Similarly, existing detailed geological maps should be checked and refined. Ordinarily a complete geological map of the site supplemented with cross sections is made prior to starting subsurface investigations, and the geological map is updated as new information is obtained during subsurface investigations. This order of investigation, the logical

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* A somewhat smaller scale (commonly about 1:5000) will usually suffice for the geological work in the surrounding extended site.

sequence, provides more opportunity for planning the subsurface investigation and locating borings in an efficient manner.

## Geophysical Studies

The use of geophysical techniques involves taking measurements at the surface or in boreholes to determine subsurface conditions. Geophysical methods include seismic, electrical, nuclear, and electromagnetic, and one or more of these methods may be employed during any stage of the investigation--reconnaissance, selection, characterization, or monitoring.

These methods are generally used in conjunction with drilling. Geophysics can be used to aid in determining the best location of future drill holes as well as in interpolating conditions between existing drill holes. Electrical and seismic methods are sometimes efficient at locating the water table. The combination of geophysical surveys in conjunction with selective drilling is often more efficient and cost-effective than drilling alone to obtain the same degree of site definition; therefore, a judicious use of both methods can produce the desired information at an overall lesser cost.

Although the fieldwork required is relatively inexpensive, the interpretation of results is difficult in some cases and requires special training. In order to obtain usable and reliable test results, a correlation must be made locally with exploration made by borings. Geologists trained in the geophysical techniques are qualified to provide information and assistance on the applicability of geophysical techniques to specific situations.

## Subsurface Exploration and Material Sampling

Subsurface exploration with borings and trenches as well as with geophysical techniques constitutes the main part of the program for characterizing an LLW site. This importance comes from the fact that the site media composed of three-dimensional soil and rock zones may provide the potential pathways for unexpected escape of radionuclides as well as being the most important part of the system for retardation and containment.

The principal methods of nonaccessible subsurface exploration are listed and discussed in Table 2. Direct access and exposure of the subsurface by trenching and opening of pits is another important exploration method in reasonably stable ground. The last item in Table 2--continuous sampling--is often the most important at LLW sites. The choice of which method and equipment to use depends on site conditions and the requirements for subsurface data.

## Table 2

## Nonaccessible Methods of Subsurface Investigation and Sampling
(from Bureau of Reclamation)

| Method | Procedure | Type of soil and in-place condition | Limitation | Use |
|---|---|---|---|---|
| Auger boring (hand). | Rotate and force auger bit into soil, withdraw and empty when full. Auger bits, 2 to 8 in., helical or post hole. | Fine-grained cohesive, fairly hard to soft, or fine grained, noncohesive, dense to loose, weakly cemented, dry or moist, with particles ¼ in. to 1½ in. depending upon size of auger. | About 20 ft., 80 ft. with tripod, unsatisfactory in unstable cohesionless soils below ground water; slow in hard soils. | (1) Advance hole. (2) Data for logging. (3) Representative disturbed samples for classification, index tests, and standard properties tests. (4) Access for field penetration and permeability tests. (5) Access for undisturbed sampling. |
| Auger boring (power). | Same as above, using powered drill rigs. Auger bits, 4 to 24 in., helical, disc, or bucket. Over 28 in. considered to be accessible. | Fine-grained as above, and coarse grained soils with particles as large as 3 in. depending upon auger. | Economical depth about 40 ft., over 100 ft. with special equipment; unsatisfactory in unstable cohesionless soils below ground water, slow in hard, dense soil. | Same as above. |
| Drive tube boring. | Force open pipe or tube, with sharpened edges, without rotation, into soil, withdraw and remove soil. Thin- or thick-wall tubing or pipe, 2 to 8 in. dia. | Fine grained cohesive and slightly cohesive soils such as loess, firm to soft clays, and silts. | About 60 ft. depending upon equipment. Not satisfactory in coarser fine-grained soils, clean sands or cohesionless soils below water table. | Same as above. |
| Percussion (churn) drilling. | Chopping and cutting action by impact of heavy chisel edged bit. Water added and cuttings form slurry which is removed intermittently by pump or bailer. For holes larger than 4 in. | Coarse-grained soil containing cobbles and boulders, and hard, dense, fine-grained soils and rock. | Unsatisfactory in unstable soil or fractured rock. No information for logging or samples for classification. | Used with other methods to advance hole through hard, cemented strata, coarse gravel, boulders, or other obstructions. |
| Wash boring. | Chopping and cutting by impact and twisting action of light-weight bit, and jetting action of circulating water to remove cuttings. For holes from 2 in. to over 8 in. dia. | Fine- or coarse grained soils with small amounts of gravel and few cobbles, fairly hard to soft, weakly cemented to loose, above or below water table. | No information for logging or samples for classification; slow in hard or cemented layers. | (1) Used with other methods to advance hole particularly through unstable soils requiring casing. (2) Penetrate fine-grained soils to establish depth to bedrock. (3) Drill holes for ground-water observation. (4) Provide access for sampling and penetration testing of impervious soils above ground water or pervious or impervious soils below. |
| Jetting. | High-velocity water jet directed downward from pipe raised and lowered in short strokes; erodes soil, which is carried upward by water. For holes 2 in. to over 10 in. dia. | Fine- or coarse grained soils; weakly cemented noncohesive, or cohesive, above or below water table. | No information for logging or samples for classification; slow in hard cohesive soils. | Same as (1), (2), and (3) for wash boring. |

## Table 2 (Continued)

| Method | Procedure | Type of soil and inplace condition | Limitation | Use |
|---|---|---|---|---|
| Rotary drilling. | Power rotation of bit, cuttings removed by circulation of drilling mud or water; holes 1½ in. to over 10 in. dia. | Fine- or coarse grained, compact or cemented soils and rock. | No information for logging or samples for classification; difficult in loose, coarse grained soil with cobbles and boulders. | (1) Advance hole. (2) Access for field penetration test (not suitable for well permeameter test or ground-water observation if drilling mud used). (3) Access for disturbed or undisturbed sampling. |
| Rotary drilling. | Power rotation of bit, cuttings removed by circulation of air. Holes 2 in. to over 10 in. dia. | Fine- or coarse grained, compact or cemented soils and rock. | Information for logging and samples for classification, unsatisfactory in loose coarse grained soil with cobbles and boulders. | (1) Advance hole. (2) Access for field penetration test. (3) Well permeameter test. (4) Ground-water observation. (5) Access for disturbed and undisturbed sampling. (6) Advance hole to install casing for nuclear moisture-density probes. |
| Continuous sampling. | Drive-tube boring or rotary drilling (core boring) which provides samples as a result of advancing the hole. | | Depends upon the method selected. | |

Table 3 indicates approximate sample weights of disturbed soil for specific tests. Such samples are recovered by split-spoon sampler or during augering, for example. Sample size by undisturbed soil recovery methods is mostly dictated by the testing needs. Thin steel tube samplers (Figure 1) are available in various stock sizes. The selection for undisturbed sampling is usually from among the following samplers:

a. Fixed piston, e.g., with Shelby tube.

b. Hydraulic piston (drilling fluid required for operation).

c. Free piston.

d. Double-tube, swivel-head, core barrel such as Denison or Pitcher (with circulating drilling fluid).

The requirement for drilling fluid prevents the use of some samplers in granular soils under unsaturated conditions and thus severely reduces their versatility for LLW sites above the water table.

An appropriate source of guidance on sampling in soils and soft rocks is:

> Soil Sampling, Engineer Manual 1110-2-1907, U. S. Army Corps of Engineers, 1972.

Soil samples often need protection from freezing or drying conditions by sheltering in a field storage facility. Undisturbed samples should be scheduled for shipment to the laboratory to minimize the delay between recovery from the borehole and testing in the laboratory.

## Water Studies and Water and Gas Sampling

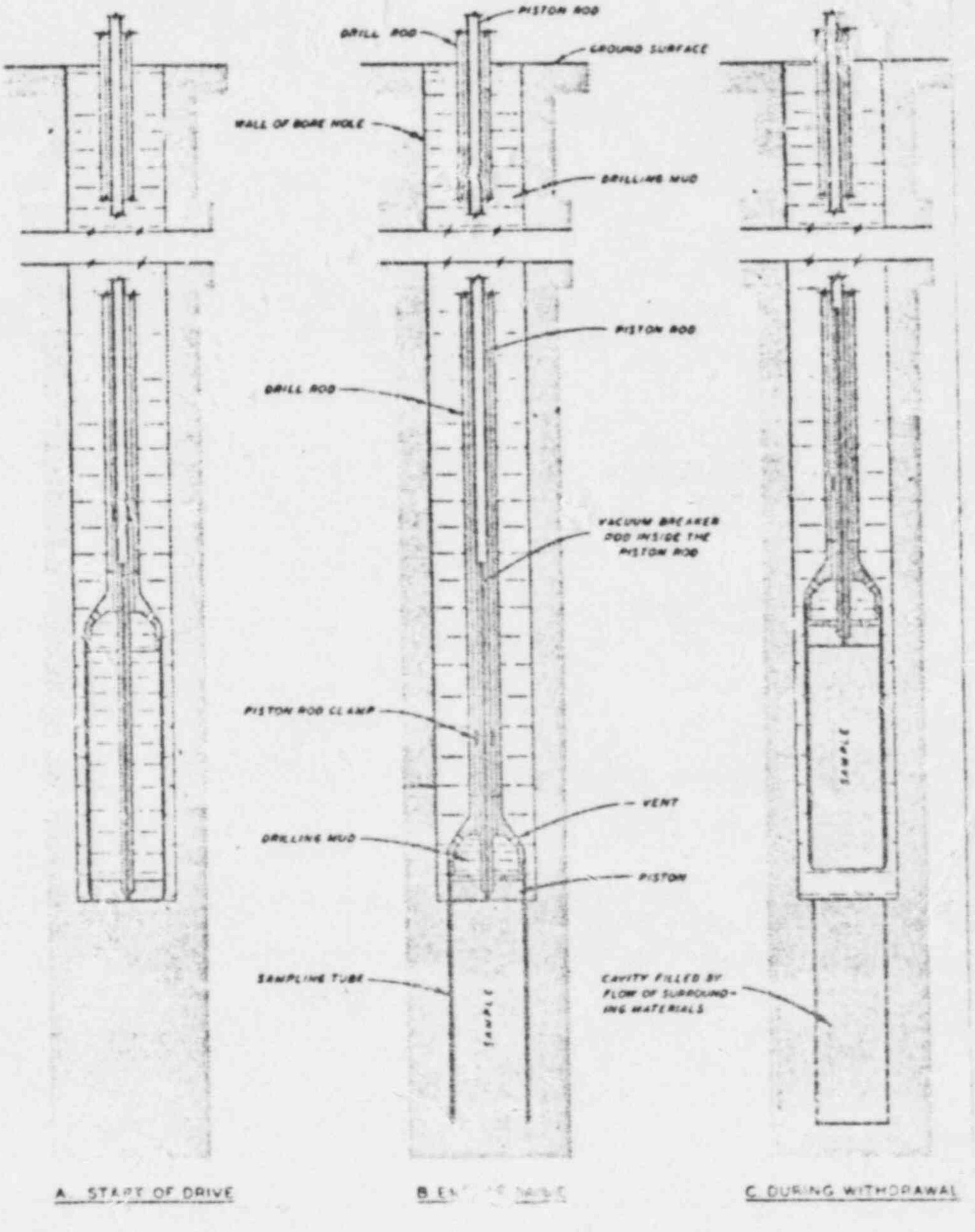
Studies of the surface water system are fairly straightforward and adequately covered in the Appendix and under Meteorological Studies. Emphasis below is on the more complex ground water. Documentation of the ground water system and its characteristics often involves direct measurement of physical conditions in situ. Thus, hydraulic conductivity, transmissivity, and hydraulic head, gradient, or potential, among other parameters, are determined from field measurements. The appropriate tests are identified in the Appendix and thus not reviewed here. Other aspects of ground water as well as surface water are the chemical parameters, and prerequisite to testing for chemical parameters are techniques for sampling.

Techniques of water sampling are not reviewed in the Appendix and, therefore, are reviewed in this section. Water may be recovered separately or along with a sample of the soil or rock. A few of the water quality parameters can be measured in situ and these are especially useful for revealing variability from stratum to stratum. A useful

## Table 3

## Soil Samples Required for Testing and Examination
(from Bureau of Reclamation)

| Tests | Sample size (weight of material smaller than maximum size required) | Maximum particle size required | Application |
|---|---|---|---|
| Classification and description | 1 lb<br>50 lb | No. 4<br>3 in | Field log of exploration holes, describing samples in laboratory. |
| Gradation | 1 lb<br>50 lb | No. 4<br>3 in | Identification and description of soils for estimating properties of foundations. |
| Consistency | 1 lb | No. 40 | |
| Specific gravity | 1 lb<br>5 lb | No. 4<br>3 in | |
| Petrographic analysis<br>Free swell.<br>Microscopic examination. | 5 lb | No. 4 (and representative coarse grains). | Petrographic tests desired when expansive soils are encountered. |
| X-ray diffraction.<br>Differential thermal<br>Thermo balance.<br>Lithologic, photo-micrographic. | | | Petrographic descriptions and analysis desired when unfamiliar soils are encountered. |
| Chemical tests<br>Sulfate content.<br>Soluble salts.<br>Corrosion.<br>Organic content. | 5 lb | No. 4 | Determine chemical composition for recommending type of cement or pipe coating required.<br>Permeability and settlement of foundation influenced by soluble salts and organic matter. |
| Water content | 1 lb<br>5 lb. (water content sample). | No. 4<br>3 in | Determine inplace water content of foundation soils, evaluating penetration tests, comparison of inplace water content with consistency limits; determine degree of saturation and dry unit weight. |
| Relative density | 25 lb<br>100 lb<br>150 lb | No. 4<br>¾ in<br>3 in | Determine 0 and 100% $D_d$ for determination of $D_d$ of foundations. |



A. START OF DRIVE

B. EN[illegible]

C. DURING WITHDRAWAL

Figure 1. Schematic o[illegible] withdrawal of piston sampler (f[illegible] Engineers)

reference providing guidance on water sampling for quantitative studies is:

> ASTM D3370-76, "Standard Practices for Sampling Water," *Annual Book of ASTM Standards: Part 31 - Water*, 11 pp.

The following sections review briefly the techniques for sampling and direct study of water at LLW sites. The details of testing samples are presented in the Appendix.

### Unsaturated zone

Two techniques are available for sampling water in the unsaturated zone.

*Soil analysis.* The soil water in the unsaturated zone may be sampled directly by recovering a sample of the soil with the water included. Pore water sampling in this manner contrasts with sampling of water directly in the field. Sample recovery methods are approximately the same as those used for obtaining soil samples for physical tests. The separation of the water and dissolved constituents from the soil is accomplished later in the laboratory using reagents of differing chemical reactivity. The whole procedure involves a degree of interpretation. A major drawback of this type of water sampling is that a sample is obtained only once, during the boring and sampling process.

*Pressure-vacuum lysimeters.* The pressure-vacuum lysimeter has the important advantage of being a permanent field installation, where repeated sampling can be made over a period of time. The device consists of a porous, ceramic cup capable of holding a vacuum, a small diameter sample accumulation chamber of polyvinyl chloride (PVC) pipe, and two sampling tubes leading to the surface (Figure 2). Once in place and stabilized, the cup is evacuated. Soil water moves into the sampler under the pressure gradient and a water sample gradually accumulates. Then the vacuum is released and pressure is applied, forcing the accumulated water to the surface through the sampling tube.

### Saturated zone

Sampling water below the water table is much more routine than that for the unsaturated zone. Many references are available on the techniques.

*Screened wells.* When the major part of the sampling program is aimed at the unsaturated zone and top of the saturated zone as is usually the case with LLW siting, a well screened over a single vertical section at the top of the saturated zone is suitable for sampling. This method of sampling is the most common for unconsolidated sediments or semiconsolidated rocks. Uncased wells or open holes in consolidated rocks can be used for the same purpose. The single well is not

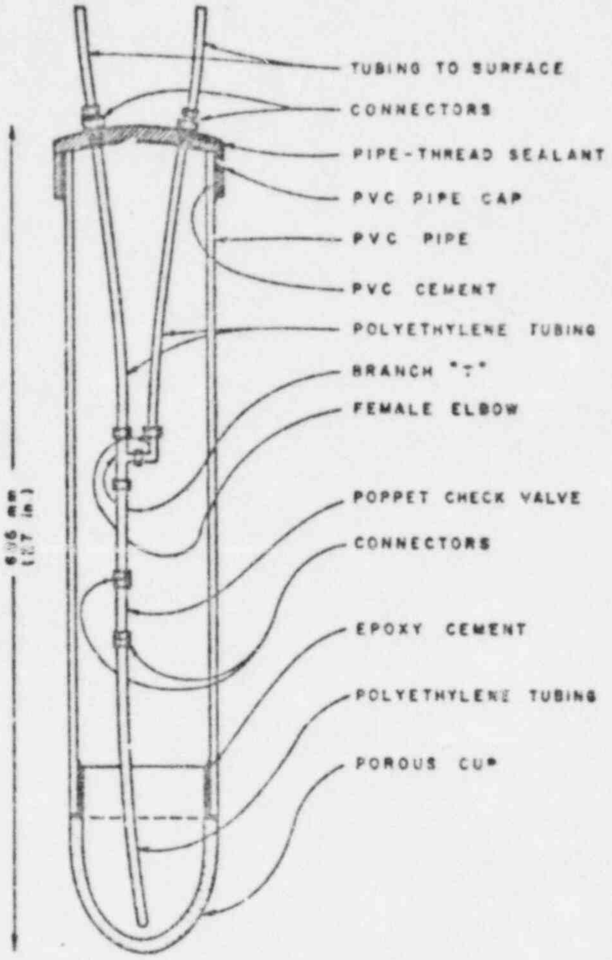
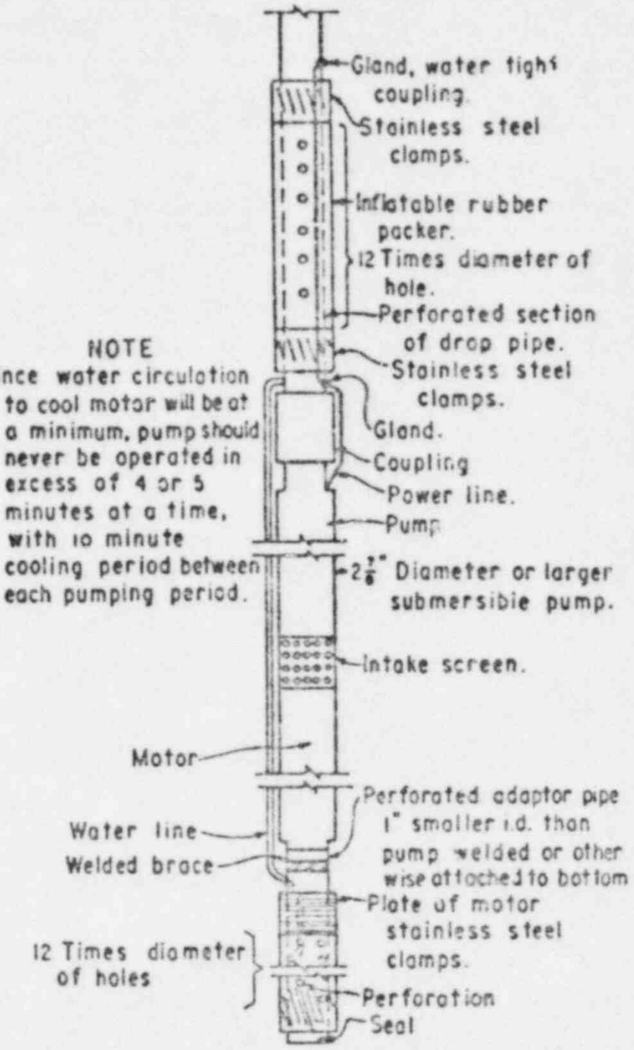


Figure 2. Elements of a modified pressure-vacuum lysimeter installation (from Environmental Protection Agency)

effective in providing information on the vertical distribution (stratification) of contaminants or head.

A well is drilled to an arbitrary depth, usually just below the water table in landfill studies. The screen is positioned to intersect the water table and bracket its expected or possible fluctuation (Figure 3). This type of construction, useful in monitoring, assures that when a contaminant reaches the ground water, it will be detected quickly in the water samples. The drawback of the construction is that only a portion of the aquifer is sampled and only the most recently infiltrated contaminant can be collected. A packer-equipped pump allows for sampling at selected levels in the interval of interest. In some cases the



NOTE
Since water circulation to cool motor will be at a minimum, pump should never be operated in excess of 4 or 5 minutes at a time, with 10 minute cooling period between each pumping period.

Figure 3. Packer-equipped pump for selective sampling of water from wells (from Bureau of Reclamation)

solution will be under partial control of a density gradient and will sink into the ground water. This denser fluid body sinking into fresher water cannot be sampled with a well that skims only the top of the water body. However, great reliance has been placed on this type of well construction to determine the extent of leachate movement into an aquifer.

Because of the emphasis placed on siting LLW facilities in the unsaturated zone, the screened well appears ideally suited for characterization and for establishing a baseline for monitoring. Screened wells are less effective for follow-on observations since information on downward migration or variations in concentration is also needed. The well screened for a single interval near the top of the saturated zone may have a distinct cost advantage over more elaborate methods of sampling such as well clusters, but cost advantage is of secondary importance.

Well clusters. Clusters of sampling points within a well or in groups of wells provide the answer to define a vertical distribution of a pollutant and, therefore, can also be useful in establishing a chemical baseline during site characterization. Well clusters are by far the most common and successful technique to date for delineating stratification of contaminants in ground water. Figure 4 illustrates the two common configurations. Each cluster consists of a group of closely spaced small-diameter wells completed at different depths, in one or more aquifers. From these depth intervals water samples are representative of the different horizons.

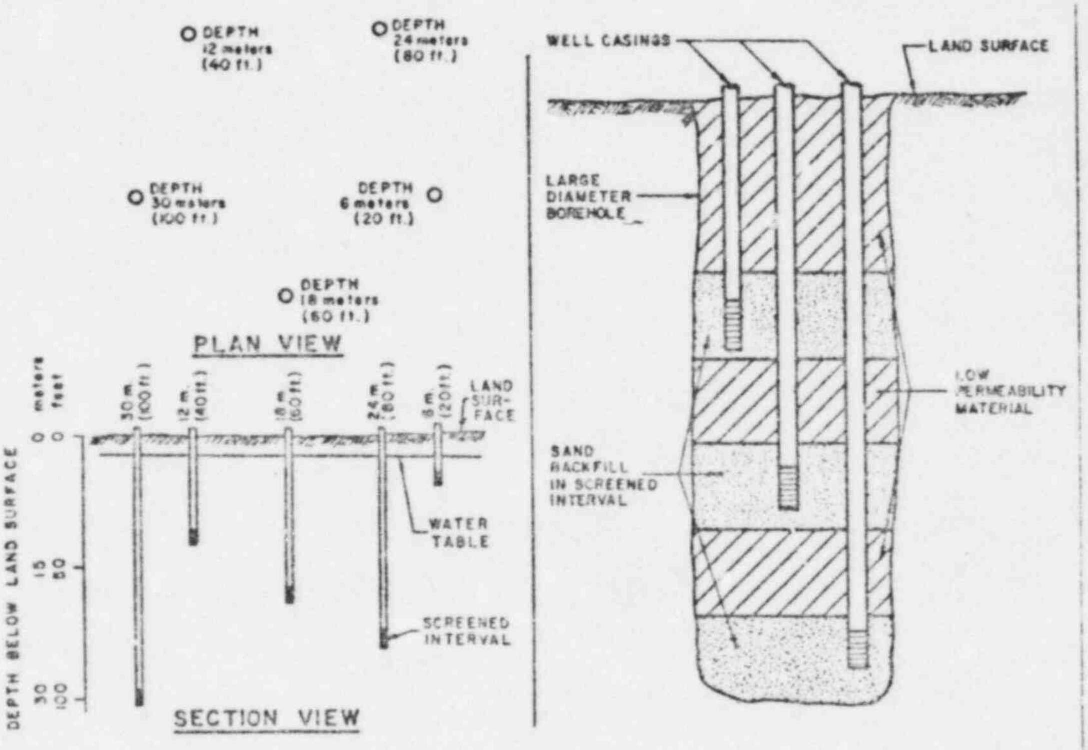


Figure 4. Typical well cluster configurations (from Environmental Protection Agency)

Seeps and springs. Seeps and small springs are convenient points for measuring and sampling shallow ground water. Activity of seeps may vary substantially over a period of time; i.e., flow rate changes reflect the influence of seasons and fluctuations caused by storms. In northern states the melting of snow can affect seep activity and contaminant concentrations. As long as these limitations are appreciated, springs, seeps, and small ponds are useful sources for directly observing and sampling this small part of the ground water flow system.

*In situ testing.* Certain characteristics of the ground water and pore water can be measured in situ within boreholes or in springs at the surface to indicate the chemistry of the water. Two parameters which can be readily measured in situ are specific conductance and temperature. Both of these parameters have been used effectively in investigating leachate from landfills since leachate is generally higher in specific conductance and temperature than natural ground water. Accordingly, the background or baseline values are also needed for site characterization. The measurements are made by use of remote-sensing probes lowered into the well. Measurements can also be made in standing or flowing water at the ground surface, though temperature would be less meaningful in this situation. Figure 5 shows the essential components of one probe for specific conductance and temperature.

Electrical resistivity surveys are among the most useful means of characterizing the chemistry of the ground water as well as that of the soil. The state-of-the-art procedure is described in the Appendix.

### Gas sampling

Methane and other gases moving within the site media may pose hazards of explosiveness or an even greater threat of conveying dangerous radionuclides to the atmosphere. Methods of sampling for baseline and detection phases of monitoring at a LLW site should follow routine procedures for air sampling to the extent possible. A useful reference providing guidance on sampling is:

> ASTM D1605-60 (Reapproved 1979), "Standard Recommended Practices for Sampling Atmospheres for Analysis of Gases and Vapors," *Annual Book of ASTM Standards: Part 26 - Gaseous Fuels; Coal and Coke; Atmospheric*, 22 pp.

Samples for site characterization and monitoring can be taken most directly from the subsurface media through boreholes. Such sampling is confined to the unsaturated zone into which gas migration is restricted. A strategy of sampling the more porous and permeable strata is appropriate; permeable zones will not only be the preferred paths of gas movement but they will also be easier to sample. Such zones can be isolated and sampled by the use of inflatable packers which effectively seal off the remainder of the hole during sampling.

Equipment and techniques are available for directly monitoring and detecting escape of gases. A portable sensing probe is widely used to detect methane in soil or confined air spaces. The specific beta radioactive isotopes carried in the migrating gases cannot be measured

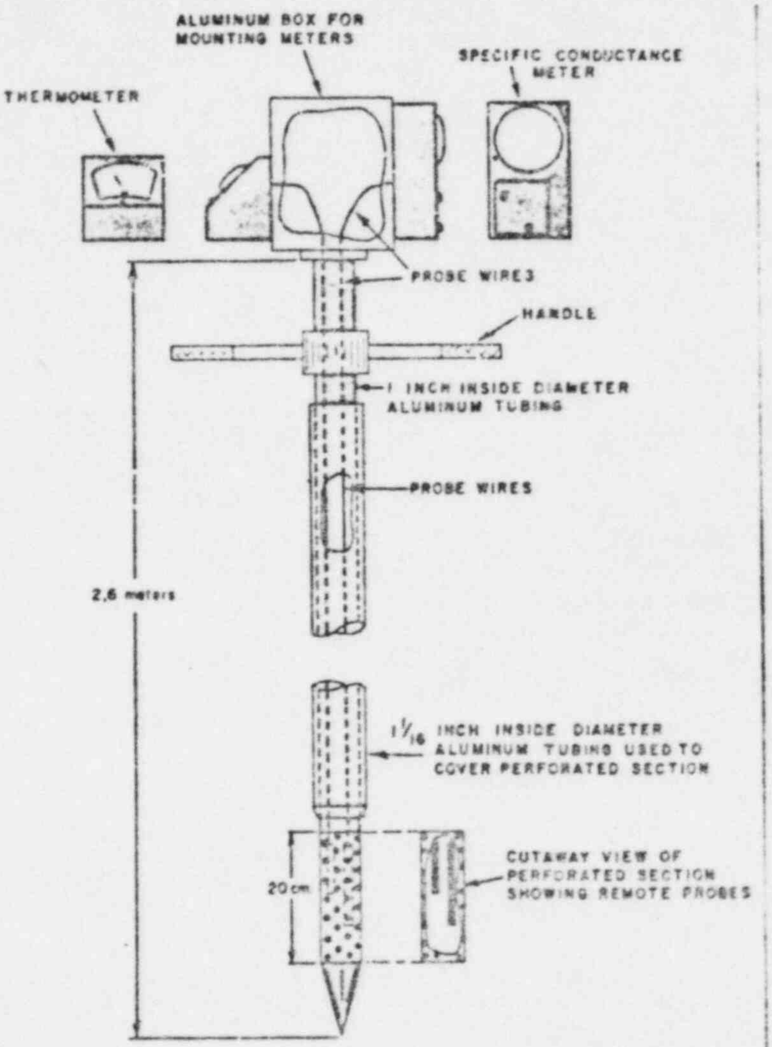


Figure 5. Schematic of probe for specific conductance and temperature (from Environmental Protection Agency)

directly in situ. The only feasible method for $^3$H and $^{14}$C is by sampling the gas or gas-filled soil.

## Meteorological Studies

Data on meteorology and associated runoff for a LLW site may be obtained from measurements at stations onsite and from the measurements recorded previously at nearby stations. Onsite station sources depend on the situation and configuration of the site and on the specific needs. Important aspects of locating a meteorological station are reviewed here as a supplement to identification of instrumentation and measurement techniques in the Appendix.

## Weather stations

Ideally the catch of a rain gage represents the precipitation falling at that point and on the surrounding area. Such a direct correspondence is difficult to obtain in practice, however, because of the effect of the wind. Precautions to minimize wind effects include the location of the gage on level ground at a distance of four times the height of a nearby object (including the instrument shelter) above the top of the gage. Rain gages should not be installed on roofs. Diffuse objects such as shrubs and orchards that reduce speed, turbulence, and eddy currents can be useful screens that improve accuracy of rain gages.

For surface temperature measurements a thermometer screen or instrument shelter should be used to minimize radiant heat while allowing air to move freely past the instrument. The shelter should be positioned on ground representative of the site but away from obstructions and at least 30 m from any extensive concrete or paved surface. Rough terrain and air drainage should be avoided because of nonrepresentative temperatures.

The principal concern with locating barometers for atmospheric pressure measurements is for the continued accurate operation of the instruments. The location should be clean relatively dry, and maintained at a steady temperature as nearly as possible. Vibrations and jarring are to be avoided. An inside wall is preferred partly to avoid appreciable changes in temperature. Wind effects on buildings causing pressure changes inside should be avoided also.

Anemometers and vanes should be positioned 6 m above the ground on a freely exposed tower above terrain that is relatively level and free from obstructions to air flow. Certain topographic effects and obstructions are known to create appreciable updrafts, downdrafts, eddy currents, or jet flow effects. Such terrain and obstructions should be avoided or the measuring equipment should be located well above them.

## Stream gaging

Despite the long records of stream gaging stations already available for use at many locations around the country, a station may be needed at the LLW site. The presence of just one major tributary between the site and an existing gaging station means that the station is remote and maybe only indirectly useful, i.e., useful for estimating drainage basin behavior in the regional setting. Accordingly it will commonly be concluded that a stream gaging station is needed to generate site-specific data useful for predictions of flood frequency and recurrence interval, average annual flows, and low flows as well as for verification of hydrological simulation. Where the decision is made to establish a gaging station onsite, preparations should proceed expeditiously. The longer the record of flows, the more useful it will be. At best, the record will be relatively short and correlations with long records from established gaging stations will be needed for some purposes. This process of comparison usually encounters adverse scale effects between the large and small drainage basins as well as subtle but sometimes important differences in geology, physiography, vegetation, and land use between the LLW site and the basin represented by the existing gaging station.

Regardless of the problems and limitations of establishing a need for a stream gaging station, the location and actual installation is fairly straightforward. The system and instrumentation for the relatively small streams and watersheds surrounding LLW sites are identified in the Appendix. One logical location for a station is where all surface runoff from the extended site merges into the main stream, usually just downstream from a tributary. A record of measurements at this point can be translated into estimates of floods and runoff rates for the encompassing basin as well as for hydrological simulation and estimates of contaminant dilution useful to monitoring.

Gaging points will also be useful within the immediate site area for verifying actual runoff in comparison to predicted values on the microscale. These data would allow more precision and confidence in designing the disposal units and cover and the drainage features. When positioned near the immediate site boundary and supplemented with chemical testing, these points document the quantity and quality of the water crossing the boundary. Such documentation can have legal as well as technical importance when the background characteristic of the site is compared with monitoring results.

## Surveying Program

The proposed rule 10 CFR 61 (61.52) specifies that boundaries of each disposal unit must be accurately located and mapped by means of a land survey. Near-surface disposal units must be marked in such a way that the boundaries can be easily relocated and defined. Three permanent control points referenced to U. S. Geological Survey or National Geodetic Survey control stations must be established on the site to facilitate surveys.

Horizontal and vertical survey control is established nationwide by a network of control arc, referenced to the North American 1927 datum for horizontal control points and the sea level datum of 1929 for vertical control points. Arcs of this basic network have been placed about 100 km apart throughout the country using first-order triangulation, precision electronic traverses, and first-order differential levels. A supplementary network is usually established by second-order survey procedures between the basic control arcs. Ultimately the spacing between stations of either the basic or supplementary network is on the order of 10 km. Leveling benchmarks are often located at intermediate positions.

Auxiliary networks are established by second- or third-order survey procedures to provide horizontal and vertical control in any immediate areas. Unless a supplementary network station falls on the LLW site, it will be expected that a survey comparable to that of an auxiliary network will be needed to establish horizontal and vertical control on the site including the three permanent monuments.

One of the final steps of site surveying involves the location of detailed points relative to the survey lines and stations. Detailed points would include the corners of trenches and points for profiles or for settlement detection.

It is important to adhere to the concept that the main control scheme such as the auxiliary network brought onto the site must have stations established to the degree of accuracy required for the purpose of the survey. When the main control scheme must be run first, it should be of an accuracy to permit the follow-on survey including detail points to furnish the proper accuracy for the detail desired. For example, if third-order accuracy is required for the detail and if control must be extended for a long distance, the starting control must be of sufficient accuracy to allow this extension without falling below the third-order requirement upon reaching detail points.

Plane coordinate systems have been developed and used in many states as control for locating and surveying property lines and civil projects. Sufficient control points are provided in such systems so that local projects can be tied in by plane surveying methods with a geodetic adjustment. For a description of the coordinate systems used in several of the states refer to:

> The State Coordinate Systems (A Manual for Surveyors), Special Publication 235, U. S. Coast and Geodetic Survey, 1945 (revised 1974), 62 pp.

## PART III: LABORATORY AND FIELD MEASUREMENTS AND OFFICE STUDIES

Laboratory and office investigations are conducted independently or supplementally to field investigations. Many of the tests for engineering and physical properties and most of the chemical tests are accomplished in the laboratory; however, some are more representative when accomplished in the field. The office studies are usually coordinated with the laboratory studies and are essential for the interpretation and averaging of data and for correlations for materials and site conditions. The following sections on testing of engineering, hydrological, and geochemical properties and constituents are brief summaries with emphasis on the sources of information on procedures. The details of test methods are provided in the Appendix.

### Engineering Properties

Critical factors in testing for engineering and index properties of soils and rocks are the laboratory facilities and the qualifications of the personnel. The technicians performing the tests must be thoroughly familiar with the apparatus, the testing procedures, and good laboratory techniques. The technicians must be conscientious in the handling of soil and must appreciate the purpose of each test they perform. Neat, thoughtful work with the recording of all test data and a continuous watchfulness for irregularities can prevent most errors. The philosophy should be that one good test is not only far better than many poor tests, but is also less expensive and less likely to permit a misjudgment in design.

Among the characteristics of good laboratory facilities are a ground floor or basement location with a solid floor. Freedom from vibrations from traffic and machinery is important. Separate areas should be designated for dust-producing activities such as sieve analysis and sample processing. Temperature control of the entire laboratory is to be preferred. A humid room large enough to permit storage of samples received from the field is desirable; a humid room is also useful for preparation of undisturbed test specimens.

Satisfactory test procedures are presented in the following important publications on laboratory testing:

> Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970.
>
> Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 1982.
>
> Earth Manual, 2nd Ed., U. S. Department of the Interior, Bureau of Reclamation, 1974.

Soils test methods recommended in the Appendix for LLW site characterization are taken mostly from these sources.

## Hydrological Parameters

The measurement of hydrological parameters is often conducted in the field as well as in the laboratory. In fact there is a prevailing opinion that hydraulic conductivity and other hydrological parameters determined in the field are more representative than laboratory determinations. Among the laboratory testing techniques, some are routine for soils testing and would more likely be accomplished in the soils testing laboratory than elsewhere. In any case, the usual concern for laboratory facilities and technical experience of personnel is of great importance.

Among the most important field techniques for measurement of hydrological properties are those that depend upon accurate records of the response of wells to pumping, water injection, and introduction of tracers. Piezometers are particularly important. The following publications provide useful guidance on observations and measurements for hydrological study purposes:

> National Handbook of Recommended Methods for Water-Data Acquisition: Chapter 2 - Ground Water, U. S. Department of the Interior, Geological Survey, 1977.
>
> Ground Water Manual, U. S. Department of the Interior, Bureau of Reclamation, 1977 (revised reprint 1981).
>
> Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 1982.

## Geochemical Properties and Constituents

Several references are recommended for providing guidance on the analysis of chemical constituents and properties of water and other natural materials at the site. In choosing the specific test methods for the Appendix, consideration has been given to the sensitivity, precision, and accuracy required and the expected high technical experience of the analyst. Two useful references providing guidance on such requirements in general are available:

> ASTM D3856-80, "Standard Guide for Evaluating Laboratories Engaged in Sampling and Analysis of Water and Waste Water," Annual Book of ASTM Standards: Part 31 - Water, 8 pp.

ASTM D3614-77, "Standard Practice for Evaluating Laboratories Engaged in Sampling and Analysis of Atmospheres and Emissions," Annual Book of ASTM Standards: Part 26 - Gaseous Fuels; Coal and Coke; Atmospheric, 10 pp.

Some of the testing will be accomplished in the laboratory, in which case the sample preparation and handling may be particularly critical. Generally, analysis should be performed as soon after sampling as is practicably possible. Other tests have the advantage of being conducted in the field with no loss of reliability. Among such tests are those for pH, oxidation-reduction potential, specific conductance, turbidity, dissolved oxygen, and specific ions by means of specific ion electrodes. Similarly, some evaluations of radioactivity are conducted in the field.

Five publications are particularly useful in the subject area of chemical testing, particularly for surface water and ground water:

Standard Methods for the Examination of Water and Wastewater, 15th Ed., American Public Health Association, 1980.

Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, U. S. Environmental Protection Agency, 1979.

Annual Book of ASTM Standards: Part 31 - Water, 1982.

National Handbook of Recommended Methods for Water-Data Acquisition: Chapter 5 - Chemical and Physical Quality of Water and Sediment, U. S. Department of the Interior, Geological Survey, 1977.

Techniques of Water-Resources Investigations: Chapter A5, Book 5, Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, U. S. Department of the Interior, Geological Survey, 1977.

## Material Indices and Correlations

A highly useful investigational technique for the experienced engineer or scientist involves the inferences or projections that can be made from readily available data such as index test results. Correlations may be the only way of inferring the previous history of a site in the case of meteorological parameters known only for the closest weather station (in comparison to a station located onsite for a relatively short period of time). Elsewhere the vast experience of the engineering profession in correlating mechanical behavior of soil with certain simple index parameters is a source of useful details which should not be overlooked. For example, the widely used hazen correlation provides a means of roughly estimating permeability of granular media indirectly from grain-size data. Some of this interpretation based on known relationships or personal experience forms a core of the geological field investigations, but correlations should be explored further by repetition in the office where an extensive synthesis and review of previous testing and literature can be accomplished.

Indices may also be correlated or used in conjunction with less abstract test data. For example, site details manifested as material colors and distinguished by differences in color may be found to be reflective also of physical properties.

## Previous Studies and Records

The site characterization stage of LLW facility siting provides an opportunity for reviewing in detail the data available in the form of reports and records. Much of this sort of review will have been accomplished during site selection, but the greater intensity of effort during site characterization will focus attention on details. For example, it may have been concluded by this time that geological characteristics and topographic setting of the LLW site are essentially the same as those existing at a construction site or along a highway some distance away. Therefore foundation investigations and material characteristics from these projections can be applied confidently and used to supplement the knowledge generated by detailed studies accomplished at the LLW site (see photograph, page x).

One of the most useful collections of records is available in the readily available source:

> Climatological Data, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, monthly reports.

Known records of precipitation and temperature as well as other climate parameters are available for many locations. To the extent that a nearby weather station mirrors the details needed at the LLW site, its record is directly useful. Similarly the details of surface runoff available at nearby stream gaging stations of the national network are often directly useful. Again where a prior history is needed for characterizing the site or for making hydrological predictions, this source may be the only one for long-term records.

The following list can be used for checking documentary material that should be reviewed as a part of the office studies:

a. Soil surveys.

b. Geologic reports and other geological literature.

c. Site engineering reports.

d. Water well records and water supply reports.

e. Oil well records.

f. Hydrological and tidal data and flood records.

g. Climate records.

h. Mining records and reports.

i. Historical earthquake and other seismic records.

j. Newspaper accounts of landslides, floods, earthquakes, subsidence, and other significant events.

k. Records of landfills and other disposal facilities.

l. Topographic maps.

# PART IV: SUMMARY

Numerous parameters and parameter groups were identified as potentially important characteristics of LLW sites in the previous report. The methods of testing or documenting these characteristics are presented in this report. All tests and procedures for measuring, observing, and documenting are listed in Table 4. This table concisely summarizes all methods discussed in the Appendix. To obtain representative values and other data, it is necessary to conform to established, widely recognized general procedures for field investigations, sampling, and testing, in addition to the specific requirements of the individual standard or state-of-the-art test methods.

## Table 4

## Recommended Testing and Documentation to Characterize LLW Sites

| | Test or Document by Type of Method | | | |
|---|---|---|---|---|
| Parameter | Standard Method | Formalized Guidance | Existing Data | Remarks |
| Air pressure | ASTM | -- | -- | -- |
| | -- | Barometer observations | -- | -- |
| | -- | -- | Weather records | -- |
| Air temperature | -- | Thermometer observations | -- | -- |
| | -- | -- | Weather records | -- |
| Anisotropy | -- | -- | Geological criteria | -- |
| | -- | -- | Permeabilities | Calculated from $K_V$ and $K_H$ |
| Apparent velocity | -- | Tracer studies | -- | -- |
| Atterberg limits | ASTM | -- | -- | -- |
| | CE | -- | -- | -- |
| Burial unit boundaries | -- | Plane surveying | -- | -- |

(Continued)

NOTE: ASTM = American Society of Testing and Materials; CE = Corps of Engineers; APHA = American Public Health Association; EPA = Environmental Protection Agency; GS = Geological Survey; BR = Bureau of Reclamation; DE = Department of Energy; and NOAA = National Oceanic and Atmospheric Administration.

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Collapse susceptibility | CE | -- | -- | -- |
| | -- | -- | Geological criteria | -- |
| | -- | -- | Grain-size data | Empirical correlation |
| Compaction relation | ASTM | -- | -- | -- |
| Consolidation relation | CE | -- | -- | -- |
| Dispersion | -- | Breakthrough curves | -- | Column or field test |
| Electrical resistivity | -- | Total salinity of soil | -- | -- |
| | -- | Surface resistivity survey | -- | -- |
| | -- | Borehole resistivity survey | -- | -- |
| | -- | -- | Specific conductance | -- |
| Erodibility parameters | CE | -- | -- | -- |
| | -- | -- | Agronomical criteria | -- |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Evapotranspiration | -- | Evaporimeter or lysimeter observations | -- | -- |
| | -- | -- | Weather records | Empirical calculations |
| Extended site boundary | -- | -- | Technical review | -- |
| Flow direction | -- | Tracer studies | -- | -- |
| | -- | -- | -- | Calculated from K and $\phi$ data |
| | -- | -- | Well data | One horizon only |
| Frost heaving | -- | -- | Geological criteria | -- |
| | -- | -- | Grain-size data | Empirical correlation |
| Gaseous constituents | APHA | -- | -- | -- |
| | ASTM | -- | -- | -- |
| Geomorphology | -- | -- | Geological criteria | -- |
| Grain-size distribution | CE | -- | -- | -- |
| | ASTM | -- | -- | -- |
| | -- | -- | -- | Parameters calculated from distribution curve |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Ground water chemistry | APHA | -- | -- | -- |
| | EPA | -- | -- | -- |
| | ASTM | -- | -- | -- |
| | GS | -- | -- | -- |
| | -- | Gas chromatography (organics) | -- | -- |
| Ground water system and boundaries | -- | -- | Geological criteria | -- |
| Hydraulic conductivities | ASTM | -- | -- | -- |
| | CE | -- | -- | -- |
| | BR | -- | -- | -- |
| | -- | Pump tests | -- | -- |
| | -- | -- | Geological criteria | -- |
| | -- | -- | Grain-size data | Granular soil only |
| Hydraulic potentials and pressures | -- | Wells | -- | -- |
| | -- | Piezometers | -- | -- |
| Immediate site boundary | -- | Technical review | -- | -- |
| | -- | -- | -- | Conformance to regulatory/legal constraints |
| Infiltration capacity | ASTM | -- | -- | -- |
| | -- | -- | Curve number estimation | -- |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Ion exchange capacity | -- | Saturation method | -- | -- |
| | -- | Mehlich method | -- | -- |
| Lithology and soils | -- | -- | Geological criteria | -- |
| Material color | ASTM | -- | -- | -- |
| | -- | Color chart | -- | |
| Material densities | ASTM | -- | -- | -- |
| | CE | -- | -- | -- |
| | -- | Gamma-gamma logging | -- | -- |
| Material radioactivity | -- | Borehole gamma survey | -- | -- |
| | -- | Gamma spectral logging | -- | -- |
| | ASTM | -- | -- | -- |
| | DE | -- | -- | Mostly near surface |
| Material temperature | -- | Thermistor | -- | -- |
| | -- | -- | Water temperature | -- |
| Material variability parameter | -- | Standard deviation | -- | -- |
| | -- | Range | -- | -- |
| Material zone boundaries | -- | Detailed logging, sampling, and analysis | -- | -- |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method<br>Standard Method | <br>Formalized Guidance | <br>Existing Data | Remarks |
|---|---|---|---|---|
| Mineralogy and clay mineralogy | ASTM | -- | -- | -- |
| | -- | X-ray diffraction | -- | -- |
| | -- | Petrography | -- | -- |
| Monument and point positions | N | -- | -- | -- |
| | | Plane surveying | -- | -- |
| | | -- | Control surveys and grids | -- |
| Oxidation-reduction potential | -- | Platinum/hydrogen electrode | -- | -- |
| | -- | -- | Geological criteria | Based on color |
| Partition coefficients | -- | Batch leach | -- | -- |
| | -- | Column test | -- | -- |
| | -- | -- | Geochemical criteria | -- |
| Penetration parameter | ASTM | -- | -- | -- |
| Permeability function | -- | Instantaneous profile | -- | Hysteresis is usually ignored |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method<br>Standard Method | <br>Formalized Guidance | <br>Existing Data | Remarks |
|---|---|---|---|---|
| Pore water age | -- | Radioisotopic ratios | -- | Contract the analysis and interpretation to a qualified laboratory |
| | -- | Stable isotopes | -- | Contract the analysis and interpretation to a qualified laboratory |
| | -- | Conductivity | -- | -- |
| | -- | Ground water chemistry | -- | -- |
| Porosities and void ratio | CE | -- | -- | -- |
| | -- | Acoustic logging | -- | -- |
| | -- | Nuclear logging | -- | -- |
| | -- | -- | Geological criteria | Especially for fracture porosity |
| Precipitation | -- | -- | Weather records | -- |
| | -- | Rain gage | -- | -- |
| Rebound index | CE | -- | -- | Related to Consolidation relation |
| | -- | -- | Geotechnical criteria | -- |
| Recharge and discharge areas | -- | -- | Geological criteria | -- |

(Continued)

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Rock classification | ASTM | -- | -- | -- |
| | -- | Durability test | -- | -- |
| | -- | -- | Seismic velocity | Soundness correlation |
| | -- | -- | Core logging indices | -- |
| Runoff | -- | Stream gaging | -- | -- |
| | -- | -- | Curve number estimation | -- |
| | ASTM | -- | -- | -- |
| Seepage velocity | -- | -- | -- | Calculated from K and $n_e$ |
| | -- | Tracer studies | -- | Requires adjustment for retardation |
| Seismic velocity | -- | Surface survey | -- | -- |
| | -- | Borehole survey | -- | -- |
| Shrinking-swelling parameter | ASTM | -- | -- | Related to <u>Consolidation relation</u> |
| | -- | -- | Geological criteria | -- |
| Soil classification | ASTM | -- | -- | -- |
| | -- | Soil taxonomy | -- | -- |
| | -- | Textural method | -- | -- |

(Continued)

Table 4, Concluded

| Parameter | Test or Document by Type of Method |  |  | Remarks |
|---|---|---|---|---|
|  | Standard Method | Formalized Guidance | Existing Data |  |
| Suction pressures | -- | Tensiometer | -- | -- |
|  | -- | Psychrometer | -- | -- |
|  | -- | Porous element | -- | -- |
| Surface water chemistry | -- | -- | -- | Same as for <u>Ground water chemistry</u> |
| Surface water system and boundaries | -- | -- | Geological criteria | -- |
| Transmissivity | -- | Pump test | -- | -- |
| Visual description | ASTM | - | -- | -- |
| Water content | ASTM | -- | -- | -- |
| Water-holding parameters | -- | -- | Agronomic data | -- |
|  | -- | -- | Suction pressure function | At defined pressures |
|  | -- | -- | -- | Same as <u>Storativity</u> |
| Water zone boundaries | -- | Borehole logging | -- | -- |
|  | -- | Water table measurements | -- | -- |
|  | -- | -- | Water contents | -- |
| Wind speeds and directions | -- | -- | Weather records | -- |
|  | -- | Anemometer and vane | -- | -- |

Table 4, Continued

| Parameter | Test or Document by Type of Method | | | Remarks |
|---|---|---|---|---|
| | Standard Method | Formalized Guidance | Existing Data | |
| Soil organics | -- | Sample ignition | -- | -- |
| Soil pH and acidity | ASTM | -- | -- | -- |
| | -- | Titration | -- | -- |
| Soil solubles | EPA | -- | -- | -- |
| | APHA | -- | -- | -- |
| Specific gravity | ASTM | -- | -- | -- |
| | CE | -- | -- | -- |
| Storativity | -- | Pump test | -- | -- |
| | -- | Neutron logging | -- | -- |
| | -- | -- | -- | Can be estimated |
| Stratigraphy | -- | -- | Geological criteria | -- |
| Strength | CE | -- | -- | -- |
| Structure | -- | -- | Geological criteria | -- |
| Suction pressure function | ASTM | -- | -- | -- |

(Continued)

# APPENDIX: LISTING OF TESTS AND OTHER MEANS OF DOCUMENTATION

In this Appendix the tests and other methods of documenting or quantifying important site parameters are presented individually.* The formalization of methods by the engineering and scientific communities ranges from step-by-step standard methods such as are suitable for controlled laboratory testing, through formal guidance on procedures and equipment, particularly for field testing, to state-of-the-art methods. The least formal methods of documentation such as involved in geological studies depend heavily on the expertise of the investigator rather than conformance to a set procedure. The reader should consider this diversity of approaches while studying this Appendix. The contents of this Appendix are summarized in Table 4 of the main text.

Before embarking on a formal testing program to characterize a site, the prospective applicant should review each parameter and parameter group carefully for pertinence of site materials, ground water regime, and configurations in the context of LLW disposal as explained in the Task 1 report (NUREG/CR-2700). As was concluded in that report, some parameters will be found to be adequately quantified from existing information, while others can be considered on a qualitative basis in combination with good engineering judgment. For those remaining cases where testing is found warranted, the procedures in this Appendix are recommended.

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* The arrangement is by parameters and parameter groups in alphabetical order.

## Air Pressure

Air pressure information is routinely compiled by and available from the National Weather Service. This source of data may be adequate for most purposes. Where a local weather station is established, the preference of the NRC (NUREG-0902) is for a continuously recording instrument, usually an aneroid barometer. Somewhat greater accuracy is expected from intermittent observations of a mercury barometer, and accordingly a mercury barometer is recommended by the National Weather Service for general purposes. The following standard and guidance are recommended:

> ASTM D3631-77, "Standard Methods for Measuring Surface Atmospheric Pressure," Annual Book of ASTM Standards: Part 26 - Gaseous Fuels; Coal and Coke; Atmospheric, 7 pp.
>
> "Measurement of Atmospheric Pressure," Section 10.E.2, National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 10-34 to 10-44.

## Air Temperature

Air temperature information is routinely compiled by the National Weather Service based on observations at numerous stations throughout the nation. This source of data may be adequate for regional and average characteristics. The published source is:

> Climatological Data, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, monthly reports.

Daily temperature information is available on tape from:

> National Weather Service, Asheville, North Carolina.

Where a local weather station is established, the NRC prefers (NUREG-0902) a continuously recording instrument, such as a mercury-in-steel thermometer. The following sources of guidance are recommended:

> "Measurement of Temperature," Chapter 4, Guide to Meteorological Instruments and Observing Practices, 2nd Ed., World Meteorological Organization, 1970, pp IV.1 to IV.6.
>
> "Surface Temperature," Section 10.C.2, National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 10-11 to 10-19.

## Anisotropy

Anisotropy of a material or material zone is usually quantified in terms of another parameter. The most important anisotropy at LLW sites is in regard to coefficients of permeability, most commonly the ratio of the horizontal permeability to the vertical permeability $K_H/K_V$ .* Thus the anisotropy ideally is based on separate tests for $K_H$ and $K_V$ . It is common practice, however, particularly in the formative and even analytical stages of site investigation, to estimate anisotropy based on the stratigraphy and lithology of the zone. In horizontally bedded silt $K_H/K_V$ may range from 10 to 1000. The source of such estimates usually lies in the experience of local geological and engineering offices and should be based on cases that have been or can be substantiated, preferably by laboratory or field tests.

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* Stratification usually provides the frame of reference so that anisotropy is inclined within inclined strata.

## Apparent Velocity

Apparent velocity is the seepage velocity as measured from tracer studies. There is no standard method for measurement of apparent velocity, but the several procedures recommended in the following reference are appropriate for LLW site characterization.

> "Measurement of Ground-Water Flow Velocity," Section 7.4.2, Ground-Water Studies, United Nations Educational, Scientific, and Cultural Organization, Paris, 1977, pp 7.4.3. to 7.4.7.

## Atterberg Limits

Standard methods for determining Atterberg limits of fine-grained soil are provided as follows:

> "Liquid and Plastic Limits," Appendix III, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp III-1 to III-20.
>
> "One-Point Liquid Limit Test," Appendix IIIA, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp IIIA-1 to IIIA-3.
>
> "Shrinkage Limit Test," Appendix IIIB, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp IIIB-1 to IIIB-9.
>
> ASTM D423-66 (Reapproved 1972), "Standard Test Method for Liquid Limit of Soils," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 4 pp.
>
> ASTM D424-59 (Reapproved 1971), "Standard Test Method for Plastic Limit and Plasticity Index of Soils," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 2 pp.

The Corps of Engineers (CE) procedures are preferred for LLW site characterization for two reasons. First, their applicability extends to argillaceous rocks such as may occur at LLW sites. Second, the conditions of the CE procedures depart less from field conditions. The ASTM procedures require air drying and no subsequent curing prior to testing. Either source (ASTM or CE) may be used, but differences in detail, such as a difference in the groover for liquid limit, make it imperative that the chosen procedure be identified and followed judiciously.

## Burial Unit Boundaries

Burial unit boundaries constitute a site parameter that enters into analysis and design of the facility. Locations are to be sufficiently accurate not only to plan and construct the facility properly but also to integrate the waste units into the geological setting and thereby utilize the setting for optimum containment. The intersections of material zone boundaries with burial unit boundaries should be retrievable from the survey data.

The corners of the burial units should be identified before and during operation and permanently marked upon completion of filling. Offset markers are preferable where subsidence may threaten the permanence. Each marker should be individually numbered and a log kept of the date of installation and the coordinates referenced to a site grid system. This positioning is to be accomplished using plane surveying techniques appropriate to achieving accuracy of ±1 cm vertically and ±10 cm horizontally. Information on surveying practice is provided under Monument and Point Positions.

## Collapse Susceptibility

Settlement due to collapse of soil structure can be evaluated from consolidation tests (see Consolidation Relation). Components of collapse due to saturation and surcharging can be evaluated separately with this method.

General methods of recognizing collapsible soils and predicting their performance have been summarized recently (Clemence and Finbarr 1981) along with a number of pretreatment techniques that may be applicable to portions of LLW sites underlain by collapsible soils but not critically situated. Confirmation of a well-defined collapse susceptibility in the vicinity of disposal units by testing or through local experience or inference would usually be so serious as to favor abandonment of the site rather than pretreatment to correct the problem. Such a dramatic site deficiency is anticipated to be exceedingly rare.

### Reference

S. P. Clemence and A. O. Finbarr, "Design Considerations for Collapsible Soils," Journal, Geotechnical Engineering Division, American Society of Civil Engineers, pp 305-317, 1981.

## Compaction Relation

The laboratory compaction test is simply intended to determine the moisture-density relation of a particular soil. The relation varies with compactive effort. Field compaction for construction is usually controlled by specifying minimum desired density and the range of moisture content (water content) within which that density can be obtained. The moisture-density relation may be obtained by one of the following standard procedures:

> ASTM D698-78, "Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 5.5-lb (2.49 kg) Rammer and 12-in. (305-mm) Drop," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 7 pp.
>
> ASTM D1557-78, "Standard Test Methods for Moisture-Density Relations of Soils and Soil-Aggregate Mixtures Using 10-lb (4.54 kg) Rammer and 18-in. (457-mm) Drop," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 7 pp.

The lower compaction energy in the first procedure is more reflective of field compaction in backfilling and capping LLW disposal units. The second procedure may be more reflective of high-energy compaction for construction of liners for disposal units.

## Consolidation Relation

Consolidation behavior is usually only consequential in saturated fine-grained soils, where drainage is slow. The rate at which water escapes from the soil during consolidation depends on the coefficient of permeability, thickness, and compressibility of the soil. The rate and amount of consolidation with load are usually determined in the laboratory by the one-dimensional consolidation test. In this test, a laterally confined soil is subjected to successively increased vertical pressure, with free drainage allowed from the bottom and top surfaces.

The recommended standard procedure for the consolidation test is in:

> "Consolidation Test," Appendix VIII, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp VIII-1 to VIII-22.

This procedural documentation is particularly complete even to the extent of being coupled to a procedure for determination of K (see Hydraulic Conductivities).

## Dispersion

A considerable amount of attention is presently being directed to quantifying dispersion accurately for representation in convective ground water solute transport models. However, the parameter has not been previously used for site characterization as a prelude to site development. Accordingly, a standard procedure or guidance for measurement is not recognized, but instead the state of the art requires special equipment besides technicians qualified through specialization and past experience with a method. Dispersion may be expressed as either the coefficient of hydrodynamic dispersion D' or the dispersivity a, two parameters having the following approximate interrelationship for isotropic media when considered in one dimension:

$$D' \ (\text{cm}^2/\text{s}) = V \ (\text{cm/s}) \times a \ (\text{cm})^*$$

where V is the average pore water velocity.

A dispersion parameter may be obtained from measurements made in the laboratory or in the field. In either case, the parameter can be estimated by obtaining the best fit between a measured tracer breakthrough curve and an analytical solution (e.g., see van Genuchten 1980). Dispersion is also reflected more directly in the slope of the curve at 0.5 relative concentration.

A breakthrough curve relates the tracer concentration in pore water exiting the test volume to the cumulative amount of water passing through after injection of the tracer. Breakthrough curves are clearly explained by Grisak and Jackson (1978) in the context of characterizing LLW sites. The tracer should be conservative, i.e., nonreactive and not adsorbed by the material, in order to avoid retardation phenomena.

Laboratory column tests provide the controlled conditions for determining accurate breakthrough curves. Comparisons have sometimes revealed a much greater value of dispersivity representative of the field (Theis 1963). This difference suggests the importance of heterogeneity, e.g., that manifested as interbedded sand and silt (at field scale), in the dispersion phenomenon. Therefore, the laboratory column test will probably be most representative and useful for characterizing dispersion in relatively uniform, homogeneous material zones.

Determination of the dispersion coefficient in the field entails tracer concentration measurements with or without pumping in wells. Most experience has been on aquifers, but fine-grained materials of low permeability can be accommodated by pumping between closely spaced holes. Klotz et al. (1980) review the determination of longitudinal dispersion in the flow direction, but show that transverse dispersion can be evaluated as well by installation of an array of observation holes across the expected direction of flow.

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* Dispersivity may also be considered in a dimensionless form.

Alternatively, a single-hole technique shows promise for low-permeability materials (Sternau et al. 1967). A volume of water tagged with a conservative tracer is injected into the formation through the well, and then the well is pumped. Where the natural ground water flow velocity is low, nearly all of the injected tracer may be recovered. A breakthrough curve is developed during well pumping.

References

G. E. Grisak and R. E. Jackson, "An Appraisal of the Hydrogeological Processes Involved in Shallow Subsurface Radioactive Waste Management in Canadian Terrain," Scientific Series No. 84, Inland Waters Directorate, Fisheries and Environment Canada, 194 pp, 1978.

D. Klotz, K. P. Seiler, H. Moser, and F. Neumaier, "Dispersivity and Velocity Relationship From Laboratory and Field Experiments," Journal of Hydrology, Vol. 45, pp 169-184, 1980.

R. Sternau, J. Schwarz, A. Mercado, Y. Harpaz, A. Nir, and E. Halevy, "Radioisotope Tracers in Large-Scale Recharge Studies of Groundwater," Isotopes in Hydrology 1966, International Atomic Energy Agency, Vienna, pp 489-505, 1967.

C. V. Theis, "Hydrologic Phenomena Affecting the Use of Tracers in Timing Groundwater Flow," Radioisotopes in Hydrology, International Atomic Energy Agency, Vienna, pp 193-206, 1963.

M. T. van Genuchten, "Determining Transport Parameters from Solute Displacement Experiments," Research Report No. 118, U. S. Salinity Laboratory, 37 pp, 1980.

## Electrical Resistivity

Dimensionally, electrical conductivity is the reciprocal of electrical resistivity. Resistivity is the preferred form in characterizing soil and rock, while conductivity is preferred for characterizing ground water.

### Field methods

Surface resistivity surveys. Field procedures, equipment requirements, and interpretation for surface resistivity surveying can be found in Department of the Army (1979), Zohdy et al. (1974), and Telford et al. (1976), and in other sources referenced in these publications. Recent work in application of surface resistivity methods specifically to monitoring waste disposal sites is discussed in Kean and Rogers (1981) and Kaufmann et al. (1981). Surface resistivity methods recommended for LLW monitoring programs involve four electrode measurement arrays and instrumentation for generating currents in the ground and detecting potential differences between surface points. Denoting the electrodes in a linear array as A, M, N, and B, the outer electrodes A and B are the current electrodes, and the inner electrodes M and N are the potential electrodes. The most commonly used arrays are the Schlumberger, for which distances $AB/2 \geq 5MN$ generally, and the Wenner, for which distances $AM = MN = NB = a$ .

Two types of surveying are possible with the Schlumberger and Wenner arrays: vertical sounding and horizontal profiling. In a vertical sounding application, the electrodes are symmetrically expanded along a line about a given surface point; the vertical sounding results are interpreted to give a vertical profile of resistivity beneath the surface point. In horizontal profiling applications, the electrode array is moved along profile lines keeping the electrode spacing constant (varying the profile measurement point). Measured potential differences $\Delta V$ are converted to apparent resistivities:

$$\rho_A = K_G(\Delta V/I)$$

where $K_G$ = geometric array factor
$I$ = current

$K_G = \pi S\left[\left(\frac{L}{S}\right)^2 - \frac{1}{4}\right]$ for the Schlumberger array, where $S = MN$ and $L = \frac{AB}{2}$ . $K_G = 2\pi a$ for the Wenner array. Generally, the Schlumberger array is preferred for vertical sounding and the Wenner array is most commonly used for horizontal profiling.

For monitoring programs, surface resistivity surveys can be conducted repeatedly at a site, require only surface location reference, and thus are not limited to monitor boreholes in a few selected locations.

Vertical resistivity sounding data generally are interpreted by curve matching or by the use of inverse computer modeling to give true resistivities as a function of depth. To use resistivity soundings to monitor for changes in resistivity, it is not absolutely necessary to convert to true resistivities; however, depth to the changes can only be determined by a complete interpretation of the sounding data. A possible problem in the application of the surface methods to LLW sites is a consequence of geometrical constraints. It may be difficult to find locations at a LLW site where the array can be expanded sufficiently to investigate to the depths required without crossing a trench; thus sounding monitor locations should be planned carefully in accordance with the proposed site development plan. A localized resistivity anomaly (such as a migrating radionuclide plume) passing beneath a sounding line will affect the measured apparent resistivity in such a way as to produce meaningless results if interpretation is attempted. As a monitor of change, soundings before and after occurrence of a localized plume will be of value; however, multiple soundings in an area will be required if depth and even plan location of the anomalous zone are desired. In areas where ground water temperatures vary seasonally, surface resistivity measurements will vary seasonally also since resistivity generally decreases as temperature increases. It may be necessary to correct resistivity survey data to a common temperature base before comparing soundings and horizontal profiling surveys conducted at different times (Kean and Rogers 1981).

Horizontal resistivity profiling can be conducted along parallel profile lines (or at least multiple profile lines across a site); the result is a grid of apparent resistivity values which can be contoured. Each contour map is produced for a constant electrode spacing and hence represents essentially a constant depth of investigation. If a Wenner array is used for the profiling, the electrode spacing should be chosen to be 1 to 2 times the depth of interest. For example, to investigate the possibility of direct lateral migration of radionuclides from the trenches, the site would be surveyed with electrode spacing of 1 to 1.5 times the depth of the trenches. To investigate the possibility of radionuclide migration down to the water table, a second resistivity survey should be conducted with a larger electrode spacing (1.5 to 2 times the depth to the water table). The resulting contour maps should be examined for relative negative changes in resistivity; i.e., the appearance of lower apparent resistivity values in the vicinity of a trench could reflect low ground water resistivity due to the presence of contaminants. Resistivity anomaly maps, prepared by subtracting earlier survey values from subsequent survey values over the site, will generally highlight areas of relative negative change more dramatically.

Electromagnetic surveys. Several electromagnetic (EM) induction devices, suitable for mapping surface conductivity variations at LLW sites, have been reported (McNeill 1980, Greenhouse and Slaine 1982). These EM devices require no direct earth contact and are frequently unaffected by fences, cables, and other cultural features, which can significantly affect the resistivity methods. Readings with EM devices, however, can be significantly affected by close proximity (within 500 m) to major power lines or transmission towers. While the EM devices have the advantage of being more rapid to use in surface mapping than the resistivity methods, they have limited depth of investigation capability. One of these devices, for example, has essentially a fixed depth of investigation of about 3 m, while another such device has six depth of investigation configurations to a maximum of 60 m, which should be sufficient for most LLW sites. Development of EM surveying equipment as well as interpretation experience at hazardous waste sites is rapidly progressing.

Resistivity logging. Single-point resistivity and spontaneous or self-potential (SP)* surveys are routinely conducted as part of a borehole geophysical logging program; these survey methods, as well as other, multiple-point resistivity methods which can be conducted in boreholes, have applicability for general purpose site characterization as well as monitoring programs. Field procedures, equipment requirements, and interpretation requirements can be found in Department of the Army (1979), Keys and MacCary (1971), Schlumberger Limited (1972), Telford et al. (1976), and other sources referenced in these publications. For monitoring applications, all of the resistivity methods are used to detect low-resistivity zones or anomalies, i.e., zones exhibiting changes to lower resistivity compared to an earlier or baseline value. SP values can often be used to determine formation water resistivities, and changes in SP values with time reflect changes in formation resistivity and ground water flow velocity. The primary limitation to the use of borehole resistivity and SP logging as monitoring methods is that the methods cannot be used in cased boreholes.

Specific conductance probes. The ground water itself (in distinction from the water-bearing soil or rock) can be characterized in regard to conductivity by measurement of specific conductance in the field along with temperature (Environmental Protection Agency 1977). In situ measurements can be made by lowering a self-contained conductance-temperature probe into a well and recording the results from surface instrumentation. In areas of high water table, the measurements can be made without installing a well. Figure 5 of the main text is a schematic illustration of such a device.

The probe can be pushed directly into soft ground; where the ground is harder, it can be inserted into a small-diameter, hand-augered hole. During insertion, the perforations are protected from clogging by an outside tube. When the probe is below the water table, the tube is retracted, allowing the ground water to flow into it. Specific conductance and temperature of the ground water can then be recorded. After removal, the perforated end of the probe is washed in clean water.

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* Ground water flowing through soil and rock can generate electrical voltages, known as spontaneous- or self-potentials, through electrokinetic and electrochemical processes.

Another advantage of the specific conductance and temperature probe method is inherent in the equipment required. Since the mechanisms involved are not bulky or cumbersome, a two-man crew can easily carry all necessary equipment into the field and make a series of probe measurements in 2 to 3 days. Also, swampy areas not readily accessible to drilling rigs or resistivity survey crews can be tested with little difficulty.

Although this method has distinct advantages, it has limitations also. The required equipment for probing is very delicate and is vulnerable to physical abuse. Any malfunctioning of the equipment due to mechanical failure or to contamination before testing can give erroneous information. To prevent this development, the equipment should be checked periodically for malfunctioning against a standard solution such as potassium chloride. Also the method applies to shallow depth only.

### Laboratory method

The electrical conductivity (or resistivity) of a soil can be determined on a soil paste in the laboratory using a wheatstone bridge. Measurements are affected by temperature, water content, specific ions, and degree of dissociation. Special tables have been constructed to relate conductivity in soils to salt concentration and are presented in the following recommended procedure:

> "Determination of Total Salinity," Section 6:3:1, Textbook of Soil Chemical Analyses, Chemical Publishing Co., New York, 1971, pp 75-80.

### References

Department of the Army, "Geophysical Exploration," Engineer Manual 1110-1-1802, U. S. Army Corps of Engineers, 1979.

Environmental Protection Agency, "Procedures Manual for Ground Water Monitoring at Solid Waste Disposal Facilities," EPA/530/SW-611, Cincinnati, 1977.

J. P. Greenhouse and D. D. Slaine, "Case Studies of Geophysical Contaminant Mapping at Several Waste Disposal Sites," Department of Earth Sciences, University of Waterloo, Ontario, 1982.

R. F. Kaufmann, T. A. Gleason, R. B. Ellwood, and G. P. Lindsey, "Ground-Water Monitoring Techniques for Arid Zone Hazardous Waste Disposal Sites," Ground Water Monitoring Review, Vol. 1, No. 3, pp 47-54, 1981.

W. F. Kean and R. B. Rogers, "Monitoring Leachate in Ground Water by Corrected Resistivity Methods," Bulletin of the Association of Engineering Geologists, Vol. 18, pp 101-107, 1981.

W. S. Keys and L. M. MacCary, "Application of Borehole Geophysics to Water-Resources Investigations," Chapter E1, Book 2, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1971.

J. D. McNeill, "Electromagnetic Terrain Conductivity Measurement at Low Induction Numbers," Technical Note 6, Geonics Ltd., Mississauga, Ontario, 1980.

Schlumberger Limited, "Schlumberger Log Interpretation: Volume I - Principles," New York, 1972.

W. M. Telford, L. P. Geldart, R. E. Sheriff, and D. A. Keys, Applied Geophysics, Cambridge University Press, New York, 1976.

A. A. R. Zohdy, G. P. Eaton, and D. R. Mabey, "Application of Surface Geophysics to Ground-Water Investigations," Chapter D1, Book 2, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1974.

## Erodibility

Erosion is primarily affected by material grain size or the mechanism of soil dispersion. Dispersive clays are a particular type of soil in which the clay fraction erodes in the presence of water by a process of deflocculation. This occurs when the interparticle forces of repulsion exceed those of attraction so that clay particles are detached and go into suspension.

### Pinhole test

The pinhole erosion test is the most reliable test for identifying dispersive soils. A recommended version of this test, along with other laboratory and field test methods for identifying dispersive soils, is described in:

> "Pinhole Erosion Test for Identification of Dispersive Clays," Appendix XIII, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970 (with change 1, 1980), pp XIII-8 to XIII-19.

It is suggested that this test be reserved for suspect material or where a simple screening test such as the crumb test indicates the need.

### Crumb test

In actual practice, the erodibility parameter usually reflects a relative behavior among soils at the site or in comparison to problem materials elsewhere. Accordingly the need is often for an approximation or index obtained with ease rather than a more formal laboratory test. The so-called crumb test is suitable in this capacity for characterizing soils at LLW sites. An appropriate standard method is as follows:

> "Crumb Test," Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970 (with change 1, 1980), pp XIII-20.

### Empirical relations and experience

Local experience assembled in soil conservation and geological agencies and offices is frequently the best avenue to characterizing local soils for erodibility. The past performance of one soil versus another, e.g., in farm pond embankments, focuses on erodible soils. Soil loss equations for estimating erosion from wind and from water are available in Skidmore and Woodruff (1968) and Wischmeier and Smith (1978), respectively.

## References

E. L. Skidmore and N. P. Woodruff, "Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss," Handbook No. 346, U. S. Department of Agriculture, 1968.

W. H. Wischmeier and D. D. Smith, "Predicting Rainfall Erosion Losses--A Guide to Conservation Planning," Handbook No. 537, U. S. Department of Agriculture, 1978.

## Evapotranspiration

### Field measurement

Evapotranspiration can be measured using evaporimeters or lysimeters. No internationally recognized standard has been developed nor is there standardization within the United States. Appropriate equipment and procedures are described in the following reference:

> "Soil Evaporimeters and Lysimeters," Section 2.3.3, Guide to Meteorological Instruments and Observing Practices, 3rd Ed., World Meteorological Organization, 1970, pp II.23 to II.27.

### Estimations

Indirect procedures are frequently used to estimate evapotranspiration. The following summary from Environmental Protection Agency (1977) addresses four methods, modified Blaney-Criddle, radiation, modified Penman, and evaporation pan methods. Also refer to Robins (1965) for a review of indirect measurement as well as estimation methods.

Prior to selecting the estimation method, data from completed climatological and agricultural surveys, specific studies, and research on crop water requirements in the area of investigation should be reviewed. Available measured climatic data should also be reviewed. If possible, meteorological and research stations should be visited, and the environment, siting, types of instruments, and observation and recording practices should be appraised to evaluate the accuracy of available data. The prediction method may then be selected on the basis of the types of usable meteorological data available and the level of accuracy desired. The types of data (measured or estimated) needed for each method are summarized in Table A.1. The methods are described very briefly here along with some general criteria for their selection and use.

Table A.1

Data Required for Estimating Evapotranspiration
(from Environmental Protection Agency)

| Factor | Modified Blaney-Criddle | Radiation | Modified Penman | Evaporation Pan |
|---|---|---|---|---|
| Temperature | Measured | Measured | Measured | ......... |
| Humidity | Estimated | Estimated | Measured | Estimated |
| Wind | Estimated | Estimated | Measured | Estimated |
| Sunshine | Estimated | Measured | Measured | ......... |
| Radiation | ......... | Measured | Measured | ......... |
| Evaporation | ........ | ......... | ........ | Measured |

The Blaney-Criddle method is recommended when only air temperature data are available and is best applied for periods of one month or more. It has been used extensively in the western United States and is the standard method used by the Soil Conservation Service. In the eastern United States, Blaney-Criddle is less widely used and often yields estimates that are too low.

The radiation method is recommended when temperature and radiation or percent cloudiness data are available. Several versions of the method exist, and because they were mainly derived under cool coastal conditions, the resulting evapotranspiration generally tends to be underestimated.

The modified Penman method is probably the most accurate and best choice when temperature, humidity, wind, and radiation data are available. Along with the radiation method, the method offers the best results for periods as short as 10 days.

Evaporation pans offer the advantage of responding to the same climatic variables as vegetation. Depending on the location and surrounding environment of the pan, pan data may be superior to data obtained by other methods; nevertheless, particular care in planning is warranted because of the influence of the surrounding environment and the pan condition on measured evaporation. Pan evaporation data are best applied for periods of 10 days or more.

Other prediction methods may be used. Some are based on correlations with certain climatic conditions and cannot be easily adapted to other conditions. For example, the Thornthwaite method, in which temperature and latitude are correlated with evapotranspiration, was developed for humid conditions in the east-central United States, and its application to arid and semiarid conditions will result in substantial underprediction of evapotranspiration. Because of its relative simplicity, it has often been applied in areas for which it is not suited. It is important to select the prediction method that can make use of the available data and that can be corrected for local climatic conditions.

## References

Environmental Protection Agency, "Field Investigation Procedures," Appendix F, Process Design Manual of the Land Treatment of Municipal Wastewater, pp F-1 to F-3, 1977.

J. S. Robins, "Evapotranspiration," Chapter 20, Methods of Soil Analysis: Part 1 - Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, American Society of Agronomy, pp 286-298, 1965.

## Extended Site Boundary

The extended site boundary is established around the area, including the LLW site, in which the site-specific data are collected. Exceptions to this guidance can be made in those cases where climatological and stream gaging records from existing stations at intermediate distances are accepted as representative of the LLW site and used as site-specific data. These usable stations remain outside the extended site boundary.

The two most important systems involved in determining the boundary are those of the surface water and the ground water. The methods of locating boundaries for both systems are discussed under Ground Water System and Boundaries and Surface Water System and Boundaries in this Appendix. A reasonable limitation of the surface water system generally is the drainage basin or basins within which the runoff from the immediate site converges to one channel. Figure A.1 schematically shows that slopes facing the site, but carrying none of the runoff from the site, need to be included. Where the ground water system is not so clearly limited by topography or other physical boundaries, it may be appropriate to fix arbitrary limits based on expected importance of the aquifer.

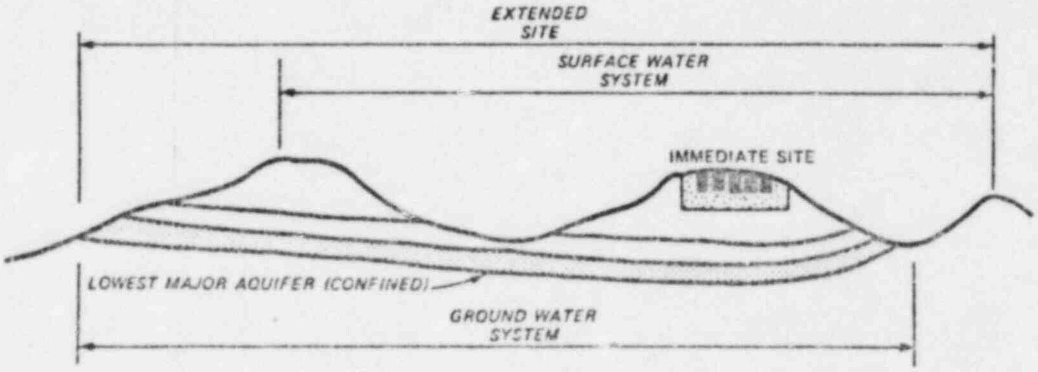

Figure A.1. Concept of extended site boundary

## Flow Direction

### Calculation methods

Flow direction is usually calculated or diagrammed indirectly from a knowledge of the hydraulic potential field and the orientation of the axis of permeability. One procedure is given by Fetter (1981) in which the effect of zone anisotropy is taken into consideration. This anisotropy is manifested in the vertical plane for the most part since the property contrast that accounts for anisotropy is developed in that plane (see Anisotropy).

It is probably most common, when concerned with the flow direction within one horizon, to use the three-point method of calculation. Three observation wells are established in the horizon and the water levels in the wells are measured. The flow direction is perpendicular to the lines of equal piezometric head constructed from the measured heads.

### Tracer observations

Flow direction is sometimes established on an areal basis by measuring tracers injected into boreholes. The state-of-the-art technique usually amounts to timing the arrival of a tracer in an array of holes down gradient from but at the same horizon as an injected well point (Karadi 1975).

Another technique that can be considered for application where sufficient experience has been established involves injection and observation from a single well as explained under Seepage Velocity. The method, however, depends on establishment of the preferred directions of migration of a radioactive tracer solution using a special collimated detector in the hole.

### References

C. W. Fetter, Jr., "Determination of the Direction of Ground Water Flow," Ground Water Monitoring Review, Vol. 1, No. 3, pp 28-31, 1981.

G. M. Karadi, "Survey of Measuring Instruments and Techniques for Ground Water Prospecting," Water Resources Instrumentation: Vol 2 - Data Acquisition and Analysis, International Water Resources Association, pp 397-410, 1975.

## Frost Heaving

The recommended procedure for evaluating the frost heave susceptibility of a soil is by use of existing correlation with grain-size characteristics. Figure A.2 presents the widely used chart developed from experience and data of the U. S. Army Cold Regions Research and Engineering Laboratory. The heaving susceptibility is quantified in terms of expected vertical displacement (by formation of ice lenses) but the correlations have their most realistic value in semiquantitative predictions and in forewarning of potential for problems so that adjustments in design can be made.

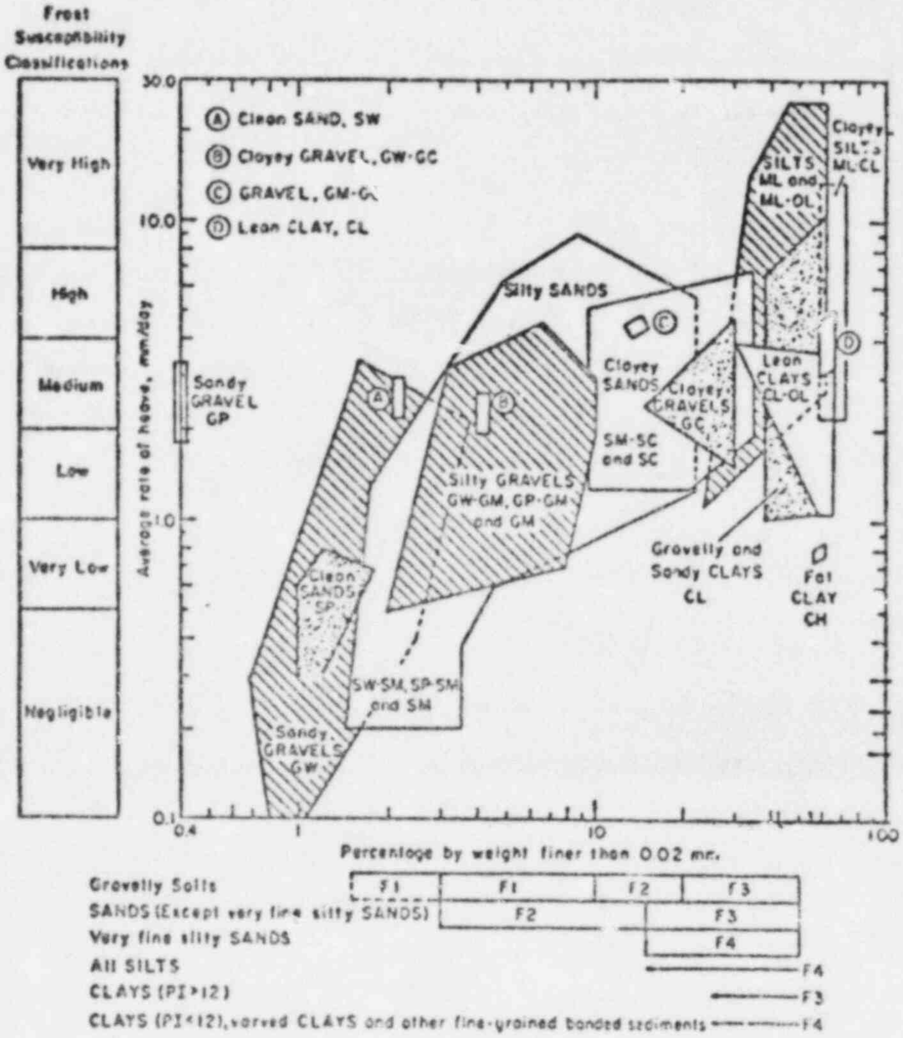

Figure A.2. Frost heaving criterion for soil
(from Corps of Engineers)

## Gaseous Constituents

Anaerobic decomposition of the wastes in a LLW site often produces gases such as methane, hydrogen sulfide, carbon dioxide, and ammonia, thus permitting a mechanism of escape for $^{3}H$ and $^{14}C$ compounds to the atmosphere. Air samples (mostly from boreholes) taken at the site may be used to evaluate release of gaseous compounds and would normally be analyzed by direct injection into a gas chromatograph using instrument manufacturers' specifications. A standard method of analysis is described in the following:

> 511, "Sludge Digester Gas," Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 15th Ed., 1980, pp 523-530.

In cases where a gas migration problem is indicated to be possible, field determinations should also be considered, using gas-specific detector probes. Detectors are commercially available for methane and hydrogen sulfide as well as other gases. Sacrifices in accuracy may be offset by greater ease of testing with resultant more complete site coverage. Application to LLW site characterization, though desirable, remains to be developed into state-of-the-art procedures.

A standard method for measuring tritium in air that requires long sampling times for low concentrations is as follows:

> ASTM D3442-75, "Standard Test Method for Tritium Content of Air," Annual Book of ASTM Standards: Part 26 - Gaseous Fuels; Coal and Coke; Atmospheric, 3 pp.

There is also some loss in efficiency when $^{3}H$ is in the form of methane. Much of the current experience in measuring radioactivity in gases from LLW has come from efforts summarized by Matuszek (1982).

### Reference

J. M. Matuszek, "Radiochemical Measurements for Evaluating Air Quality in the Vicinity of Low-Level Waste Burial Sites - The West Valley Experience," in Low-Le[illegible]e Disposal: Site Characterization and Monitoring, NUREG/CP-[illegible]2, U. S. Nuclear Regulatory Commission, 1982 (in preparati

## Geomorphology

Although this section is primarily concerned with geomorphological documentation, it also encompasses closely related geological parameters. Similarly, see further discussions of parameters related to geomorphology under Stratigraphy.

### Landforms

The geological characterization should include the identification of the physiographic province and lower order physiographic subdivisions in which the LLW site is located. Specific landforms including, but not limited to, floodplains, stream terraces, dunes, swamps, karst, and glacial features should be identified from field observations as well as from aerial photography and topographic maps and should be plotted or otherwise shown on appropriate topographic coverage of the site.

### Fluvial conditions

The characterization of fluvial conditions should include the plotting of all temporary and permanent streams as well as their catchment boundaries on appropriate topographic or other maps. Catchments whose boundaries extend beyond the site should be included on the map. The order of each stream should be determined, i.e. first-, second-, third-order, etc., and the stream patterns, e.g., trellis, dendritic, or rectangular, should also be identified. Longitudinal profiles of main stream or principal stream should be plotted as well as typical stream cross sections. Knickpoints or other indicators of potential fluvial instability should be identified on the profiles and sections and examined in the field. Field studies should include the identification of floodplains and terraces inferred from maps and imagery; particular attention should be given to evidence of historical flooding and channel instability as indicated by steep, unstable banks, sediments and debris choked channels, and incised or knicked channels. Historical aerial photographic coverage should be consulted in order to verify overall channel stability over the years.

### Geological hazards

The identification and evaluation of actual and potential geological hazards, at the site or which may affect the site, should be conducted by a synthesis of all available geological information to include geological literature and field investigations. Generally, reports and maps prepared by federal and state geological surveys will provide sufficient information for site selection and initial phases of site characterization. Hays (1981) has presented maps of the contiguous United States which show areas where earthquakes, volcanism, karstic terrain, expansive soils, landslides, and flooding occur.

## Reference

W. W. Hays, ed., "Facing Geologic and Hydrologic Hazards - Earth Science Considerations," Professional Paper 1240-B, U. S. Department of the Interior, Geological Survey, 109 pp, 1981.

## Grain-Size Distribution

### Direct measurement

Grain-size distribution is determined by a combination of sieve analysis and hydrometer analysis for materials retained on and passing the U. S. Standard No. 200 sieve, respectively. The sieve analysis consists of passing a sample through a set of sieves and weighing the amount retained on each sieve. The analysis is performed on material retained on a No. 200 sieve but is applicable to soils containing small amounts of material passing the No. 200 sieve, provided the grain-size distribution of that portion is not of interest.

The hydrometer analysis is conducted on the material passing the No. 200 sieve to determine the percentage of dispersed soil particles remaining in suspension at a given time, with finer material remaining in suspension longer. Standard procedures are presented in:

> "Grain-Size Analysis," Appendix V, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp V-1 to V-28.
>
> ASTM D422-63 (Reapproved 1972), "Standard Method for Particle-Size Analysis of Soils," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 11 pp.

The first procedure has instructions for working with shale such as found at some LLW sites.

Certain useful parameters can be calculated from grain-size distribution data as explained under Lithology and Soils and Hydraulic Conductivities.

### Parameter calculations

Generalities on the size of grains can be determined from direct measurement. The coefficient of uniformity and coefficient of curvature are parameters determined from grain-size distribution curves and used in the Unified Soil Classification System (see Soil Classification). These parameters provide a means of characterizing grain-size distribution curves, giving information on engineering properties, and comparing different materials.

Other parameters more familiar to geologists are median, mean, standard deviation (for sorting), skewness, and kurtosis of sediment grains, which sometimes provide a better means of comparing and describing grain size (Folk 1980). The percentages coarser than a given size are plotted as cumulative curves on probability paper. Grain sizes may be given in ∅ units, the negative logarithm to base 2 of the particle diameter in millimeters. The graphic measures are calculated using the formulas:

$$\underline{\text{Median}} = \phi_{50}$$

$$\underline{\text{Graphic Mean}} = \frac{\phi_{16} + \phi_{50} + \phi_{84}}{3}$$

$$\underline{\text{Inclusive Graphic Standard Deviation}} = \frac{\phi_{84} - \phi_{16}}{4} + \frac{\phi_{95} - \phi_{5}}{6.6}$$

$$\underline{\text{Inclusive Graphic Skewness}} = \frac{\phi_{84} + \phi_{16} - 2\phi_{50}}{2\,(\phi_{84} - \phi_{16})} + \frac{\phi_{95} + \phi_{5} - 2\phi_{50}}{2\,(\phi_{95} - \phi_{5})}$$

$$\underline{\text{Graphic Kurtosis}} = \frac{\phi_{95} - \phi_{5}}{2.44\,(\phi_{75} - \phi_{25})}$$

The skewness describes the symmetry of the size-frequency curve and the kurtosis describes the peakedness of the curve.

The mode is the most frequently occurring particle size. Some materials may be bimodal or even trimodal. Ordinarily the mode or modes cannot be readily determined from cumulative curves and must, therefore, be identified from histograms or noncumulative, size-frequency plots.

## Reference

R. L. Folk, Petrology of Sedimentary Rocks, Hemphill Publishers, Austin, Texas, 1980.

## Ground Water Chemistry

Table A.2 gives a summary of special sampling and handling requirements for most of the parameters included under organic, inorganic, and quality categories. Guidance on containers, sample size, preservation, and storage time is provided.

### Inorganic constituents

Metals in solution are readily determined by atomic absorption spectroscopy, using direct aspiration, the furnace technique, the gaseous hydride method, or the cold vapor technique. Specific instructions for instrument operation are furnished by the manufacturers. A general discussion of atomic absorption methods for metals is given in Methods for Chemical Analyses of Water and Wastes (cited below).

Fluoride, nitrogen, and sulfate are determined by colorimetric techniques; chloride, iodide, and sulfide are determined by titration methods; and dissolved oxygen is determined in the field using a membrane electrode. Carbon dioxide is determined by calculation based on sample pH and alkalinity.

Specific standard procedures are presented in two references as follows:

Standard Methods for the Examination of Water and Wastewater, 15th Ed., American Public Health Association, 1980.

| | |
|---|---|
| arsenic, selenium | 303E, "Determination of Arsenic and Selenium by conversion to their Hybrides and Aspiration of the Gas into an Argon-Hydrogen or Nitrogen-Hydrogen Flame," pp 160-163. |
| cesium, strontium | 303A, "Determination of Antimony, Bismuth, Cadmium, Calcium, Cesium, Chromium, Cobalt, Copper, Gold, Iridium, Iron, Lead, Lithium, Magnesium, Manganese, Nickel, Platinum, Potassium, Rhodium, Ruthenium, Silver, Sodium, Strontium, Thallium, Tin, and Zinc by Direct Aspiration into an Air-Acetylene Flame," pp 152-155. |
| carbon dioxide (dissolved) | 406C, "Carbon Dioxide and Forms of Alkalinity by Calculation," pp 268-269. |
| chloride | 407C, "Chloride/Potentiometric Method," pp 273-275. |
| hydrogen sulfide | 427D, "Sulfide/Iodometric Method," pp 448-449. |
| | 427E, "Calculation of Un-ionized Hydrogen Sulfide," p 450. |

## Table A.2

## Summary of Special Water Sampling and Handling Requirements
(from American Public Health Association)

| Determination | Container | Minimum Sample Size mL | Preservation | Maximum Storage Recommended/Regulatory[†] |
|---|---|---|---|---|
| Acidity | P, G(B) | 100 | Refrigeration | 24 hr/14 days |
| Alkalinity | P, G | 200 | Refrigerate | 24 hr/14 days |
| BOD | P, G | 1,000 | Refrigerate | 6 hr/48 hr |
| Boron | P | 100 | None required | 28 days/28 days |
| Bromide | P, G | – | None required | 28 days/28 days |
| Carbon, organic, total | G | 100 | Analyze immediately; or refrigerate and add $H_2SO_4$ to $pH < 2$ | 7 days/28 days |
| Carbon dioxide | P, G | 100 | Analyze immediately | –/– |
| COD | P, G | 100 | Analyze as soon as possible; or add $H_2SO_4$ to $pH < 2$ | 7 days/28 days |
| Chlorine, residual | P, G | 500 | Analyze immediately | 0.5 hr/2 hr |
| Chloride dioxide | P, G | 500 | Analyze immediately | 0.5 hr/2 hr |
| Chlorophyll | P, G | 500 | 30 days in dark; freeze | 30 days/– |
| Color | P, G | 500 | Refrigerate | 48 hr/48 hr |
| Conductivity | P, G | 500 | Refrigerate | 28 days/28 days |
| Cyanide | | | | |
| Total | P, G | 500 | Add NaOH to $pH > 12$, refrigerate in dark | 24 hr/14 days |
| Amenable to chlorination | P, G | 500 | Add 100 mg $Na_2S_2O_3$/L | –/– |
| Fluoride | P | 300 | None required | 28 days/28 days |
| Grease and oil | G, wide-mouth, calibrated | 1,000 | Add $H_2SO_4$ to $pH < 2$; refrigerate | 28 days/28 days |
| Hardness | P, G | 100 | Add $HNO_3$ to $pH < 2$ | 6 months/6 months |
| Iodine | P, G | 500 | Analyze immediately | 0.5 hr/– |
| Metals, general | P(A), G(A) | – | For dissolved metals filter immediately, add $HNO_3$ to $pH < 2$ | 6 months/6 months |
| Chromium VI | P(A), G(A) | 300 | Refrigerate | 24 hr/48 hr |
| Copper by colorimetry* | | | | |
| Mercury | P(A), G(A) | 500 | Add $HNO_3$ to $pH < 2$, 4 C | 28 days*/28 days |
| Nitrogen: | | | | |
| Ammonia | P, G | 500 | Analyze as soon as possible or add $H_2SO_4$ to $pH < 2$, refrigerate | 7 days/28 days |
| Nitrate | P, G | 100 | Add $H_2SO_4$ to $pH < 2$, refrigerate | 48 hr/48 hr |

[*] See text for additional details. For determinations not listed, use glass or plastic containers, preferably refrigerate during storage and analyze as soon as possible. Refrigerate = storage at 4 C, in the dark. P = plastic (polyethylene or equivalent); G = glass; G(A) or P(A) = rinsed with 1 + 1 $HNO_3$; G(B) = glass, borosilicate; G(S) = glass, rinsed with organic solvents.

[†] Environmental Protection Agency, Proposed Rules, *Federal Register* 44: No. 244, Dec. 18, 1979.

Table A.2 (Continued)

| Determination | Container | Minimum Sample Size m. | Preservation | Maximum Storage Recommended/Regulatory† |
|---|---|---|---|---|
| Nitrate + nitrite | P, G | 200 | Analyze as soon as possible or refrigerate; or freeze at −20 C | none/28 days |
| Nitrite | P, G | 100 | Analyze as soon as possible or refrigerate; or freeze at −20 C | none/48 hr |
| Organic, Kjeldahl | P, G | 500 | Refrigerate; add $H_2SO_4$ to pH 2 | 7 days/28 days |
| Odor | G | 500 | Analyze as soon as possible; refrigerate | 6 hr/— |
| Organic compounds: | | | | |
| Pesticides | G(S), TFE-lined cap | — | Refrigerate; add 100 mg $Na_2S_2O_3$/L if residual chlorine present | 7 days/7 days |
| Phenols | P, G | 500 | Refrigerate; add $H_2SO_4$ to pH < 2 | */28 days |
| Purgeables by Purge and Trap | G, TFE-lined cap | 50 | Refrigerate; add 100 mg $Na_2S_2O_3$/L if residual chlorine present | 7 days/14 days |
| Oxygen, dissolved: | G, BOD bottle | 300 | | |
| Electrode | | | Analyze immediately | 0.5 hr/1 hr |
| Winkler | | | Titration may be delayed after acidification | 8 hr/8 hr |
| Ozone | G | 1,000 | Analyze immediately | 0.5 hr/— |
| pH | P, G | — | Analyze immediately | 2 hr/2 hr |
| Phosphate | G(A) | 100 | For dissolved phosphate filter immediately; refrigerate; freeze at −10 C | 48 hr/48 hr |
| Residue | P, G | — | Refrigerate | 7 days/7-14 days |
| Salinity | G, wax seal | 240 | Analyze immediately or use wax seal | 6 months/— |
| Silica | P | — | Refrigerate, do not freeze | 28 days/28 days |
| Sludge digester gas | G, gas bottle | — | — | — |
| Sulfate | P, G | — | Refrigerate | 28 days/28 days |
| Sulfide | P, G | 100 | Refrigerate; add 4 drops 2N zinc acetate/100 mL | 28 days/7 days |
| Taste | G | 500 | Analyze as soon as possible; refrigerate | 24 hr/— |
| Temperature | P, G | — | Analyze immediately | —/— |
| Turbidity | P, G | — | Analyze same day; store in dark up to 24 hr | 24 hr/48 hr |

*Methods for Chemical Analysis of Water and Wastes*, EPA 600/4-79-020, U. S. Environmental Protection Agency, Cincinnati, 1979.

| | |
|---|---|
| barium | 208.2, "Barium (Atomic Absorption, furnace technique)," 2 pp. |
| chromium | 218.1, "Chromium (Atomic Absorption, direct aspiration)," 2 pp. |
| | 218.2, "Chromium (Atomic Absorption, furnace technique)," 2 pp. |
| copper | 220.1, "Copper (Atomic Absorption, direct aspiration)," 2 pp. |
| | 220.2, "Copper (Atomic Absorption, furnace technique)," 2 pp. |
| cyanide | 335.3, "Cyanide, Total (Colorimetric, Automated UV)," 4 pp. |
| fluoride | 340.3, "Fluoride (Colorimetric, Automated Complex-one)," 4 pp. |
| iodide | 345.1, "Iodide (Titrimetric)," 4 pp. |
| iron | 236.1, "Iron (Atomic Absorption, direct aspiration)," 2 pp. |
| | 236.2, "Iron (Atomic Absorption, furnace technique)," 2 pp. |
| lead | 239.1, "Lead (Atomic Absorption, direct aspiration)," 2 pp. |
| | 239.2, "Lead (Atomic Absorption, furnace technique)," 2 pp. |
| mercury | 245.1, "Mercury (Manual Cold Vapor Technique)," 6 pp. |
| nitrogen (nitrate) | 353.1, "Nitrogen, Nitrate-Nitrite (Colorimetric, Automated, Hydrazine Reduction)," 5 pp. |
| oxygen (dissolved) | 360.1, "Oxygen, Dissolved (Membrane Electrode)," 2 pp. |
| silver | 272.1, "Silver (Atomic Absorption, direct aspiration)," 2 pp. |
| | 272.2, "Silver (Atomic Absorption, furnace technique)," 2 pp. |
| sulfate | 375.4, "Sulfate (Turbidimetric)," 3 pp. |
| zinc | 289.1, "Zinc (Atomic Absorption, direct aspiration)," 2 pp. |
| | 289.2, "Zinc (Atomic Absorption, furnace technique)," 2 pp. |

## Organic constituents

Among the many organic constituents that have been detected in ground water, several of the pesticides have received special attention. Certain chlorinated hydrocarbons and chlorophenoxys are identified for determination in ground water at those solid waste disposal sites (other than LLW sites) regulated by 40 CFR 257. Standard tests are as follows:

> Annual Book of ASTM Standards: Part 31 - Water, American Society for Testing and Materials.

| | |
|---|---|
| endrin, lindane, methoxychlor, and toxaphene | ASTM D3086-79, "Standard Test Method for Organochlorine Pesticides in Water," 24 pp. |
| 2,4-D, 2,4,5-TP | ASTM D3478-79, "Standard Test Method for Chlorinated Phenoxy Acid Herbicides in Water," 8 pp. |

The importance of gas chromatography (GC) such as used in these standard methods extends well beyond detecting these few specific constituents. GC will reveal the presence of other organic contaminants as well and may be useful once the site is operating to determine possible migration of pollutants from the trenches. Of special concern in this regard is the fact that complex organic molecules can sometimes facilitate migration of radionuclides in the form of chelates.

## Quality parameters

Most of the parameters contained in this section are characteristics used to determine corrosivity or the aesthetic qualities set forth in the Safe Drinking Water Standards. They are generally considered physical properties, and procedures for determination are simple and straightforward. Standard procedures are presented in three references as follows:

> Standard Methods for the Examination of Water and Wastewater, 15th Ed., American Public Health Association, 1980.

| | |
|---|---|
| color | 204, A-E, "Color," pp 60-70. |
| specific conductance* | 205, "Conductivity," pp 70-73. |
| temperature* | 212, "Temperature," pp 124-125. |

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* Field measurements of specific conductance, temperature, and oxidation-reduction potential are effective in characterizing the water in place as a part of the soil or rock medium. See separate discussions of field methods under Electrical Resistivity, Material Temperature, and Oxidation-Reduction Potential.

Methods for Chemical Analysis of Water and Wastes, EPA 600/4-79-020, U. S. Environmental Protection Agency, Cincinnati, 1979.

| | |
|---|---|
| alkalinity | 310.1, "Alkalinity (Titrimetric, pH 4.5)," 3 pp. |
| dissolved solids | 160.1, "Residue, Filterable (Gravimetric, Dried at 180°C)," 2 pp. |
| hardness | 130.1, "Hardness, Total (mg/l as $CaCO_3$) (Colorimetric, Automated EDTA)," 4 pp. |
| pH | 150.1, "pH (Electrometric)," 3 pp. |
| odor | 140.1, "Odor (Threshold Odor, Consistent Series)," 7 pp. |
| suspended solids | 160.2, "Residue, Non-filterable (Gravimetric, Dried at 103-105°C)," 3 pp. |
| turbidity | 180.1, "Turbidity (Nephelometric)," 4 pp. |

Annual Book of ASTM Standards: Part 31 - Water, American Society for Testing and Materials.

| | |
|---|---|
| oxidation-reduction potential* | ASTM D1498-59, "Standard Practice for Oxidation-Reduction Potential in Water," 7 pp. |

An alternative reference emphasizing field analysis of the relatively unstable parameters--specific conductance, temperature, pH, carbonate and bicarbonate, oxidation-reduction potential, and dissolved oxygen is available also as:

> "Guidelines for Collection and Field Analysis of Ground-Water Samples for Selected Unstable Constituents," Chapter D1, Book 1, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1976.

## Radiological parameters

The same basic principles apply to sampling for radioactivity as for sampling for other parameter tests. However, because most of the radioactivity found in water samples will be in submicrogram quantities, care must be taken to assure that the radioactivity does not adhere to the surface of containers. The procedures for analysis have been well

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* Field measurements of specific conductance, temperature, and oxidation-reduction potential are effective in characterizing the water in place as a part of the soil or rock medium. See separate discussions of field methods under Electrical Resistivity, Material Temperature, and Oxidation-Reduction Potential.

defined based on past experience with radioactive fallout from weapons testing and from surveillance at nuclear facilities.

The gross alpha and gross beta analyses are generally considered to be screening techniques and actually have very little value in assessing exposure rates. For example, if the sample contains large amounts of dissolved solids, the gross alpha determination is useless because the majority of the activity is masked by self-absorption. Specific alpha determinations require extensive chemical separation and detection by either alpha scintillation or alpha spectroscopy using surface barrier detectors. Similarly, $^{14}C$ and $^{3}H$ will not be major contributors to the gross beta measurement because of their very low energies, and concentrations must be obtained by some other method such as liquid scintillation counting. The gamma spectral analysis is one of the most useful analytical methods available for both qualitative and quantitative assessment of gamma-emitting radionuclides. Recent advances in GeLi detectors provide excellent resolution for the gamma energy spectrum with much improved sensitivity.

Specific standard methods from four source references are as follows:

Annual Book of ASTM Standards: Part 31 - Water, American Society for Testing and Materials.

| | |
|---|---|
| gross alpha | ASTM D1943-81, "Standard Test Method for Alpha Particle Radioactivity of Water," 5 pp. |
| gross beta | ASTM D1890-81, "Standard Test Method for Beta Particle Radioactivity in Water," 7 pp. |
| gross gamma (spectral) | ASTM D3649-78, "Standard Practice for Gamma-Ray Spectrometry," 12 pp. |
| $^{238}Pu$, $^{239}Pu$ | ASTM D3865-80, "Standard Test Method for Plutonium in Water," 6 pp. |

Prescribed Procedures for Measurement of Radioactivity in Drinking Water, EPA-600/4-80-032, U. S. Environmental Protection Agency, Cincinnati, 1980.

| | |
|---|---|
| $^{134}Cs$, $^{137}Cs$ | 901.0, "Radioactive Cesium in Drinking Water," pp 15-20. |
| $^{60}Co$ | 901.1, "Gamma Emitting Radionuclides in Drinking Water," pp 21-25. |
| $^{131}I$ | 902.0, "Radioactive Iodine in Drinking Water," pp 26-30. |
| $^{90}Sr$ | 905.0, "Radioactive Strontium in Drinking Water," pp 58-74. |
| $^{3}H$ | 906.0, "Tritium in Drinking Water," pp 75-82. |

Procedures for Radiochemical Analysis of Nuclear Reactor Aqueous Solutions, EPA-R4-73-014, U. S. Environmental Protection Agency, Cincinnati, 1973.

| | |
|---|---|
| $^{14}$C | "Carbon-14," pp 38-42. |

Standard Methods for the Examination of Water and Wastewater, 15th Ed., American Public Health Association, 1980.

| | |
|---|---|
| $^{226}$Ra | 706, "Radium 226 by Radon in Water (Soluble, Suspended, and Total)," pp 590-600. |
| $^{228}$Ra | 707, "Radium 228 (Soluble) (Tentative)," pp 600-603. |

A fifth source of standard test methods including alternative procedures for $^{14}$C and $^{3}$H is available as:

"Methods for Determination of Radioactive Substances in Water and Fluvial Sediments," Chapter A5, Book 5, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1977.

## Ground Water System and Boundaries

The geological delineation of the pertinent ground water system or systems and their boundaries will consist of the collection and synthesis of ground water information derived from literature sources as well as from information obtained during site exploration. Generally, this characterization includes the identification of significant confined and unconfined aquifers, aquicludes, aquitards, piezometric heads, and directions of ground water flow. These data should be related to stratigraphy and lithological data and presented on maps and cross sections at the same scale or on the same maps and cross sections as the geologic data. At many sites, principal aquifers can be identified from literature sources; however, perched aquifers and confined aquifers may only be identified from site exploration and testing. Piezometric heads or potentiometric levels should be plotted on cross sections and contoured on site maps as indicated above. Tabulations should also be prepared which relate each aquifer or confining bed and its hydraulic characteristics to the site geology. The tabulation should also include all available data on ground water utilization.

## Hydraulic Conductivities

The hydraulic conductivity (coefficient of permeability) can be measured by routine laboratory tests or evaluated from field tests. Field tests are often preferred because of their more realistic scale.

### Laboratory tests

The standard constant head test procedure is recommended for determining permeability of granular soils. A falling head test is more convenient for fine-grained soil, as is that test utilizing a consolidometer. Guidance on selecting a test method is given in Table A.3.

Table A.3

Soil Permeabilities and Test Methods

| Soil Type | Coefficient of Permeability cm/s | Method of Determination | | |
|---|---|---|---|---|
| | | Field | Laboratory | |
| Clean gravel; coarse sand, medium sand, and fine sand; sand and gravel mixtures; very fine sand | 10 | Multiple-hole pump test | Constant-head permeameter | -- |
| | $10^0$ | ↓ | ↓ | -- |
| | $10^{-1}$ | | | Falling head permeameter |
| | $10^{-2}$ | | | ↓ |
| | $10^{-3}$ | | | |
| Silty sand; organic silt; silt; glacial till; silty clay | $10^{-4}$ | Multiple/Single hole pump test | -- | |
| | $10^{-5}$ | | -- | |
| | $10^{-6}$ | Single-hole pump test | -- | |
| "Impervious" soils, e.g. homogeneous clay below zone of weathering | $10^{-7}$ | -- | Consolidometer | |
| | $10^{-8}$ | -- | ↓ | |
| | $10^{-9}$ | -- | | |

Appropriate standards for hydraulic conductivity are as follows:

ASTM D2434-68 (Reapproved 1974), "Standard Test Method for Permeability of Granular Soils (Constant Head)" Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 7 pp.

"Falling-Head Permeability Test with Permeameter Cylinder," Appendix VII, Section 4, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp VII-13 to VII-16.

Designation E-15, "One-Dimensional Consolidation of Soils," Earth Manual, 2nd Ed., U. S. Department of the Interior, Bureau of Reclamation, 1974, pp 509-521.

"Permeability Tests with Consolidometer," Appendix VII, Section 8, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp VII-22 to VII-24.

Laboratory tests can be run on oriented specimens to permit calculation of vertical and horizontal conductivities. The fabric of the soil may indicate that measurement on planes other than vertical and horizontal are necessary. A comparison of the permeability (e.g., $K_h/K_v$) can be used to quantify the anisotropy. Almost all soils are anisotropic with respect to permeability.

Field tests

The field tests for hydraulic conductivity are much more expensive than laboratory tests, but the same field setups can sometimes be used for evaluating other parameters also. Tests can be either single-hole tests or multiple-hole tests.

Single-hole tests. In the single-hole test the response of the water pressure or water level is measured as a function of time as water is pumped into or out of the hole. A single-hole test may be run on any material regardless of the permeability value, and therefore is preferred over a multiple-hole test for strata that are not considered to be aquifers.

The single-hole test measures the permeability within a section of hole. In a cased hole, the test section is either screened or open. In an uncased hole, the test section is bounded by a packer above and may be bounded by a packer below or left open. A profile of permeability may be produced by conducting several tests at different levels within the hole. Each level is tested by relocating packers in the uncased hole or by testing through the bottom of an uncased hole as the hole is advanced. Radial flow is usually assumed in interpreting the single-hole test results. In rock or stiff clay, flow may take place preferentially along joints or fractures so that the assumption of radial flow is inappropriate.

A single-hole test may be performed in less than an hour and is less expensive than multiple-hole tests. A multiple-hole test requires 12 hours to several days to complete (excluding drilling time). The permeability coefficient that is determined from a single-hole test applies only to the material within a few feet of the test section. It is best to conduct several single-hole tests on a stratum where possible to determine the variability of permeability. The single-hole test procedures are given as follows, with the latter one particularly appropriate for rock strata:

Designation E-18, "Field Permeability Tests in Boreholes," Earth Manual, 2nd Ed., U. S. Department of the Interior, Bureau of Reclamation, 1974, pp 573-578.

RTH 381-80, "Suggested Method for In Situ Determination of Rock Mass Permeability Using Water Pressure Tests," Rock Testing Handbook, U. S. Army Corps of Engineers, 1980.

Gibb et al. (1981) review water withdrawal pump tests on low-yielding monitoring wells at several nonnuclear waste disposal sites. Attention is focused on the relatively large volume of the water stored within the well and on the consequences to drawdown and collection of samples representative of the aquifer itself.

Multiple-hole tests. A multiple-hole test uses a control well and several observation wells to test an aquifer (the test is also known as an aquifer test or pump test). Water is pumped out of the control well and the response of the aquifer as drawdown and recovery is monitored in the observation wells

In designing a test, decisions must be made concerning the location of the wells, selection of the pump, and selection of the observational equipment (i.e., piezometers, flowmeters, barometers, etc.). Information must be collected about the geological and hydrological settings of the aquifer to identify the conditions governing flow. Some wells only partially penetrate the aquifer. Examples of necessary information are aquifer thickness and the approximate values of transmissivity and storage coefficient. Based on this information, response curves must be selected that are appropriate for the aquifer boundary conditions. Even so, some uncertainty about the aquifer boundary conditions (i.e., leaky aquifer, semiconfined) will remain. Aquifer testing is routine but time-consuming, expensive, and fraught with potential errors. The technique is usually among the most important and useful means of LLW site characterization. Guidance on conducting an aquifer test is presented in:

"Analysis of Discharging Well and Other Test Data," Chapter V, Ground Water Manual, U. S. Department of the Interior, Bureau of Reclamation, 1977 (revised reprint 1981), pp 85-173.

"Aquifer-Test Design, Observation, and Data Analysis," Chapter B1, Book 3, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1971.

Many other references, e.g. textbooks, provide similar treatments of the subject matter and most will suffice for guidance as long as site conditions are adequately represented.

## Approximate correlation

A correlation between a grain-size parameter and hydraulic conductivity is often used in place of testing when working with granular soils. The empirical Hazen formula utilizes the $D_{10}$ size (10 percent finer by weight) as follows:

$$K = c\ (D_{10})^2$$

With $K$ in units of centimeters per second and $D_{10}$ in units of centimeters, the coefficient $c$ is about 100.

## Reference

J. P. Gibb, R. M. Schuller, and R. A. Griffin, "Procedures for the Collection of Representative Water Quality Data from Monitoring Wells," Cooperative Groundwater Report 7, Illinois Geological Survey, 1981.

## Hydraulic Potentials and Pressures

The measurement of the hydraulic potential field requires the determination of pore water pressure at numerous points within the site media. Measurement techniques are determined by degree of saturation at the point of measurement.

### Unsaturated conditions

Pore water pressures above the water table are negative. The hydraulic potential above the water table can be called the suction potential. Measurement techniques to determine suction pressures are specified under Suction Pressures in this volume. Recommended procedures for design of measurement systems and interpretation of measurements are given in:

> "Hydraulic Head," Chapter 11, Methods of Soil Analysis: Part 1- Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, American Society of Agronomy, 1965, pp 180-196.

This source of guidance is recommended because of its simultaneous consideration of both saturated and unsaturated domains.

### Saturated conditions

The preferred method of obtaining hydraulic potentials is frequently by direct measurement of water levels in observation wells. These wells can function also as sampling points from which a volume of ground water can be withdrawn. The discussion of the installation and use of observation wells is given elsewhere (Water Zone Boundaries).

Pore water pressures below the water table must sometimes be measured using piezometers, particularly in fine-grained soils. Several types of piezometers are available--diaphragm, closed system, and open system. A Casagrande open piezometer (3/8 in. I.D.) can be considered for use at LLW sites. This type of instrument is simple and reliable. Time lag in measurement of pore pressure changes may be on the order of several days in soils with K of $10^{-7}$ cm/s. This lag is acceptable for analyzing water flow. Such a lag may be too long if the purpose of the system is to analyze stability by determining effective stress. Guidance and procedures for installation, testing, maintenance, and taking measurements are given in:

> Instrumentation of Earth and Rock-Fill Dams (Groundwater and Pore Pressure Observations), Engineer Manual 1110-2-1908, U. S. Army Corps of Engineers, Part 1, 1971.

This source of guidance is recommended for its balance between permeable and low-permeability situations in distinction from the many references emphasizing aquifers only.

## Immediate Site Boundary

It is anticipated that in most cases, the boundary of the immediate site will be largely predetermined by the following factors considered during or before selection of the site:

a. Availability of land.

b. Topographic configuration.

c. Projected disposal volume requirements.

d. Legal or statutory constraints, including width of buffer zone, distance to nearest residence or water well, and depth to the water table.

The evaluation of this parameter during the characterization of the site amounts to a review of the predetermined boundary and determining criteria in the context of the more refined site setting and details. It is also to be expected that some adjusting or refining may be indicated as necessary. The preliminary status of the boundary in the subsurface is particularly flexible, and this boundary need not even be horizontal, or even a plane at all. However, the basal boundary should be well-defined and preferably on technical grounds so that performance criteria related to the boundary will have direct significance. The two most likely technical grounds for defining the subsurface part of the boundary are (a) coincidence with a particular geological contact having significance in the hydrogeological setting, and (b) a surface paralleling the ground surface.

## Infiltration Capacity

### Field measurement

Infiltration rate can be measured in the field in accordance with the following standard method:

> ASTM D3385-75, "Standard Test Method for Infiltration Rate of Soils in Field Using Double-Ring Infiltrometers," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 6 pp.

When test results are plotted as infiltration rate against elapsed time from the beginning of the test, a curve commonly called the infiltration capacity is obtained. The ultimate infiltration rate after a more or less constant rate is achieved is of special importance as reflective of long-term capacity for infiltration.

The infiltration rate may also be estimated on the basis of previous experience with similar soils in the vicinity of the site. Ideally this estimation may amount to application of previous test results obtained for agricultural or other purposes, but the condition of the soil, the soil moisture, and the vegetation all must be integrated into the comparison.

### Indirect measurement or estimation

Infiltration rates appropriate for longer periods can be obtained by use of site-specific stream gaging data or from the curve number method of estimating runoff (see Runoff). The runoff amount is subtracted from the site-specific precipitation amount for the appropriate time period to obtain the corresponding infiltration amount. The period under consideration is always of great importance since infiltration from storms is invariably less than that from equivalent cumulative rainfall spread over a long interval.

# Ion Exchange Capacity

## Cation exchange capacity

The cation exchange capacity (CEC) is a measure of the reversibly bound cations in the mineral and organic material that may potentially be released to a leaching solution when replaced by other cations; and therefore the testing procedure consists of saturating the material with a solution of a highly soluble salt in which the high concentration of cation will replace the bound cations. The sample can then be washed and saturated with a second salt solution. The second leachate is then analyzed to total CEC. Ammonium acetate is usually chosen as the first saturating solution since it is highly buffered and the leaching solution emerges with the same pH as the solution added. The ammonia is an easily measured parameter. Results may be biased low if samples are high in clay minerals or calcareous materials due to the incomplete replacement of adsorbed hydrogen and aluminum ions by ammonium acetate. CEC may be measured according to procedures specified in these references:

> "Cation Exchange Capacity," Procedures for Handling and Chemical Analysis of Sediment and Water Samples, EPA/CE-81-1, U. S. Army Corps of Engineers, Waterways Experiment Station, 1981, pp 3-20 to 3-27.
>
> "Cation Exchange Capacity," Chapter 57, Methods of Soil Analysis: Part 2 - Chemical and Microbiological Properties, American Society of Agronomy, 1965, pp 891-901.

## Anion exchange capacity

Anion exchange capacity is analogous to CEC and is a measure of positive charges. Many of the transition elements and most of the actinides are adsorbed on soils as anions. Phosphoric acid is used as the exchange medium. Anion exchange may be measured according to procedures in the following reference:

> "Anion Exchange Capacity (Mehlich)," Section 7:3:4, Textbook of Soil Chemical Analyses, Chemical Publishing Co., New York, 1971, pp 105.

## Lithology and Soils

The evaluation of lithology and soils often has its greatest importance in correlating material zones from place to place within the site and with strata found well beyond the immediate site boundaries, i.e., outside the area of intense subsurface investigation. The viewpoint is heavily geological; otherwise, the tests and other methods of describing and documenting are already covered under Soil Classification, Rock Classification, Grain-Size Distribution, and Mineralogy and Clay Mineralogy. The experienced geologist is capable of adequately generalizing and extending over a large area the characteristics of rock and soil otherwise obtained by detailed examination of only samples recovered from the subsurface. Accordingly the methods of evaluation should be based on geological criteria emphasizing texture, fabric, grain size, and gross mineralogy; e.g., Figure A.3 shows one established method of describing grain shape and roundness. It is recommended, however, that this geological characterization of lithology and soils over the large area be made in terms of the methods suggested under the other appendix headings to the extent needed to assure technical continuity, e.g., grain-size descriptions should follow the methods given under Grain-Size Distribution.

One of the important aspects of lithology of strata is concerned with the gross mineralogy of each. Although some sites may be dominated by clastic sedimentary strata largely composed of quartz, it is also quite common to find two or more mineralogically distinct types of strata at other sites. The more common major constituents to be checked in a stratum include: quartz, calcite, dolomite, clay minerals, glass, and organic matter. Corresponding stratum types may be siltstone, marl, dolomite, clay or shale, volcanic ash or tuff, and carbonaceous shale. An experienced geologist is well qualified to recognize visually and describe these specific material types in the course of the field investigation.

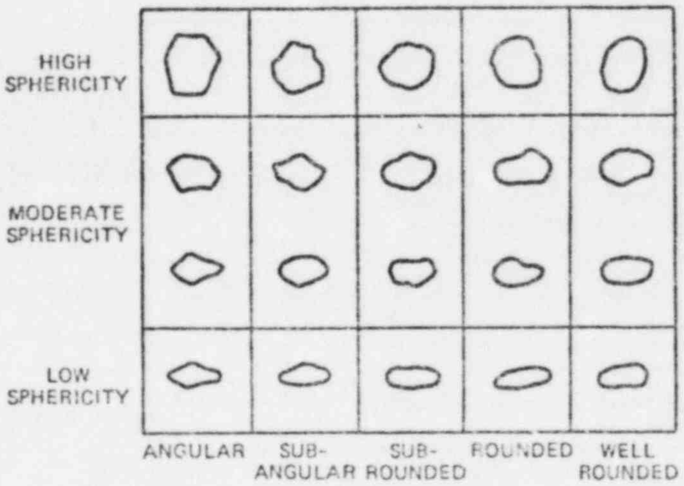


Figure A.3. Visual estimation of roundness and sphericity

## Material Color

Positive color identifications obtained by comparison with a standard color chart are recommended for systematic descriptions appropriate at LLW sites. Charts especially prepared for describing the colors of soil and rock are available from the Munsell Color Company, 2441 North Calvert Street, Baltimore, MD 21218. The ASTM standard method of specifying color by the Munsell system is:

> ASTM D1535-80, "Standard Method of Specifying Color by the Munsell System," Annual Book of ASTM Standards: Part 27 - Paint, Tests for Formulated Products and Applied Coatings, 23 pp.

More specifically and in an abbreviated but sufficient treatment, the use of color in visually classifying or describing rock (also appropriate for soil since the range of colors is similar) is reviewed in the following guidance:

> "Rock-Color Chart," Geological Society of America, 1963 (reprinted).

Finally, color plays an important part in the visual description of soil samples according to ASTM D2488 (see Visual Description).

## Material Densities

The measurement techniques presented below are in terms of bulk density $\gamma_m$. Measurements are made either in the laboratory or in the field.

### Laboratory measurement

Laboratory techniques for density determinations of soil/rock specimens follow either volumetric methods or displacement methods. Volumetric methods are particularly suitable for rock core and for soils which can be cut and trimmed to known cylindrical or parallelepiped dimensions. Mass and linear dimensions should be measured with an accuracy which will result in a volumetric error of less than 1 percent. Corps of Engineers standards for a volumetric method using a ring specimen cutter and a displacement method involving immersion of a wax-coated specimen are as follows:

> "Volumetric Method," Appendix II, Section 3, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp II-2 to II-8, II-11 to II-12.
>
> "Displacement Method," Appendix II, Section 4, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp II-8 to II-11, II-13.

### Field measurement

Surface methods. Four surface techniques are commonly used for quantitative field determinations of density--sand-cone, rubber balloon, drive-cylinder, and nuclear methods. All four of these techniques have applicable standard test methods which are as follows:

> ASTM D1556-64 (Reapproved 1974), "Standard Test Method for Density of Soil in Place by the Sand-Cone Method," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 4 pp.
>
> ASTM D2167-66 (Reapproved 1977), "Standard Test Method for Density of Soil in Place by the Rubber-Balloon Method," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 4 pp.
>
> ASTM D2937-71 (Reapproved 1976), "Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 5 pp.

ASTM D2922-81, "Standard Test Methods for Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 10 pp.

Regarding the first three methods it can be said that acceptable results can be obtained by any if applied properly, but generally the preference based on expected accuracy is according to the order listed. The rubber balloon method is usually simpler and faster than the other two methods. The drive cylinder method cannot be used effectively in soils with gravel or shell fragments or in soils susceptible to falling from the tube. The fourth, the nuclear method, is a rapid, nondestructive method suitable for characterizing density variations over a site. Experience indicates less variation and more accuracy than the sand-cone method. Drawbacks to the nuclear method are (a) possible safety hazard in using radioisotopes, (b) variation in volume sampled depending on material type, and (c) accuracy depends on careful and consistent calibration and standardization procedures.

Subsurface methods. Bulk density of soil and rock can be determined from gamma-gamma borehole logs. Descriptions of gamma-gamma or formation density logging equipment, field procedures, and interpretation can be found in reports by Department of the Army (1979), Keys and MacCary (1971), Schlumberger Limited (1972), International Atomic Energy Agency (1971), Crosby et al. (1981), and other sources referenced by these publications. Basically, a radioactive source in a borehole sonde emits gamma rays which undergo various energy-degrading interactions with electrons in the surrounding soil or rock. A gamma ray detector in the sonde detects back-scattered radiation; the logarithm of the count rate is about inversely proportional to the electron density, which for most materials is directly proportional to formation $\gamma_m$. Thus, after calibration, gamma-gamma log response can be related to the bulk density of the formation.

Gamma-gamma logs can be obtained in dry or fluid-filled boreholes which can be cased or uncased. Calibration is essential for quantitative interpretation of gamma-gamma logs; the most practical procedure for LLW site studies is to calibrate by direct correlation of logs in selected boreholes with laboratory-determined $\gamma_m$ values of samples from the boreholes. This procedure allows count rate versus $\gamma_m$ curves to be developed for each lithology encountered; $\gamma_m$ can then be determined from gamma-gamma logs in other boreholes. Quantitative analysis of gamma-gamma logs should not be attempted where a caliper log indicates washout zones, since the response is dependent on borehole diameter. (Decentralized and multiple-detector sondes minimize borehole effects and are preferable to centered sonde systems.) Also, quantitative analysis should only be attempted in boreholes of the same diameter and condition (i.e., cased or uncased) as the ones used for the correlation calibration. Beyond these precautions the following equation, determined for each lithology, can be used to calculate $\gamma_m$ values:

$$\log CR = e - f\ \gamma_m$$

where CR is the gamma-gamma count rate and e and f are empirical constants determined from the correlation calibration procedure for each lithology. Alternatively, gamma-gamma sondes can be calibrated in standard test pits; however, because of source decay and possible change in detector sensitivity, field standardization with blocks of various density, such as aluminum, is required to maintain accuracy (Department of the Army 1979). Gamma-gamma logging can provide a continuous log of bulk density in a borehole superior in coverage to the selected point determinations from sampling programs. Qualitatively, gamma-gamma logs can be used in conjunction with other borehole logs for lithologic characterization and lateral stratigraphic correlation.

## References

J. W. Crosby, B. Konstantinidis, and P. Davis, "Geotechnical Applications of Borehole Geophysics," *Journal, Geotechnical Engineering Division*, American Society of Civil Engineers, Vol. 107, 1981.

Department of the Army, "Geophysical Exploration," Engineer Manual 1110-1-1802, U. S. Army Corps of Engineers, 1979.

International Atomic Energy Agency, "Nuclear Well Logging in Hydrology," Technical Reports Series No. 126, Vienna, 1971.

W. S. Keys and L. M. MacCary, "Application of Borehole Geophysics to Water-Resources Investigations," Chapter E1, Book 2, *Techniques of Water-Resources Investigations*, U. S. Department of the Interior, Geological Survey, 1971.

Schlumberger Limited, *Schlumberger Log Interpretation: Volume I - Principles*, New York, 1972.

Gamma spectral logging. Gamma spectral logging is a procedure by which not only gamma emission rates but also gamma energy spectra are obtained. This technique allows location of zones of radionuclide migration as well as identification of specific radioisotopes involved. Although single-channel analyzers with variable energy window adjustments can be used to search selectively for specific radionuclides, a preferable procedure is to use a multichannel spectral analyzer (Keys and MacCary, 1971; Eggers, 1976). Only $^{40}$K and members of the $^{238}$U and $^{232}$Th decay series occur naturally in significant quantities in soil and rock; Figure A.4 from Keys and MacCary (1971) is a stylized representation of the spectra of these gamma sources. Depending on the concentrations of each source, the measured background spectrum will consist of the superposition of the individual spectra.

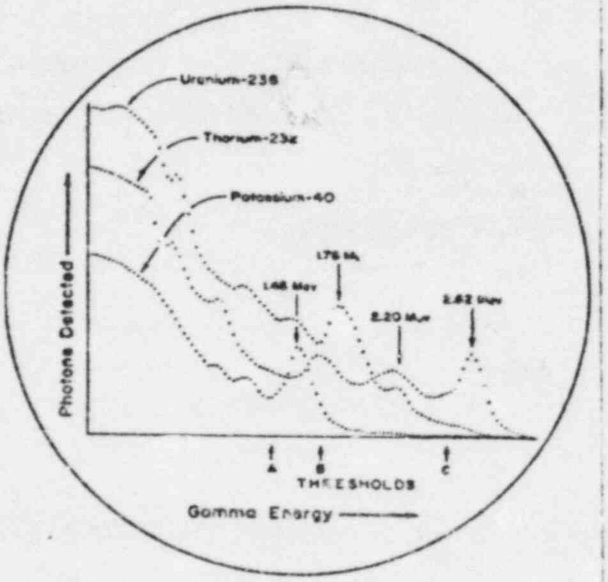


Figure A.4. Stylized gamma spectra of naturally occurring gamma sources (from Geological Survey)

Spectra of migrating radionuclides will be superposed on the background spectrum. Gamma spectral logging at LLW sites (Eggers 1976) has identified $^{60}$Co, $^{134}$Cs, and $^{137}$Cs locally. Generally, because of the time required to obtain a gamma spectrum at a given depth, only a few selected horizons will be examined. Selection of horizons is facilitated by inspection of the gamma emission rate log. Gamma spectra might be obtained, for example, above, in, and below zones showing suspect changes in gamma emission rate. Using spectral stripping methods, it is possible to determine concentrations of the naturally occurring radionuclides as well as the migrating radionuclides. Eggers (1976) reports a radionuclide concentration detection limit of 0.1 pCi/g. The radius of investigation of gamma logging tools is 0.5 m or less, depending on

## Material Radioactivity

There are both laboratory and field procedures for testing levels of radioactivity and identifying radionuclides in the soil and rock materials at a LLW site. Both approaches are important and have their places in characterization.

### Field methods

Natural gamma emission rates are normally measured in borehole geophysical logging programs where the objectives are lithologic identification and stratigraphic correlation between boreholes according to radionuclides occurring naturally. Recording the gamma energy spectra in a borehole at various depths can identify the specific radionuclide sources, both natural and contaminants; gamma spectral borehole logging is not a common part of site characterization at present but deserves attention.

Gamma emission logging. Procedures, equipment, and interpretation techniques for natural gamma logging can be found in Keys and MacCary (1971), Department of the Army (1979), and other sources which are referenced in these publications. A borehole sonde containing a scintillation detector system (commonly using a thallium-activated sodium iodide crystal) is used to record gamma emission rate as a function of depth. Since a natural gamma log can be run repeatedly in a given borehole, it can be used as a monitoring technique to detect radionuclide migration. The monitoring function is based on the following consideration: radionuclide migration will be detected as increased radiation rates, in a given depth range, over the normal background levels. For gamma logging to serve as a monitoring technique, boreholes should be cased and capped at the bottom to prevent ground water intrusion into the borehole. Also, the same logging system should be used, if possible, each time, and should be carefully calibrated using a small, standard gamma source just prior to logging a hole.

Monitor boreholes should be installed and then logged several times prior to any possible radionuclide migration from disposal trenches; these logs form a background catalog for comparison with subsequent gamma logs to detect contaminant migration. Ideally, the catalog should include gamma logs acquired before trench construction, during trench filling, and immediately after trench closure. As a minimum, the catalog should include several logs acquired very shortly after trench closure. Each time a monitor borehole is logged, the record should be continued to the maximum elevation possible above the borehole (1.5 m typically, depending on tripod height). These measurements are another source of monitoring data and can be viewed as a supplement to health physics air-monitoring activities (environmental monitoring above the ground surface is beyond the scope of this report).

soil or rock density and gamma ray energy; thus the monitor borehole would have to be closer than 0.5 m to the path of migrating radionuclides for detection by gamma logging.

### Beta emission and spectral logging

Efforts aimed at developing a system for measuring beta emission in the field have been under way for some time, particularly at Pacific Northwest Laboratory. The system includes a probe for logging in uncased boreholes. Spectra are recorded in the borehole and then analyzed in the office for individual radionuclides by stripping methods using a computer program. The system has been applied to surface surveys also. The anticipated importance of this promising instrumentation and field techniques is contingent upon the continued success of developmental efforts.

### Laboratory methods

The sampling and testing of soil and rock is an important method for determining the amounts of radionuclides that have accumulated, particularly in the near-surface zone. The radionuclides may include naturally occurring potassium, thorium, and uranium in addition to recent contributions from the air, for example. It is necessary that the abundances of gamma emitters such as $^{137}$Cs , $^{134}$Cs , $^{60}$Co , $^{54}$Mn , $^{103}$Ru , and $^{106}$Ru ; beta emitters such as $^{90}$Sr ; and alpha emitters such as $^{241}$Am , $^{238}$Pu , and $^{239}$Pu be accurately measured since all are conservatively suspected of being present in LLW. Adequate documentation may sometimes take the form of gross alpha, gross beta, and gross gamma of samples of the soil. Preconstruction baseline concentrations or levels of radioactivity are usually considered essential. As a sequel to the characterization some sites may need to be sampled and tested periodically during operation and after closure as a part of the monitoring program.

Sampling. Methods for taking soil samples near the surface are described in the following procedure:

> B-05 "Soil Sampling," EML Procedures Manual, HASL-300, U. S. Department of Energy, Environmental Measurements Laboratory, 1981, 11 pp.

Samples below the near-surface zone should be recovered using the soil and rock sampling techniques summarized in Part II.

Background radiation data for vegetation at the LLW may also be documented. Procedures similar to those for sampling soil may be employed. The vegetation is not included as a part of the site in this report, but in a broad sense it can be regarded as part of the near-surface zone and also perhaps usefully reflective of the radioactivity in soil immediately below.

Gamma emitters. Gamma emitters may be analyzed in the laboratory to an activity level of approximately 1 nCi for most nuclides by direct gamma spectral analysis of the soil using either a NaI (Tl, or Ge(Li) detector mated to a multichannel pulse height analyzer. The Ge(Li) detector has a definite advantage for complex spectra because of the high resolution attainable for energy peak separation. Any gamma-emitting nuclide of significant concentration will be readily detected by this procedure. The following practice is recommended.

> ASTM D3649-78, "Standard Practice for Gamma-Ray Spectroscopy," Annual Book of ASTM Standards: Part 31 - Water, 12 pp.

This practice applies to solid as well as aqueous samples though a correction for density may be necessary in the efficiency factor.

Beta and alpha emitters. Specific beta emitters and alpha emitters can be measured in the laboratory with radiochemical separation. The following standard procedures are recommended:

> EML Procedures Manual, HASL-300, U. S. Department of Energy, Environmental Measurements Laboratory, 1981.

| | |
|---|---|
| strontium | E-Sr-01 "Radiochemical Determination of Strontium-90," 29 pp. |
| americium | E-Am-02 "Radiochemical Determination of Americium (Soil)," 6 pp. |
| plutonium | E-Pu-06 "Radiochemical Determination of Plutonium in Kilogram Soil Samples," 6 pp. |

Dosimeter measurements. Almost all nuclear facilities utilize a system of thermoluminescent dosimeters (TLD's) to measure the gamma background radiation around a facility and to quantitate any increase in exposure due to facility operation. This TLD system for environmental monitoring is outside the scope of site characterization and monitoring discussed in this report but can still be regarded as an existing source of useful supplemental information. Results may be expressed either as an integrated dose (mR) or dose rate (mR/hr). Guidance on the technique is found in:

> C-04 "Thermoluminescent Dosimetry," EML Procedures Manual, HASL-300, U. S. Department of Energy, Environmental Measurements Laboratory, 1981, 11 pp.

Again this sampling and analysis falls in the realm of environmental monitoring and is largely beyond the scope of the present report.

# References

Department of the Army, "Geophysical Exploration," Engineer Manual 1110-1-1802, U. S. Army Corps of Engineers, 1979.

D. E. Eggers, "The Applications of Borehole Geophysics to the Selection and Monitoring of Nuclear Waste Disposal Sites," *17th U. S. Symposium on Rock Mechanics, Site Characterization*, 1976.

W. S. Keys and L. M. MacCary, "Application of Borehole Geophysics to Water-Resources Investigations," Chapter E1, Book 2, *Techniques of Water-Resources Investigations*, U. S. Department of the Interior, Geological Survey, 1971.

## Material Temperature

Material temperature measurements can be useful for defining site media in the hydrological system and also for monitoring for changes that might signal changes in water chemistry. For either purpose the interrelationship to seasonal effects of the surface environment must be carefully documented to avoid unmanageable complications. Accordingly the development of at least one year of temperature time history is recommended as a part of complete temperature testing, particularly when included as a part of a monitoring program.

Useful temperature measurements may be made directly on ground water discharging from a well with a mercury thermometer or by testing recovered water samples (see Ground Water Chemistry). Downhole temperatures, however, are preferred for details and to pinpoint stratification in ground water. Special logging sensors can produce accurate measurements, but the passage of the probe itself can disturb the temperature profile. Temperature logging is mostly limited to the saturated zone. Well temperatures are representative to the extent that continuity and thermal stability are maintained between the well and surrounding formation. Drilling mud temporarily disrupts the stability, for example.

Temperature measurements in boreholes are usually obtained with thermistor sensors which exhibit changes in electrical resistance as a function of temperature. A device is arranged as one leg of a wheatstone bridge circuit and measurements are commonly accurate to 0.1°C. Commercial thermistor probes are also available for measuring temperature to a depth as great as 3 m.

A full summary of temperature logging in boreholes is provided by Keys and MacCary (1971). Brown et al. (1977) review the concepts and observational strategy involved.

### References

R. H. Brown et al., eds., Ground-Water Studies, United Nations Educational, Scientific, and Cultural Organization, Paris, 1977.

W. S. Keys and L. M. MacCary, "Application of Borehole Geophysics to Water-Resources Investigations," Chapter E1, Book 2, Techniques in Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1971.

## Material Variability

Establishing variability of material within a zone or of one type is fairly straightforward but still can benefit from careful planning before and during the field investigation. Once planning is completed, the data collection and analysis should be carried out with precision in the tradition of statistical studies. Precautions worth observing are to keep the statistical analysis or summarization simple and to limit the inferences generated from it.

The standard deviations $S_i$ of selected indexing parameters are suited to quantify heterogeneity.[1] Close-interval sampling of a zone at least a few meters in thickness should provide a sufficient number of values, approaching a number that is statistically significant (perhaps 10 values). For some sites, it may be appropriate to calculate the ranges of values rather than the $S_i$, provided the values are more or less symmetrically distributed about the mean. To quantify the heterogeneity or uniformity of each zone in this manner it would be necessary to establish some guidance on acceptable limits of the statistic $S_i$ or range.

The statistical sample (collection of values) will need to be checked graphically or by calculation to reveal any trend across the zone. The presence of a trend may necessitate subdivision of the zone into two zones and regrouping of the sample values. Even with a trend of values across the zone, a somewhat similar and comparable standard deviation can still be obtained from a regression analysis.

## Material Zone Boundaries

The accurate delineation of material zones is perhaps the most important accomplishment of a successful program of site characterization. The prescription of rigid, detailed procedures for collecting and synthesizing information to establish soil and rock zones within natural settings is not warranted since considerable variation in preferred methods exists among competent engineering organizations. It is necessary, however, to conform to certain minimum general procedures, as indicated below.

### Subsurface sections

The establishment of most zone boundaries is the culmination of analysis of the subsurface conditions as represented along vertical sections through the site. A typical detailed section for another purpose, related to spillway construction, is shown in Figure A.5. The Bureau of Reclamation Earth Manual summarizes minimum requirements in preparation of their subsurface sections and delineation of material zones as follows.

> The use of sections to show the subsurface conditions believed to exist is both highly beneficial and potentially dangerous, since interpretation of conditions is necessarily involved. Where sections are used in contract documents, the information shown is limited to factual data such as the ground surface line and logs of drill holes located in their actual position with respect to the ground surface line. Although the choice of sections is made to simplify interpretation, actual locations of features such as bedrock, water table, etc., are not shown by continuous lines but only where they are encountered in each hole. The exceptions to these restrictions are the cross sections of exploratory trenches, tunnels, and shafts where conditions can be mapped by actual observation.
>
> On the other hand, sections showing the subsurface conditions believed to exist are highly desirable in geological reports, materials reports, and design data for dams, canals, and other project features. The location of the sections should be chosen so as to present in the best possible way the conditions described. Cross-valley sections are generally much more informative than a series of sections parallel to the valley. Also sections should cross physical features as nearly as practicable at right angles. A clear differentiation should always be maintained between factual and interpretive data. The commonly used system which ranges between dotted and solid lines, in which dots represent purely hypothetical interpretation, a solid line represents fact, and dashed lines define the degree of reliability

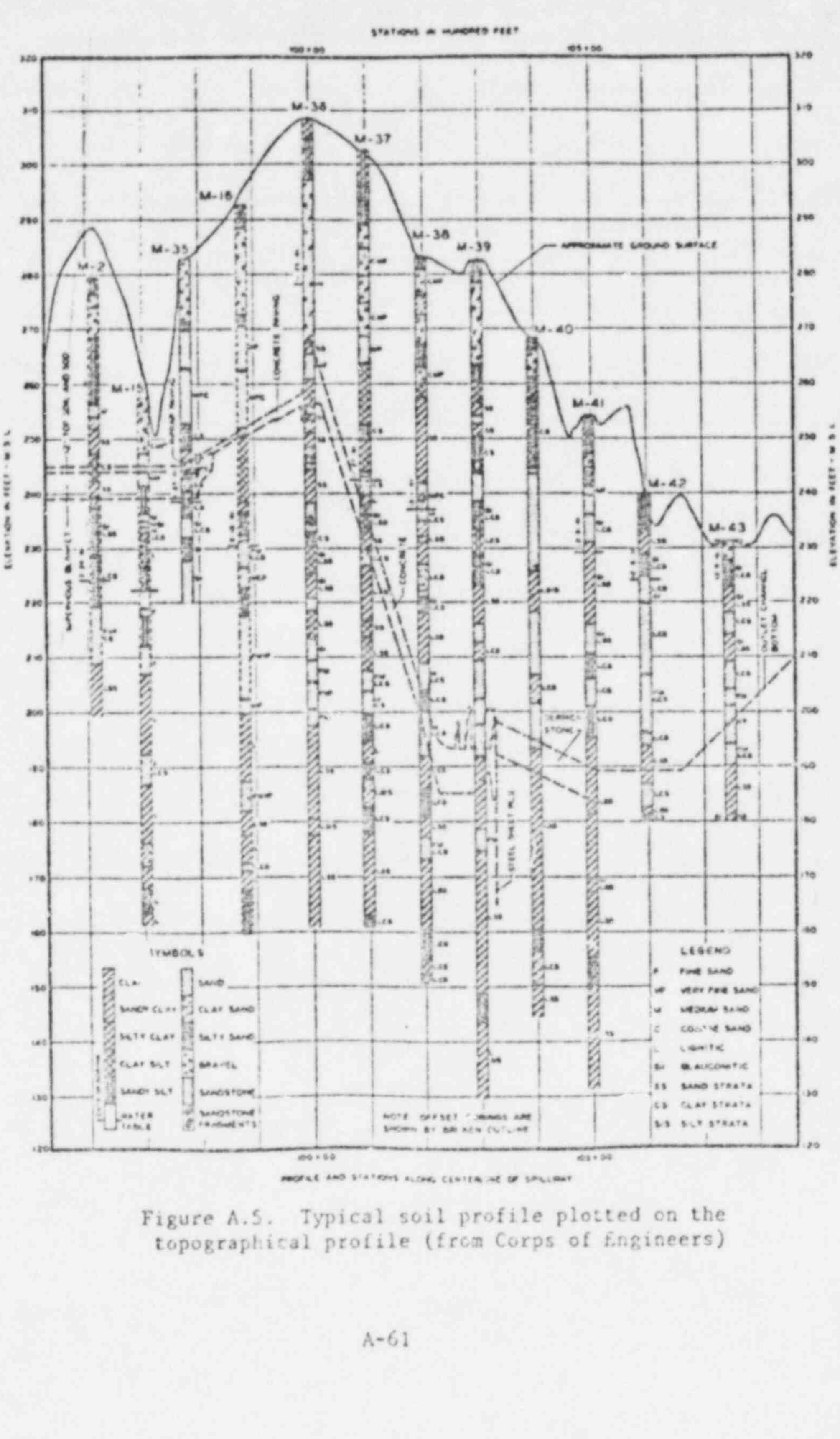


Figure A.5. Typical soil profile plotted on the topographical profile (from Corps of Engineers)

> of intermediate data according to length of dash, is recommended. Lines of different weight should not be used for this purpose but should be reserved for use as a method of emphasis. The cross section should always show the name of the person who made the interpretation and the date the interpretation was made.

In application to LLW site characterization, the tone of the foregoing guidance should be modified only moderately to accommodate the emphasis placed on quantitative measurements and descriptions of density, soil-water chemistry, color, etc., besides the more traditional basis in classification, grain size, and blow count or drilling rate.

Figures A.5 and A.6 illustrate the great variation in site complexity and the frequent dilemma encountered in attempting to represent actual conditions. The profile in Figure A.6, with a boring spacing of 30 ft (10 m), clearly reveals within the upper 50 ft a sequence of zones of sand separated by zones of fat clay at elev 290, 270, and 260 ft. On the other hand the section in Figure A.5 is complex, and considerable interpretation is exercised in establishing zones other than the gravelly bed near elev 270 ft and a clay bed near 220 ft. Additional borings at intermediate positions would be helpful in reducing the uncertainty.

## Soil boring logs

Even beyond the interpretation, a subsurface section is only as complete as the field and laboratory data obtained from the individual borings. Therefore, guidance on collection of data and samples is important to site characterization. The following soil boring records for subsurface investigations are largely from Corps of Engineers EM 1110-2-1907, but are also appropriate for soil or rock at LLW sites. A geologist or geotechnical engineer should be responsible for logging and collection of samples.

All pertinent borehole and sample data must be recorded on a log. Figures A.7 and A.8 represent a typical log of an undisturbed sample boring. Clear and accurate data are required for determination of the soil profile. Location of the samples and any observations that may contribute to an estimate of the conditions of the samples or the physical properties of the in situ soil should be recorded. The boring log should contain the following data:

a. Proper identification data such as name of project; job number or contract number; boring number; boring location referenced to survey control lines, coordinates, or some permanent object; and ground surface elevation referenced to an established datum.

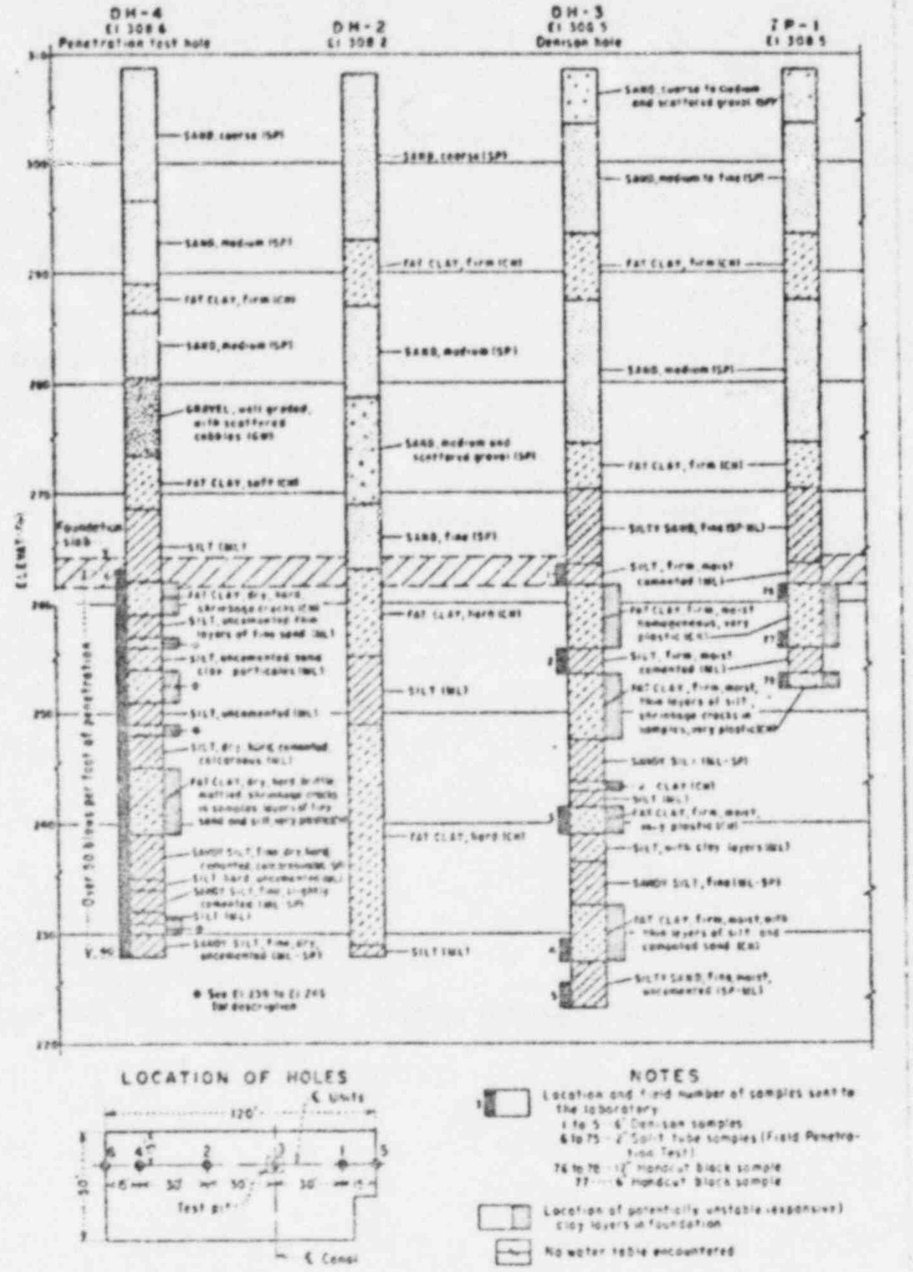
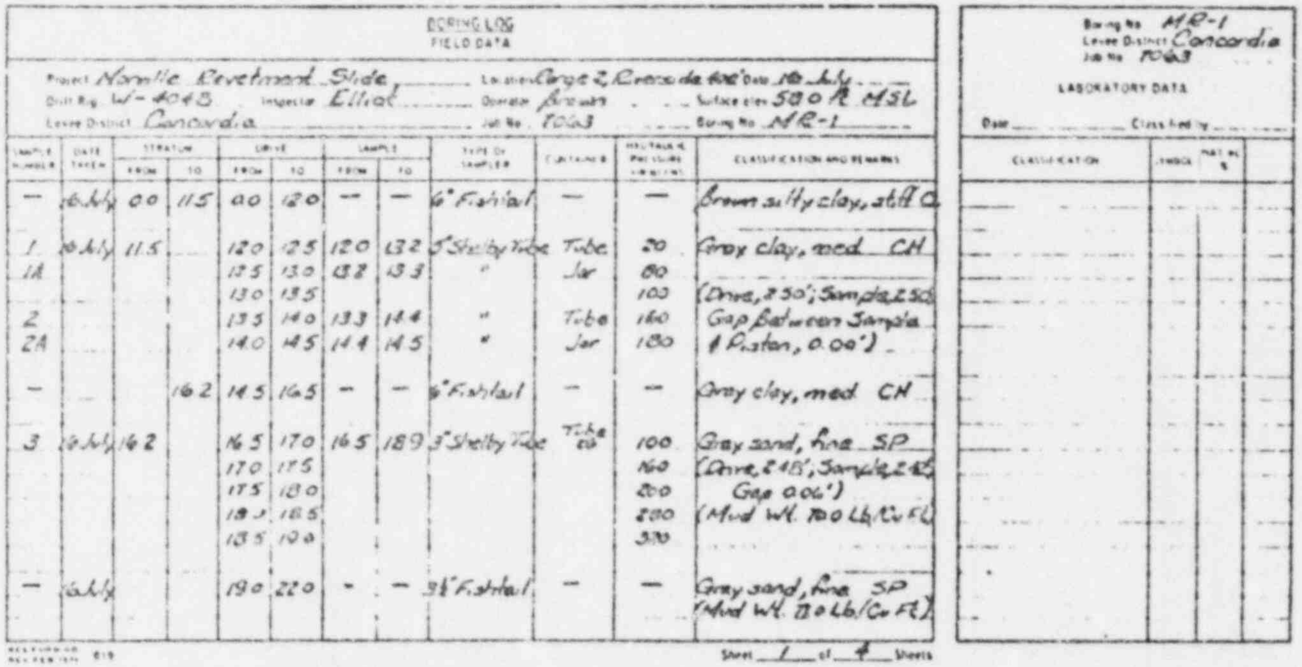


Figure A.6. Typical soil profile for foundation investigation (from Bureau of Reclamation)



BORING LOG
FIELD DATA

Project Morville Revetment Slide
Drill Rig W-4043
Inspector Elliot
Levee District Concordia
Location [illegible]
Operator Brown
Job No. 7063
Date 16 July
Surface elev 58.0 ft MSL
Boring No. MR-1

| SAMPLE NUMBER | DATE TAKEN | STRATUM FROM | STRATUM TO | DRIVE FROM | DRIVE TO | SAMPLE FROM | SAMPLE TO | TYPE OF SAMPLER | CONTAINER | HYDRAULIC PRESSURE [illegible] | CLASSIFICATION AND REMARKS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| — | 16 July | 0.0 | 11.5 | 0.0 | 12.0 | — | — | 6" Fishtail | — | — | Brown silty clay, stiff CL |
| 1 | 16 July | 11.5 |  | 12.0 | 12.5 | 12.0 | 13.2 | 5" Shelby Tube | Tube | 20 | Gray clay, med CH |
| 1A |  |  |  | 12.5 | 13.0 | 13.2 | 13.3 | " | Jar | 80 |  |
|  |  |  |  | 13.0 | 13.5 |  |  |  |  | 100 | (Drive, 2.50'; Sample, 2.50' |
| 2 |  |  |  | 13.5 | 14.0 | 13.3 | 14.4 | " | Tube | 160 | Gap Between Sample |
| 2A |  |  |  | 14.0 | 14.5 | 14.4 | 14.5 | " | Jar | 180 | & Piston, 0.00') |
| — |  |  | 16.2 | 14.5 | 16.5 | — | — | 6" Fishtail | — | — | Gray clay, med CH |
| 3 | 16 July | 16.2 |  | 16.5 | 17.0 | 16.5 | 18.9 | 3" Shelby Tube | Tube | 100 | Gray sand, fine SP |
|  |  |  |  | 17.0 | 17.5 |  |  |  |  | 160 | (Drive, 2.48'; Sample, 2.42' |
|  |  |  |  | 17.5 | 18.0 |  |  |  |  | 200 | Gap 0.06') |
|  |  |  |  | 18.0 | 18.5 |  |  |  |  | 280 | (Mud Wt. 70.0 Lb/Cu Ft) |
|  |  |  |  | 18.5 | 19.0 |  |  |  |  | 330 |  |
| — | 16 July |  |  | 19.0 | 22.0 | - | — | 3½" Fishtail | — | — | Gray sand, fine SP<br>(Mud Wt. 73.0 Lb/Cu Ft) |

Sheet 1 of 4 Sheets

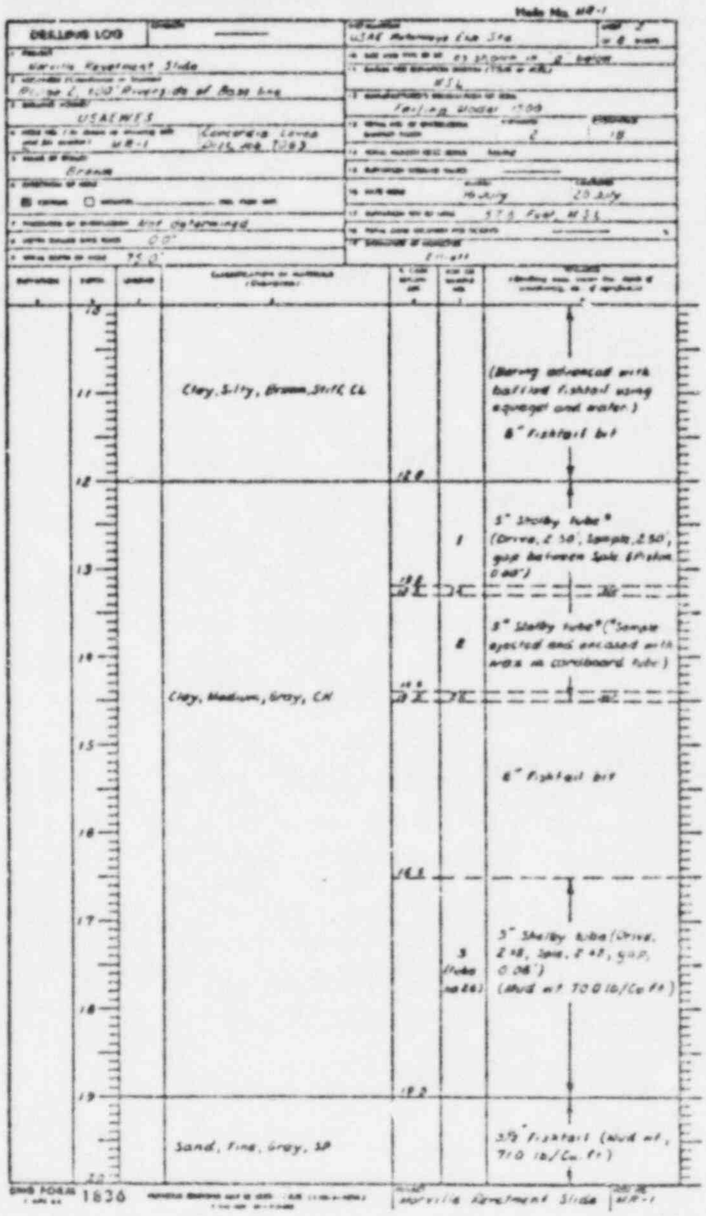
Boring No. MR-1
Levee District Concordia
Job No. 7063

LABORATORY DATA

Date ______ Classified by ______

| CLASSIFICATION | SYMBOL | NAT WC % |  |
|---|---|---|---|
|  |  |  |  |

Figure A.7. Example field and laboratory data sheet for undisturbed samples (from Corps of Engineers)



Hole No. HR-1

**DRILLING LOG**

USAE Waterways Exp Sta

Morville Revetment Slide

USAEWES

HR-1

Brown

Not determined

0.0'

75.0'

as shown in 2 below

MSL

Failing Model 1500

| | | | |
|---|---|---|---|
| 2 | 18 | | |
| 16 July | 20 July | | |

57.5 Feet, MSL

| | | | | | | |
|---|---|---|---|---|---|---|
| | 10–12 | | Clay, Silty, Brown, Stiff CL | | | (Boring advanced with baffled fishtail using aquagel and water.)<br>6" Fishtail bit |
| | 12 | | Clay, Medium, Gray, CH | 12.0 | 1 | 5" Shelby tube* (Drive, 2.50', Sample, 2.50', gap between Sple & Piston 0.00') |
| | | | | | 2 | 5" Shelby tube* (*Sample ejected and encased with wax in cardboard tube) |
| | 15–16 | | | | | 6" Fishtail bit |
| | 17–18 | | | 16.5 | 3<br>(Tube no 86) | 5" Shelby tube (Drive, 2.48, Sple, 2.47, gap, 0.08')<br>(Mud wt 70.0 lb/Cu ft) |
| | 19–20 | | Sand, Fine, Gray, SP | 19.2 | | 3½" Fishtail (Mud wt, 71.0 lb/Cu. ft) |

ENG FORM 1836

Morville Revetment Slide

HR-1

Figure A.8. Example log of soil boring (from Corps of Engineers)

b. Identification of the drill rig and names of the rig operator and inspector are required should questions later arise concerning the field operations.

c. Record size of the borehole and the method of advance, with a designation of the tools used (including type and size of sampler), casing set, and/or drilling fluid used. Composition of drilling mud and its unit weight should be determined periodically, and any changes in consistency should be noted. Any drilling-fluid loss should also be noted, with depths and approximate amounts of loss given for each occurrence. Artesian flow and odors should also be recorded.

d. A detailed record of the depths of all major changes in character of the soil (such as classification, color, water content, consistency, etc.), and detailed descriptions of each major stratum must be made. Descriptions of the soil should be based on examination of samples taken from each stratum and should include visual classification according to the Unified Soil Classification System. If the sample is not extruded, a description of the soil at the top and bottom of the tube should be given. Changes that occur in zones not sampled can usually be determined by the action of the drill rig and bit, and changes in the drilling-fluid return. When a change is detected, the penetration of the bit should be stopped, the depth determined to the nearest 0.1 ft (3 cm), and sample taken immediately. This ensures that a sample of each stratum is obtained before additional changes are encountered.

e. When the depth to the ground water table can be ascertained, it should be recorded along with time of recording and depth of hole and casing when recorded.

f. Samples should be numbered consecutively with depth, and the sample numbers and dates on which the samples were taken should be recorded. A representative, disturbed specimen (scraps) of each undisturbed sample should be sealed in a container before the undisturbed sample is preserved. This specimen should be identified by the same number as that of the undisturbed sample with a letter suffix added to distinguish it from the undisturbed sample. The top and bottom of each drive should be determined to the nearest 0.1 ft (3 cm) and recorded.

g. The length of drive, length of sample obtained, and gap between the bottom of the sampler piston and the top of the sample should be recorded to the nearest 0.01 ft (3 cm). These data may later be used to compute the sample recovery ratios. The length of drive should be determined by measuring the distance the drill rod was moved with respect to a reference mark on the piston-rod extension. The length of sample recovered, and the gap between the bottom of the sampler piston and the top of the sample, may be measured when the sampler head, with the piston locked in position, is removed from the sampler tube. When hydraulic pressure is used to advance the sampler, the pressure should be recorded for each 0.5 ft (15 cm) of penetration. This gives a qualitative estimation of the penetration resistance of the soil, which may be of value in estimating the in situ soil condition. The rate of penetration of the sampler should also be recorded, along with the type of sample container used. Any unusual change in drill action, obstructions encountered, and/or other observations should also be noted on the log of boring.

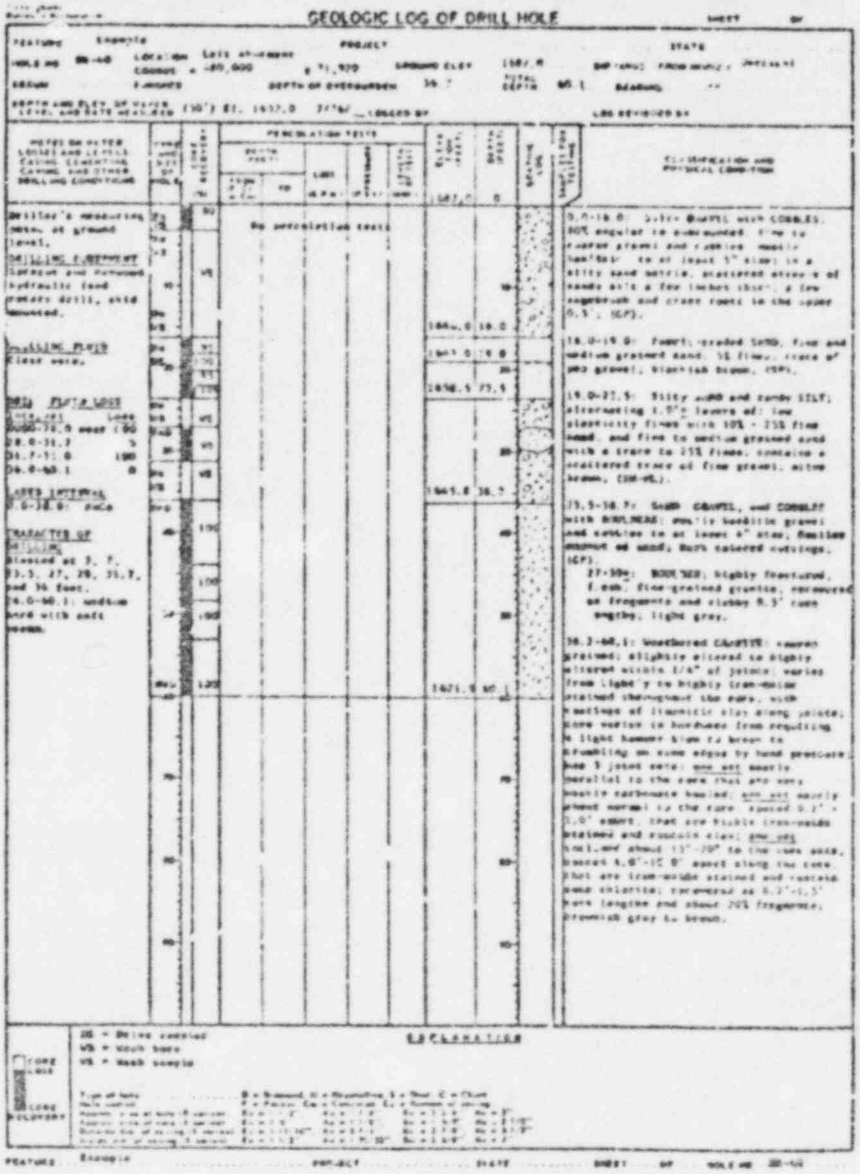
Rock boring logs

For investigating rock materials, the general requirements above should be supplemented with particular attention to geological aspects. The Bureau of Reclamation summarizes the accepted geological viewpoint approximately as follows. An example of a rock core log is shown in Figure A.9. As with soils investigations, a geologist should have responsibility for logging and sampling of rock.

Description of rock cores. The basic objective of describing rock cores is to provide a concise record of the important geological and physical characteristics of the core materials.

Description of the rock core should include its typical rock name followed by data on its lithologic and structural features, physical condition including alteration, and any special geologic, mineralogic, or physical features pertinent to interpretation of the subsurface conditions. Attention should be given to: (a) the attitude and severity of joints, seams, or fractures and whether open or filled, as well as to evidence of shearing, crushing, mineralization, or faulting; (b) planes of bedding, lamination or layering, and the ease of splitting along such planes; (c) color, grain size and shape, and (in sedimentary rocks like sandstone) the mineralogy of the grains and cementing material as well as the extent to which the cementing material occupies the intergrain spaces; and (d) the degree of alteration or weathering and hardness of the rock. In the latter case supplementary phrases such as "breaks with sharp hammer blow," "crumbles easily in the fingers," or "hard as common brick" are helpful. Estimates of the average length of core pieces in successive sections of the hole aid in calling attention to changes in formations or rock conditions in the hole not otherwise recognizable but nonetheless useful in evaluating subsurface conditions in the engineering sense. Percent core recovery is often a particularly useful index. Consideration should be given to photographing all core (in core boxes) shortly after recovery as a supplement to the rock boring logs.

The purpose of the coring and logging of rock is to secure evidence of the in-place condition of the rock; therefore, it is imperative that extreme care be taken to prevent, or minimize, the damage to the rock core that might be the result of using improper drill tools or the improper conduct of the core drilling process. This type of damage, often



GEOLOGIC LOG OF DRILL HOLE

Figure A.9. Example log of soil and rock boring (from Bureau of Reclamation)

called mechanical damage, may have a marked effect on the amount and condition of the core recovered, particularly in soft, friable, or severely fractured rock. Mechanical damage to rock core can be minimized by the proper selection of drill tools such as the drill bit and core barrel, and by employing a driller who is experienced in rock coring.

Adequate logs or descriptions of rock core can be prepared solely through visual examination of the core piece by piece, with the occasional aid of simple field tests. Detailed microscopic or laboratory testing to define rock type or mineralogy is generally necessary only in special cases.

## Laboratory data

The addition of other parameter data to records of borings such as in Figures A.5 to A.9 will facilitate the important decisions of where to place zone boundaries. Figure A.10 shows how field penetration resistance and water content data have been plotted in the office by the Bureau of Reclamation for a much more useful boring profile. The average interval for these data is, however, substantially greater than is suggested in the Task 1 report for properly investigating LLW sites. Figure A.11 similarly shows a profile prepared in the office and made more informative by incorporation of water contents, strengths, and other parameter data determined in the laboratory. Despite the large sampling interval (exceeding 30 cm on the average), the basis for placing a zone boundary, for example, at the 25.3 ft-depth, has been made much sounder. Specific guidance on the parameters to use in zoning has been presented in the Task 1 report. The tests for evaluating the parameters are given elsewhere in this Appendix.

## Summary

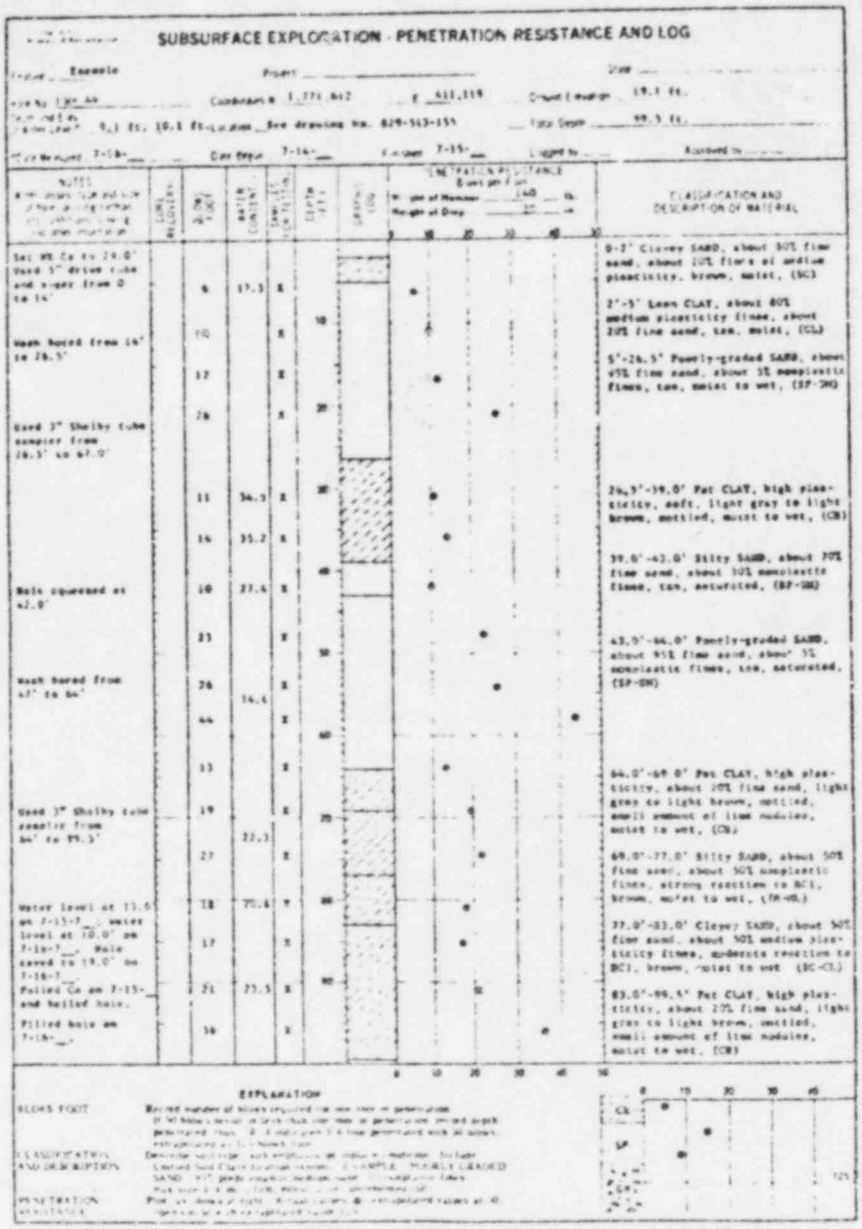
In summary, the sequence of steps for choosing zone boundaries are:

a. Collect and record detailed information during boring and sampling.

b. Supplement boring data with results of field and laboratory testing.

c. Present the results of field and laboratory investigations in a condensed form as soil and rock profiles and sections.

d. Choose the boundaries where descriptive parameters and physical and chemical properties indicate material discontinuity in groups of neighboring holes.



## SUBSURFACE EXPLORATION · PENETRATION RESISTANCE AND LOG

Feature Example  Project ____  State ____

Hole No. TP-66  Coordinates N 1,771,842  E 611,119  Ground Elevation 19.1 ft.

9.1 ft. 10.1 ft. Location See drawing No. 829-513-155  Total Depth 99.5 ft.

7-16-__  Date Begun 7-14-__  Finished 7-15-__  Logged by ____  Approved by ____

PENETRATION RESISTANCE
Blows per Foot
Weight of Hammer 140 lb.
Height of Drop 30 in.

| Blows per foot | Water content |
|---|---|
| 6 | 17.3 |
| 10 | |
| 17 | |
| 26 | |
| 11 | 34.5 |
| 14 | 35.2 |
| 10 | 27.6 |
| 23 | |
| 26 | 14.6 |
| 44 | |
| 13 | |
| 19 | |
| | 22.3 |
| 27 | |
| 18 | 20.6 |
| 17 | |
| 21 | 23.5 |
| 16 | |

NOTES

Set NX Cs to 14.0'. Used 5" drive tube and auger from 0 to 14'

Wash bored from 14' to 26.5'

Used 3" Shelby tube sampler from 26.5' to 47.0'

Hole squeezed at 42.0'

Wash bored from 47' to 64'

Used 3" Shelby tube sampler from 64' to 99.5'

Water level at 11.6' on 7-15-7__; water level at 10.0' on 7-16-7__. Hole caved to 19.0' on 7-16-7__.

Pulled Cs on 7-15-__ and bailed hole.

Filled hole on 7-16-__.

CLASSIFICATION AND DESCRIPTION OF MATERIAL

0-2' Clayey SAND, about 80% fine sand, about 20% fines of medium plasticity, brown, moist, (SC)

2'-5' Lean CLAY, about 80% medium plasticity fines, about 20% fine sand, tan, moist, (CL)

5'-26.5' Poorly-graded SAND, about 95% fine sand, about 5% nonplastic fines, tan, moist to wet, (SP-SM)

26.5'-39.0' Fat CLAY, high plasticity, soft, light gray to light brown, mottled, moist to wet, (CH)

39.0'-43.0' Silty SAND, about 70% fine sand, about 30% nonplastic fines, tan, saturated, (SP-SM)

43.5'-64.0' Poorly-graded SAND, about 95% fine sand, about 5% nonplastic fines, tan, saturated, (SP-SM)

64.0'-69.0' Fat CLAY, high plasticity, about 20% fine sand, light gray to light brown, mottled, small amount of lime nodules, moist to wet, (CH)

69.0'-77.0' Silty SAND, about 50% fine sand, about 50% nonplastic fines, strong reaction to HCl, brown, moist to wet, (SM-ML)

77.0'-83.0' Clayey SAND, about 50% fine sand, about 50% medium plasticity fines, moderate reaction to HCl, brown, moist to wet (SC-CL)

83.0'-99.5' Fat CLAY, high plasticity, about 20% fine sand, light gray to light brown, mottled, small amount of lime nodules, moist to wet, (CH)

EXPLANATION

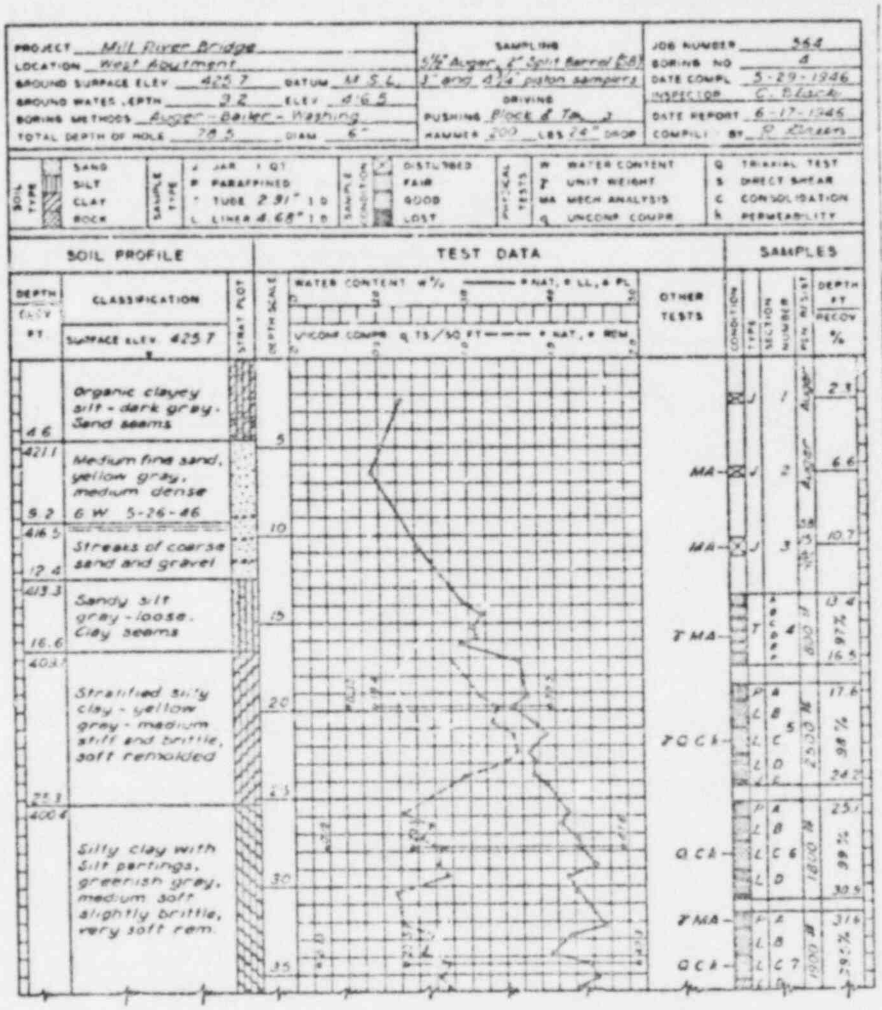
BLOWS FOOT

CLASSIFICATION AND DESCRIPTION

PENETRATION RESISTANCE

FEATURE Example  PROJECT ____  STATE ____  HOLE NO. TP-66

Figure A.10. Example log of penetration resistance and drill hole data (from Bureau of Reclamation)



PROJECT Mill River Bridge
LOCATION West Abutment
GROUND SURFACE ELEV 425.7 DATUM M.S.L.
GROUND WATER DEPTH 9.2 ELEV 416.5
BORING METHODS Auger - Bailer - Washing
TOTAL DEPTH OF HOLE 78.5 DIAM 6"

SAMPLING
5½" Auger, 2" Split Barrel (SB)
3" and 4¼" piston samplers
DRIVING
PUSHING Block & Ta. 3
HAMMER 200 LBS 24" DROP

JOB NUMBER 364
BORING NO 4
DATE COMPL 5-29-1946
INSPECTOR C. Black
DATE REPORT 6-17-1946
COMPILED BY R. Green

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| SOIL TYPE | ☐ SAND | SAMPLE TYPE | J JAR 1 QT | SAMPLE CONDITION | ☒ DISTURBED | PHYSICAL TESTS | W WATER CONTENT | | Q TRIAXIAL TEST |
| | ▥ SILT | | P PARAFFINED | | ☐ FAIR | | γ UNIT WEIGHT | | S DIRECT SHEAR |
| | ▨ CLAY | | T TUBE 2.91" I.D. | | ☐ GOOD | | MA MECH ANALYSIS | | C CONSOLIDATION |
| | ▩ ROCK | | L LINER 4.68" I.D. | | ■ LOST | | q UNCONF COMPR | | k PERMEABILITY |

SOIL PROFILE — TEST DATA — SAMPLES

| DEPTH / ELEV FT. | CLASSIFICATION (SURFACE ELEV. 425.7) |
|---|---|
| 4.6 / 421.1 | Organic clayey silt - dark grey. Sand seams |
| 9.2 / 416.5 | Medium fine sand, yellow gray, medium dense<br>G.W. 5-26-46 |
| 12.4 / 413.3 | Streaks of coarse sand and gravel |
| 16.6 / 409.1 | Sandy silt gray - loose. Clay seams |
| 25.3 / 400.4 | Stratified silty clay - yellow grey - medium stiff and brittle, soft remolded |
| | Silty clay with silt partings, greenish gray, medium soft slightly brittle, very soft rem. |

| OTHER TESTS | CONDITION | TYPE | SECTION | NUMBER | PEN. RESIST. | DEPTH FT / RECOV % |
|---|---|---|---|---|---|---|
| | ☒ | J | | 1 | Auger | 2.9 |
| MA | ☒ | J | | 2 | Auger | 6.6 |
| MA | ☒ | J | | 3 | 58/15/… | 10.7 |
| γ MA | | T | A B C D E F | 4 | 800 # | 13.4<br>97%<br>16.5 |
| γ Q C k | | P L L L L | A B C D E | 5 | 2500 # | 17.6<br>98%<br>24.2 |
| Q C k | | P L L L | A B C D | 6 | 1800 # | 25.1<br>99%<br>30.5 |
| γ MA<br>Q C k | | P L L | A B C | 7 | 1900 # | 31.6<br>99% |

Figure A.11. Example office report on detailed exploration and undisturbed sampling (from Corps of Engineers)

## Mineralogy and Clay Mineralogy

The mineralogy of LLW site soils and rocks can be determined on the basis of visual, petrographic, and x-ray diffraction techniques. The procedures for visual descriptions are identified under Visual Description. Ordinarily, the mineralogy, particularly of fine-grained materials, cannot be determined on the basis of visual examination alone and, therefore, requires identification by petrographic or x-ray diffraction methods. Standard methods of examining and describing the common rock-forming materials including clay minerals are given in:

> ASTM C294-69 (Reapproved 1975), "Standard Descriptive Nomenclature of Constituents of Natural Mineral Aggregates," Annual Book of ASTM Standards: Part 14 - Concrete and Mineral Aggregates, 9 pp.
>
> ASTM C295-79, "Standard Practice for Petrographic Examination of Aggregates for Concrete," Annual Book of ASTM Standards: Part 14 - Concrete and Mineral Aggregates, 11 pp.

Generally, the identification and analysis of clay minerals must be conducted using x-ray diffraction and in limited cases, petrographic methods. Currently, there are no standardized procedures for the x-ray identification of clay minerals. However, the differences in the procedures of various laboratories, agencies, or institutions should not detract appreciably from the results of these analyses. X-ray diffraction procedures suitable for the identification of both clay and nonclay minerals are found in Whittig (1965) but there are numerous other references that are also suitable as guidance.

### Reference

L. D. Whittig, "X-ray Diffraction Techniques for Mineral Identification and Mineralogical Composition," Methods of Soil Analysis: Part 1 - Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, American Society of Agronomy, pp 671-697, 1965.

## Monument and Point Positions

Survey control monuments, burial unit boundary markers, and other point positions such as monitoring well locations should be determined to third-order class II accuracy in accordance with guidance in:

> "Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys," U. S. Department of Commerce, National Oceanic and Atmospheric Administration, 1975, 30 pp.

The relatively low level of accuracy in third-order, class II surveying is considered adequate for LLW sites.

## Oxidation-Reduction Potential

The oxidation-reduction potential is the electromotive force generated when a platinum electrode calibrated against a standard hydrogen electrode is immersed in a soil. A positive value indicates that the soil is in an oxidized state and a negative value indicates a reduced state. The oxidation state of a sample affects solubilities and adsorbing properties. Field measurements should be made if at all possible since disturbance of the soil and transportation will cause drastic changes due to the alteration of aeration, temperature, and moisture. The recommended procedure is:

> "Oxidation Reduction Potential," Procedures for Handling and Chemical Analysis of Sediment and Water Samples, EPA/CE-81-1, U. S. Army Corps of Engineers, Waterways Experiment Station, 1981, pp 3-52 to 3-53.

An alternative method is available as:

> "Potentiometric; Independent Salt Bridge Method," Section 17:4:2, Textbook of Soil Chemical Analyses, Chemical Publishing Co., New York, 1971, pp 459-460.

A distinction between oxidizing and reducing conditions can sometimes be made by the experienced geologist on the basis of material color. Oxidizing conditions associated with the unsaturated zone are manifested by tones of red, brown, buff, and yellow. Reducing conditions in saturated material are reflected in the tones gray, green, and blue.

## Partition Coefficients

The distribution (or partition) coefficient for each radionuclide moving in ground water through one site material is defined by:

$$K_d = \frac{\text{quantity adsorbed/mass of soil}}{\text{quantity dissolved/volume of water}}$$

More precisely $K_d$ is the ratio of the equilibrium concentration on the solid phase to the equilibrium concentration when initially in solution.

$K_d$ is a function of many variables including pH, oxidation-reduction potential, solute chemistry, ion concentration, chemistry of leachate, and water content. Laboratory measurements of $K_d$ are valid only to the extent that they duplicate field conditions.

The simplest procedure for determining $K_d$ is to use a batch technique where a measured weight of the soil (or rock) is mixed or agitated with a measured volume of water containing a known amount of the radionuclide of interest. The water is then filtered off and the radioactivity remaining in the water is measured to determine the amount of radionuclide adsorbed by the soil. A procedure has been proposed as a standard batch test by Pacific Northwest Laboratory (PNL) as follows:

> "Proposed Standard Batch $K_d$ Procedure," Appendix A, Methods for Determining Radionuclide Retardation Factors: Status Report, PNL-3349, Pacific Northwest Laboratory, Richland, 1980, pp A.1 to A.8.

The same concept can also be applied by allowing the leaching solution to pass through the soil packed in a column. Flow rates can be controlled to simulate those through the soil in the natural environments. Column tests are sometimes preferred because of advantages of scale and more realistic simulation. Guidance on a suitable procedure is presented in the PNL report (Relyea et al. 1980).

### Reference

J. F. Relyea, R. J. Serne, and D. Rai, "Methods for Determining Radionuclide Retardation Factors: Status Report," PNL-3349, Pacific Northwest Laboratory, Richland, 1980.

## Penetration Parameter

The standard procedure using a split-spoon sampler accomplishes the resistance measurement at the same time as disturbed samples are recovered. The method is appropriate for all soils except gravelly soils, either above or below the water table.

> ASTM D1586-67 (Reapproved 1974), "Standard Method for Penetration Test and Split-Barrel Sampling of Soils," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 3 pp.

A second method that may be considered for obtaining an index of penetration resistance but no sample is the Dutch cone test. The parameter reflects the resistance to slow, steady advance of the core into soil. The method is intended mostly for foundation studies but can also provide data for correlating and characterizing strata as long as gravelly materials are not encountered. The method is standardized as:

> ASTM D3441-79, "Standard Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests in Soil," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 8 pp.

## Permeability Function

Permeability (or hydraulic conductivity) in unsaturated soils is a variable that depends on the pore space available for flow as explained in the Task 1 report (NUREG/CR-2700). This space can be measured either directly as volumetric water content or indirectly by measuring the suction pressure of the water. The permeability variable can be plotted as a function of suction pressure, water content, or degree of saturation. Measurement of the permeability function is difficult because of the accuracy limitations in the measurement of high suction pressures, low water content, and low flow.

Laboratory tests to measure unsaturated permeability have been developed by Laliberte and Corey (1967), Klute (1965), and Ingersoll (1981). In each of these methods, the Darcy equation is used to calculate the permeability coefficient. The methods vary substantially in other respects. Laliberte and Corey use oil in place of water and calculate intrinsic permeability in units of area; accordingly that method is not recommended for characterizing LLW sites. Ingersoll and Klute use water and calculate permeability in the more familiar dimension of velocity. The test described by Klute (1965) is the recommended method for laboratory determinations of permeability for arriving at permeability function. Field methods are usually preferred, however.

Field tests to determine the permeability function use an infiltration model. The suction profile and the water content are measured as a function of time. The procedure is called the instantaneous profile method. The test was described by Hillel et al. (1972). A modification of the test by the inclusion of an impeding layer on top is called the crust test and is described by Bouma (1980). The detailed procedures for field measurement of permeability above the water table are given in Bouma et al. (1974). These tests may also be performed in the laboratory using a soil column. The instantaneous profile test is the recommended method for obtaining the data for permeability function. Exposure at the ground surface or in a trench is necessary.

Several empirical methods are available to construct the permeability function from the soil water retention data. Two of the most frequently used are the modified Millington and Quirk (1960) and Green and Corey (1971) methods. These methods do not require direct measurement of outflow and can be used on field data from crust tests or instantaneous profile tests as well as from water retention curves developed in the laboratory. The disadvantages of these methods are that hysteresis is ignored and the accuracy of the permeability function is no better than the accuracy of the soil moisture characteristic data. The methods are only applicable to granular soils so that usage for LLW sites is limited.

Hysteresis is significant in the permeability-suction pressure function, but it is not usually significant in the permeability-water content function. Because the permeability-water content function is less sensitive to hysteresis, it is more widely used in unsaturated flow models than the permeability-suction pressure function.

## References

J. Bouma, "Field Measurement of Soil Hydraulic Properties Characterizing Water Movement Through Swelling Clay Soils," Journal of Hydrology, Vol. 45, pp 149-158, 1980.

J. Bouma, F. G. Baker, and P. L. M. Veneman, "Measurement of Water Movement in Soil Pedons Above the Water Table," Information Circular 27, University of Wisconsin-Extension, Madison, 1974.

R. E. Green and J. C. Corey, "Calculation of Hydraulic Conductivity: A Further Evaluation of Some Predictive Methods," Soil Science Society of America, Proceedings, Vol. 35, pp 3-8, 1971.

D. Hillel, V. D. Krentos, and Y. Stylianow, "Procedure and Test of an Internal Drainage Method for Measuring Soil Hydraulic Characteristics In Situ," Soil Science, Vol. 114, pp 395-400, 1972.

J. Ingersoll, "Method for Coincidentally Determining Soil Hydraulic Conductivity and Moisture Retention Characteristics," Special Report 81-2, U. S. Army Corps of Engineers, Cold Regions Research and Engineering Laboratory, Hanover, N.H., 13 p, 1981.

A. Klute, "Laboratory Measurement of Hydraulic Conductivity of Unsaturated Soil," Methods of Soil Analysis: Part 1 - Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling, American Society of Agronomy, pp 253-261, 1965.

G. E. Lalibe e and A. T. Corey, "Hydraulic Properties of Disturbed and Undisturbed Soils," Permeability and Capillary of Soils, Special Technical Publication 417, American Society for Testing and Materials, pp 56-71, 1967.

R. J. Millington and J. P. Quirk, "Transport in Porous Media," Seventh International Congress Soil Science, Transactions, 1960.

## Pore Water Age

Radioisotopes, stable isotopes, and more common solutes have been used in the past to date the ground water. Water dating can involve not only some very sophisticated laboratory analyses by specialists in that subject area but also requires the talents of imaginative staff geologists to anticipate the conditions where such analyses will have meaning and be useful for understanding the hydrology of the LLW site. Appreciating these prerequisites, the evaluating organization should carefully consider and compare the two options--water typing and absolute age dating--for applicability before undertaking an elaborate program.

### Age dating

Generally, the concepts and strategy of water dating involve the change in radioactivity in time between an input point and the point in question. The input point may be on the recharging ground surface or at a subsurface transition from an adjacent ground water subsystem. The most useful isotope for dating in the range of tens of years is tritium with a half-life of 12.35 yr. Tritium is produced in the atmosphere by natural processes or has been introduced from thermonuclear tests and enters the recharge zone in a characteristic abundance with respect to that of common hydrogen. Water found to be low in tritium can be assumed to have been long removed in time from the surface recharge area. An abundance of tritium is less confidently assessable. Tritium has the advantage of experiencing little or no major interference from soil and rock and the chemical processes in transit. For gross dating, tritiated water can be classified grossly as very young, e.g., perhaps 50 yr or younger depending on the amount.

The radioisotope $^{14}C$ is useful for extending the dating range back hundreds of years since its half-life is 5730 yr. However, other processes such as exchange, dilution, or removal that change the concentration can be important and must be accurately evaluated and taken into account. Much of the $^{14}C$ moves in solution as bicarbonate ions.

Methods for analyzing tritium and $^{14}C$ in water are identified under Ground Water Chemistry. However, it is not considered generally appropriate to prescribe the methods for separating or concentrating and for testing these radioisotopes for age dating since the methods are highly sophisticated and not confidently applicable by inexperienced laboratories. It is more appropriate to choose a laboratory from the relatively few that are recognized as qualified to make the analyses and associated calculations to arrive at water ages. This contracting for service should be made early enough that the laboratory personnel can also advise on sampling as well as the overall objective and technical approach.

## Water typing

Ground water can be classified into one of various types on the basis of its composition and properties. In turn, conclusions on age and mobility of water usually follow from such distinction. Formational water is frequently classified according to which of the following ions predominate--sodium, calcium, magnesium, chloride, bicarbonate, and sulfate. In some sedimentary rocks and marine and glacial marine soils, the presence of sodium and chloride ions reflects the original connate water, beyond participation in the present-day flow system. The specific methods of analyzing water for the common dissolved constituents are given elsewhere in this Appendix.

A distinction between water types with and without considerable solute can be made for a broad but very useful generalization. Using specific conductance, one commonly finds and may be able to map a contrast between rapidly circulating relatively unmineralized meteoric water at shallow depth and relatively immobile formational water below with considerable dissolved constituents.

Another approach to distinguishing types of water and interpreting their significance relates the concentration of some identifiable component to its characteristic concentration in some source. The relationship can be analyzed to arrive at relative contributions from the source or conversely may exclude any connection because of a significant chemical difference. The components that can be used are dissolved salts, trace elements, and stable isotopes of oxygen and hydrogen. Methods for determining some trace elements and dissolved salts are given elsewhere in this Appendix. Methods for analyzing for trace elements not included here can be found in the references in Part III, under Hydrological Parameters. The stable isotopes of oxygen and hydrogen should be analyzed and evaluated under contract by one of the relatively few laboratories qualified for such work, as recommended for water dating.

## Porosities and Void Ratio

Porosity, void ratio, and relative density are closely related weight-volume parameters, but standard procedures are available for measurement of each.

### Laboratory measurement

Standard procedures for measurement of porosity of soil or rock (also for the parameters void ratio and relative density) are as follows:

> "Unit Weights, Void Ratio, Porosity, and Degree of Saturation," Appendix II, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp II-1 to II-13.
>
> RTH 109-80, "Method of Determining Effective (As Received) and Dry Unit Weights and Total Porosity of Rock Cores," Rock Testing Handbook, U. S. Army Corps of Engineers, 1980.

It is important to realize that porosity determined in the laboratory represents only the intact material and has limited applicability to hydraulics at those LLW sites where porosity along fractures is important.

### Field measurements

Three geophysical techniques are available for measuring porosity in the field--acoustic, neutron, and gamma-gamma logging. A summary of logging is presented in the following references and should guide the potential user in deciding which if any is appropriate:

> "Acoustic Logging Methods," Section 2.D.2.a.2, National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 2-64 to 2-66.
>
> "Nuclear Logging Methods," Section 2.D.2.a.3, National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 2-66 to 2-74.

Generally, the geophysical techniques produce porosity values representative of a rather large volume of material (1 $m^3$ typically). Fracture porosity is not distinguished apart from intergranular porosity, so that the techniques often give a bulk porosity with components of both in rock media. Comparisons with porosities for unfractured specimens determined in the laboratory may allow for close estimation of fracture porosity alone.

## Estimation of effective porosity

For some purposes, the porosity can be estimated on the basis of field examination or information retrieved in the process of logging or describing boring samples. The important parameter effective porosity may most reasonably be obtained in this way since numerous angle borings would offer the only investigational alternative and even then would carry about the same degree of uncertainty.

Effective porosity can be distributed anisotropically as, for example, along bedding surfaces so that the important effect of this space along fractures can be manifested as preferred directions of seepage and migration of radionuclides. The experienced geologist is well versed in techniques of collecting the structural data and making the appropriate interpretations and analyses, and in most cases a geological analysis is essential.

## Precipitation

Precipitation is routinely measured by the National Weather Service and the records of numerous stations throughout the nation are available in:

> Climatological Data, U. S. Department of Commerce, National Oceanic and Atmospheric Administration, monthly reports.

This source of data is often adequate for regional and even site-specific characterization.

If a local weather station is established, the precipitation can be measured in accordance with the guidance in:

> "Measurement of Precipitation and Evaporation," Chapter 7, Guide to Meteorological Instruments and Observing Practices, 2nd Ed., World Meteorological Organization, 1970, pp VII.1 to VII.10.
>
> "Measurement of Precipitation," Section 10.B.2, National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 10-4 to 10-10.

## Rebound Index

Testing for a rebound index is closely related to consolidation testing; therefore see Consolidation Relation. It is anticipated that this parameter will rarely be of concern. A careful review of regional and local experience with excavating the media found at the site may be sufficient documentation in most cases.

## Recharge and Discharge Areas

The most effective procedure for determining ground water recharge and discharge areas is by way of extensive subsurface investigations of the ground water system. A three-dimensional array of observation wells produces a potentiometric surface directly. The surface, in turn, focuses attention on the areas of interest of intersections with the ground surface. Prior to development of most of these subsurface data, approximations of the recharge and discharge will depend on interpretations based largely on available inventory and documentations.

Documentation will be conducted primarily through records and technical literature but will be augmented by some field studies. These preliminary studies should extend well beyond the immediate site. The data to be collected will consist of the following: locations of all natural ground water recharge and discharge; locations of all domestic, agricultural, municipal, and industrial extraction and recharge wells; lagoons and reservoirs; and all actual or potential sources of surface water or ground water pollution such as chemical and sewage plants, landfills, and hazardous waste burial sites. The positions and conditions given above should be tabulated, described, and plotted on maps or cross sections for the purpose of integrating these data with those describing geology and hydrology.

## Rock Classification

### Geological system

A general classification of the common igneous, metamorphic, and sedimentary rocks is presented in:

> ASTM C294-69 (Reapproved 1975), "Standard Descriptive Nomenclature of Constituents of Natural Mineral Aggregates," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 9 pp.

No other detailed, standardized classification is available. It is recommended that rock classification be conducted by a trained and experienced geologist and that the classification that is applied be consistent throughout the LLW site as well as with regional usage. A basis for rock classification can be an appropriate petrology textbook. The detailed geological classification of rocks will require the application of visual methods (see Visual Description) and may require x-ray diffraction methods (see Lithology and Soils), as well as petrographic methods which are described in:

> ASTM C295-79, "Standard Practice for Petrographic Examination of Aggregates for Concrete," Annual Book of ASTM Standards: Part 14 - Concrete and Mineral Aggregates, 11 pp.

Petrographic methods pertain to both grain mounts and thin sections. The examination of individual grains will be useful in the classification and mineralogical identification of soils as well as rocks, and thin sections will provide information on mineralogy, classification, texture, and fabric of rocks.

### Rock soundness

The soundness or durability of rocks and weakly cemented or lithified soils or sediments may be determined in several separate ways.

Durability test. Slaking tests are available for relatively weak materials containing argillaceous components. One simple test consists of observing the behavior of a sample upon immersion in distilled water. The material may either be air- or oven-dried or at field water content. Those materials which disintegrate after a few minutes are expected to weather relatively rapidly in an excavation; whereas, those materials which exhibit only minor change would weather less. A more formal slake-durability test (Franklin and Chandra 1972) involves the rotation of the sample in a mesh basket partially immersed in water. The sample is oven-dried and tested for 10 min at 20 rpm, then dried and tested again. The ratio of the weight retained to that of the original sample expressed as a percentage is defined as the slake-durability index.

Seismic velocity. Seismic investigations usually produce information that can be translated into rock soundness. The well established correlation of seismic velocity with soundness in the form of rippability is discussed extensively in Handbook of Ripping (1966). The methods for determining seismic velocity are discussed elsewhere (see Seismic Velocity).

Core logging indices. The most effective means of classifying rock according to soundness often arises during logging of the core. Numerous systems are available or can be developed to distinguish soft, hard, and intermediate grades of rock. Table A.4 shows the classes used by the Panama Canal Company after many years of experience in coring soft rocks. This particular system can be considered for direct use at LLW sites since the soft clay-rich rocks in the Canal Zone are similar to formations expected to be encountered at LLW sites--clay shale, siltstone, and argillaceous sandstone. Many other systems are available for consideration also.

## References

J. A. Franklin and R. Chandra, "The Slake-Durability Test," International Journal of Rock Mechanics and Mining Science, Vol. 7, pp 325-341, 1972.

Handbook of Ripping, 3rd Ed., Caterpillar Tractor Co., Peoria, Ill., 1966.

## Table A.4

### Core Logging Indices for Classifying Rock and Overburden According to Hardness
(from Panama Canal Company)

| | |
|---|---|
| **Overburden** | |
| OH-1 - Soft | Easily squeezed through fingers. Consistency of fresh putty. (Muck, some clays.) |
| OH-2 - Medium Soft | Cannot be squeezed readily through the fingers, but is easily indented with the finger point at moderate pressure. |
| OH-3 - Medium Hard | Nonpenetrable at moderate finger pressure. A pencil point can be readily pushed into sample. |
| OH-4 - Hard | Difficult to take drive sample. Difficult to punch pencil point into sample. |
| OH-5 - Very Hard | Material of near rock character. |
| **Rock** | |
| RH-1 - Soft | Slightly harder than very hard overburden, rock-like character but crumbles or breaks easily by hand. (Some clay-shales and uncemented sandstones and conglomerates.) |
| RH-2 - Medium Soft | Cannot be crumbled between fingers, but can be easily picked with light blows of the geology hammer. (Some shales and slightly cemented sandstones and conglomerates.) |
| RH-3 - Medium Hard | Can be picked with moderate blows of geology hammer. Can be cut with knife. |
| RH-4 - Hard | Cannot be picked with geology hammer, but can be chipped with moderate blows of the hammer. |
| RH-5 - Very Hard | Chips can be broken off only with heavy blows of the geology hammer. |

## Runoff

### Curve number estimation

The Soil Conservation Service has developed a method of runoff prediction that uses a curve number (CN) based on extensive field plot measurements over many years. Having been developed for areas of a few to many acres, the method is well suited for LLW sites of about the same size (as opposed to methods designed for large watersheds). The procedure for making the CN estimations is presented in:

> "Estimation of Direct Runoff from Storm Rainfall," Chapter 10, National Engineering Handbook: Section 4 - Hydrology, U. S. Department of Agriculture, Soil Conservation Service, 1972.

### Direct measurement

Direct measurement of runoff by stream gaging is the preferred method where site-specific data are needed to verify predicted behavior or for other analytical uses. The relationship between runoff and precipitation in short time increments can distinguish subtle but sometimes important delayed runoff such as follows paths of subflow just below the ground surface. Appropriate directions for open channel flow measurements are provided in the following standards:

> ASTM D1941-67 (Reapproved 1975), "Standard Method for Open Channel Flow Measurement of Water and Waste Water by the Parshall Flume," Annual Book of ASTM Standards: Part 31 - Water, 11 pp.
>
> ASTM D2034-68 (Reapproved 1975), "Standard Method for Open Channel Flow Measurement of Water and Waste Water by Weirs," Annual Book of ASTM Standards: Part 31 - Water, 7 pp.

Other useful guidance specifically on stream gaging is found in:

> "Discharge Measurements at Gaging Stations," Chapter A8, Book 3, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1969, 65 pp.

## Seepage Velocity

The seepage velocity can be calculated with Darcy's law using values of effective porosity, permeability, and hydraulic gradient (see Task 1 report NUREG/CR-2700).

The seepage velocity may also be directly measured using tracers as discussed under Apparent Velocity. It is, however, important to realize that tracers may be susceptible to retardation and other interferences along the travel path. In most cases the progress of any tracer other than tritium may be slower than the progress of the water itself. This distinction between seepage velocity and apparent velocity is explained in the Task 1 report.

## Seismic Velocity

Seismic velocities are determined by surface refraction surveys, crosshole surveys, and uphole/downhole surveys. Field procedures, equipment requirements, and interpretation techniques for these methods can be found in Department of the Army (1979), Zohdy et al. (1974), Telford et al. (1976), Butler and Curro (1981), and other sources referenced in these reports.

### Surface refraction method

Seismic refraction surveys can be used to map qualitatively the lateral, near-surface variations in porosity and density; the methods are discussed under Material Densities and Porosities and Void Ratio. Considerably more information about the subsurface can be obtained from more detailed analysis and interpretation of these data. Using multichannel seismographs, typically 12 or 24 geophones at 1.5- to 6-m spacing are laid along a line on the surface and an explosive or impulsive energy source is triggered at each end of the line. Analysis of the travel time data gives P-wave velocities of subsurface materials and depths to boundaries between materials with different velocities. Depths determined from refraction surveys are usually accurate to ±10 percent.

A valuable application of the refraction method is for mapping of depths to the water table in unconsolidated sediments. The P-wave velocity characteristically jumps from about 500 m/s to about 1500 m/s at the water table. The water table in partially consolidated sediments and soft rocks can also frequently be determined by the occurrence of the characteristic 1500-m/s velocity.

There are two primary limitations to the seismic refraction method: (a) the method is suited to the situation where seismic velocity monotonically increases with depth, and a material with seismic velocity lower than the material above cannot be detected and can lead to errors in depth determinations; and (b) for certain combinations of layer thickness and seismic velocity, a layer will be missed.

### Uphole/downhole method

For the uphole/downhole method, one borehole is required for each test location, and a seismic energy source close to the top of the borehole is used in conjunction with a receiver in the borehole, or visa versa. By varying the depth of the receiver typically in 1-m increments, a plot of arrival time versus depth can be obtained for P or S waves. Generally, straight line segments can be fit to the data. Slopes of the segments give interval velocities and intersections of the segments give depths to interfaces.

The uphole/downhole method does not suffer from the two limitations of the surface seismic refraction method. Thickness resolution of layers or zones of different materials, however, is limited by the in-hole testing increment; i.e., only zones thicker than the in-hole testing increment can be detected.

## Crosshole method

For the crosshole seismic method, two or three boreholes are required for each test location. A seismic source (small explosive charge for P-wave generation and weight drop or vibrator for vertically polarized S-wave generation) is placed in one borehole and a receiver (geophone) is placed in the second borehole. The receiver should be held in firm contact with the borehole with a bowspring or rubber bladder to ensure good coupling. The most common procedure is to raise synchronously both source and receiver from bottom to top of the boreholes. Generally, the boreholes should be spaced 3 to 6 m apart and the in-hole testing increment should be 1 m for LLW site studies.

Like the uphole/downhole method, the crosshole method does not suffer from the two limitations of the seismic refraction method. Again, the thickness resolution is limited by the in-hole testing increment. The boreholes should ideally be vertical; but borehole deviation surveys should be considered to determine borehole separation as a function of depth for the usual case where the boreholes depart slightly from vertical. Dividing the borehole separations by corresponding travel times for the waves gives a vertical profile of apparent velocities. These apparent velocities must be interpreted to give true velocities for material between the boreholes. Generally, the apparent velocities will equal the true velocities except for cases when a refracted wave arrives before a wave which travels directly between the boreholes (for borehole separations in the 3- to 6-m range, the problem is minimized).

## References

D. K. Butler and J. R. Curro, "Crosshole Seismic Testing: Procedures and Pitfalls," *Geophysics*, Vol. 46, pp 23-29, 1981.

Department of the Army, "Geophysical Exploration," Engineer Manual 1110-1-1802, U. S. Army Corps of Engineers, 1979.

W. M. Telford, L. P. Geldart, R. E. Sheriff, and D. A. Keys, *Applied Geophysics*, Cambridge University Press, New York, 1976.

A. A. R. Zohdy, G. P. Eaton, and D. R. Mabey, "Application of Surface Geophysics to Ground-Water Investigations," Chapter D1, Book 2, *Techniques of Water-Resources Investigations*, U. S. Department of the Interior, Geological Survey, 1974.

## Shrinking-Swelling Parameter

It is anticipated that shrinking and swelling behavior will be fairly common at LLW disposal sites, particularly where clay and shaly strata are abundant. For this reason a careful review of regional and local experience with excavating and using soil and rock such as found at the site should be conducted as a part of documentation. In the rare cases where the behavior is potentially serious, laboratory testing may be warranted. Consolidation test results are reflective of swelling behavior when viewed as an unloading phenomenon (see Consolidation Relation). Rock soundness tests and indices are also useful and sometimes more convenient for generalizations and comparisons among site media.

## Soil Classification

### Engineering system

The classification of soils for engineering purposes should be accomplished primarily according to the Unified Soil Classification System (USCS). This classification is accomplished using the following standard:

> ASTM D2487-69 (Reapproved 1975), "Standard Test Method for Classification of Soils for Engineering Purposes," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 5 pp.

### Agricultural system

The classification of soil for agricultural purposes including soil surveys is based upon morphology, composition, texture, and soil profile development and is given in:

> Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys, U. S. Department of Agriculture, 1975.

The textural classification of soils which constitutes a part of the system above provides additional information beyond that given by the USCS in terms of the amount of clay-sized material in the soil and is a useful supplement for characterizing LLW sites.

## Soil Organics

The term soil organics refers to the entire nonmineral fraction of soil (and to a lesser extent of rock) including any vegetable or animal matter present. Organic matter holds moisture, affects the ion exchange capacity of the soil, and is directly involved in nutrient release. The total organic matter content of soil is estimated either from the total organic carbon content or from the loss in weight when organic matter is destroyed. Total organic carbon is easily determined by sample ignition of acid-treated samples. The following reference presents procedures for measuring organic carbon in soils:

> "Organic Carbon," Chapter 90, Methods of Soil Analysis: Part 2 - Chemical and Microbiological Properties, American Society of Agronomy, 1965, pp 1367-1378.

The same reference source provides explanations of how organic carbon is related to total carbon and organic matter in soil testing. Total organic matter may be approximated by multiplication of the figure for organic carbon by a factor of 1.7 or 2.5 for topsoils and subsoils, respectively.

## Soil pH and Acidity

### pH measurement

The recommended method for determining soil pH both in the field and in the laboratory utilizes an electronic pH meter with a glass-calomel electrode system. If the pH is above 9, a special glass electrode must be used in which the sodium in the glass has been replaced by lithium. Glass electrodes are soaked in dilute acid before use and must not be allowed to dry out. They are usually kept immersed in distilled water. The pH meter-electrode system must be calibrated with buffer solutions each time it is used. The standard test developed for corrosion studies is equally suitable for general characterization of soil at LLW sites, as discussed in the following reference:

> ASTM G51-77, "Standard Test Method for pH of Soil for Use in Corrosion Testing," Annual Book of ASTM Standards: Part 10 - Metals - Mechanical, Fracture, and Corrosion Testing; Fatigue: Erosion and Wear; Effect of Temperature, 6 pp.

### Titratable acidity

The soil pH does not take into account the effect of aluminum, iron, and manganese which can affect the acidity of a soil. For this reason, titratable acidity is determined by titration of barium chloride-triethanolamine leachates from soil, as discussed in this reference:

> "Barium Chloride-Triethanolamine Method," Section 59-3, Methods of Soil Analysis: Part 2 - Chemical and Microbiological Properties, American Society of Agronomy, 1965, pp 910-911.

## Soil Solubles

A distilled water leach of the soil is analyzed to determine the concentrations of soluble anions and cations. The leachate samples are essentially water samples; therefore, procedures for these analyses were taken from standard sources approved for use under the Safe Drinking Water Act or the National Pollutant Discharge Elimination System. Where two methods are recommended for metals, both are atomic absorption techniques but a direct aspiration technique is preferred for higher concentration and the furnace technique for lower concentrations (below 50 ppb). The anions are measured by conventional titrimetric or turbidimetric procedures. Specific methods are recommended from the following source as indicated:

> Methods for Chemical Analysis of Water and Wastes, EPA-600/4-79-020, U. S. Environmental Protection Agency, Cincinnati, 1979.

| | |
|---|---|
| aluminum | 202.1, "Aluminum (Atomic Absorption, direct aspiration)," 2 pp. |
| | 202.2, "Aluminum (Atomic Absorption, furnace technique)," 2 pp. |
| calcium | 215.1, "Calcium (Atomic Absorption, direct aspiration)," 2 pp. |
| iron | 236.1, "Iron (Atomic Absorption, direct aspiration)," 2 pp. |
| | 236.2, "Iron (Atomic Absorption, furnace technique)," 2 pp. |
| magnesium | 242.1, "Magnesium (Atomic Absorption, direct aspiration)," 2 pp. |
| manganese | 243.1, "Manganese (Atomic Absorption, direct aspiration)," 2 pp. |
| | 243.2, "Manganese (Atomic Absorption, furnace technique)," 2 pp. |
| potassium | 258.1, "Potassium (Atomic Absorption, direct aspiration)," 2 pp. |
| sodium | 273.1, "Sodium (Atomic Absorption, direct aspiration)," 2 pp. |
| carbonate | 310.1, "Alkalinity (Titrimetric pH 4.5)," 3 pp. |
| chloride | 325.3, "Chloride (Titrimetric, Mercuric Nitrate)," 3 pp. |
| sulfate | 375.4, 'Sulfate (Turbidimetric)," 3 pp. |

The determination of the bicarbonate anion should be accomplished using the following standard:

> 406C, "Carbon Dioxide and Forms of Alkalinity by Calculation," Standard Methods for the Examination of Water and Wastewater, 15th Ed., American Public Health Association, 1980, pp 268-269.

## Specific Gravity

The specific gravity of a soil for use in engineering calculations is usually expressed in three different forms--specific gravity of solids, $G_s$ ; apparent specific gravity, $G_a$ ; and bulk specific gravity, $G_m$ . Both $G_a$ and $G_m$ are applied to soils coarser than the No. 4 sieve, while $G_s$ is for finer soils. The $G_s$ is not applied to coarse particles because they normally contain voids from which air cannot be displaced unless the particles are ground into finer particles to eliminate the voids. Thus, when dealing with coarser particles, it is more convenient to work with the $G_a$ of the particle mass. $G_s$ or $G_a$ is used in all calculations involving fundamental properties of a soil mass; $G_m$ is used in special calculations, such as corrections of density and water content for soils containing gravel sizes.

Definitions and recommended detailed procedures for determining the values of $G_s$ , $G_a$ , and $G_m$ are given in:

ASTM D854-58 (Reapproved 1979), "Standard Test Method for Specific Gravity of Soils," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 3 pp.

ASTM C127-77, "Standard Test Method for Specific Gravity and Absorption of Coarse Aggregate," Annual Book of ASTM Standards: Part 14 - Concrete and Mineral Aggregates, 4 pp.

"Specific Gravity," Appendix IV, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp IV-1 to IV-13.

## Storativity

Storativity can be measured in unconfined aquifers and must be estimated for confined aquifers. Storativity is dimensionless because it is the volume of water released from a unit volume of aquifer due to a unit change in head. In unconfined aquifers the storativity (approximately equivalent to specific yield) is usually determined using methods for measuring water content (see Water Content). Neutron logging is often the best method to measure the storativity in an unconfined aquifer (see Porosities and Void Ratio).

Storativity is determined from pump test data in confined aquifers. The storativity is extracted from the time-drawdown data in accordance with the guidance in:

> "Analysis of Discharging Well and Other Test Data," Chapter V, Ground Water Manual, U. S. Department of the Interior, Bureau of Reclamation, 1977 (revised reprint 1981), pp 85-173.

For approximations or preliminary calculations, the storativity can be estimated to equal 0.1 to 0.2 in unconfined aquifers. The storativity in confined aquifers is very roughly $10^{-6}$ multiplied by the aquifer thickness (in feet).

## Stratigraphy

The documentation of stratigraphy is logically directed to soils and rocks separately. Three broad classes of strata are transported deposits, residual deposits, and geological strata. The following descriptions, mostly from the Bureau of Reclamation Earth Manual, suggest the variety of subclasses and the amount of detail and in turn potential value in a thorough stratigraphical characterization. The methods of documentation follow traditional geological procedures and criteria, and geological training and experience are prerequisites of the investigator.

### Transported deposits

Transported soils bear no relation to the underlying rock as they do not cover rock from which they were derived. Transported soils may be stratified or heterogeneous, and their physical properties may show abrupt changes in both the vertical and horizontal directions. The natural means of transporting soils are flowing water, ice, gravity, and wind. The mode of transportation and the environment of deposition have considerable influence on the properties of soil and soil deposits.

Colluvial soils. Soil deposits which have been transported primarily by the action of gravity are called colluvial deposits. Landslides, mudflows, and avalanches are examples of such actions. This form of soil transportation and distribution often works in conjunction with another. For example, material can be weathered from ridges, transported by gravity to a stream in a valley below, and transported further by the flowing water. In glacial times, such gravity-transported material was carried further by glaciers. Glacial activity also triggered landslides which carried large masses of soil and rock onto the glacier for further transportation.

Fluvial soils. Soils whose properties are affected predominantly by the action of water to which they have been subjected are designated fluvial soils. Fluvial soils are characterized by roundness of individual grains. Frequently, there is considerable sorting action, so that a deposit is likely to be stratified or lensed. Individual strata may be thin or thick, but the material in each stratum will have a small range of grain sizes. The three principal types of fluvial soils, reflecting the water velocity of deposition--torrential outwash, valley fill, and lakebeds--are discussed separately below.

The typical landforms of torrential outwash deposits are alluvial cones and alluvial fans. Outwash deposits vary in size and character from small, steeply sloping deposits of coarse rock fragments to gently sloping plains of fine-grained alluvium several square kilometers in area. The deposition results from the abrupt flattening of the stream gradient that occurs at the juncture of hilly terrain and adjacent valleys or plains. The coarser sediment is deposited first, on the steeper slopes at the head of the fan, while the finer sediment is carried to the outer edges. In arid climates where mechanical rather than chemical weathering predominates, the cones and fans are composed largely of rock fragments, gravel, sand, and silt. In humid climates where the slopes tend to be relatively gentle, the material is expected to contain much more sand, silt, and clay.

Sand and gravel grains from these deposits are generally subrounded to subangular reflecting movement over relatively short distances, and the deposits have only poorly developed stratification. The torrential outwash deposits are likely sources of sand and gravel for embankments and for aggregate, but the presence of boulders may limit their usefulness. The soils are typically skip-graded, resulting in a GP or SP classification. Because torrential deposits are consolidated only by self weight, settlement should be anticipated in fine-grained variants when used as foundations.

Valley fill or floodplain deposits are generally finer, more stratified, and better sorted than are torrential outwash deposits. The degree of variation from the latter depends largely on the volume and on the gradient of the stream. The surface of these stream deposits is nearly flat. The nature of the materials in the deposit can be deduced by the characteristics of the stream. Braided streams usually indicate the presence of sand and gravel; whereas, meandering streams in broad valleys are commonly associated with fine-grained soils (silts and clays) with linear bar sand deposits.

An important type of valley fill deposit is the terrace. It represents an earlier stage of valley development into which the river subsequently has become entrenched. Remnants of such deposits are recognized by their flat tops and steep faces, usually persistent over an extended reach of the valley. Examination of the eroded faces facilitates classification and description of the deposits, and the extent of the drainage network on the face is helpful in determining relative permeability. Free-draining material has almost no lateral erosion channels; whereas, impervious clays are finely gullied laterally. Terrace sands and gravels were laid down in the geologic past. These terraces are found along streams throughout the United States and are prevalent in the glaciated regions of the northern sections. Sands and gravels in terrace deposits usually occur in layers and are well graded. They provide excellent sources of construction materials.

Lake sediments, or lacustrine deposits, are the result of sedimentation in still water. Except near the edges of the deposits where alluvial influences are important, the materials are very likely to be fine-grained silt and clay. The stratification is frequently so fine that the materials appear to be massive in structure. Lacustrine deposits are recognizable by their flat surfaces surrounded by high ground. The materials they contain are likely to be impervious, compressible, and low in shear strength.

Lake sediment deposits have been used for low-permeability linings of reservoirs and canals and for low embankments, confirming a potential for comparable uses at LLW facilities in constructing embankments, covers, and impervious liners. Moisture control in these soils is usually a problem, however, since the water content is very difficult to change. High organic contents are occasionally encountered and present special problems.

Lake sediments generally provide poor foundations for structures. Their characteristics may be expected to be so questionable that special laboratory and field testing may be required even during reconnaissance.

Glacial deposits. The results of the advances and retreats of the great North American continental ice sheets during glacial times are represented by recognizable landforms. Glacial deposits are important sources of construction materials and may even constitute major portions of the immediate site at the LLW disposal facility. Glacial deposits (glacial drift) are generally heterogeneous and erratic in nature; hence, they are costly to explore. Particle sizes range widely, from clay or silt up to huge boulders; and the particle shapes of the coarse grains are typically subrounded or subangular, sometimes with flat faces. Deposits of the glacier proper can be distinguished from deposits formed by the glacier melt water--moraine as opposed to outwash.

Glacial till is that part of the glacial drift deposited directly from the ice with little or no transportation by water. It consists of a heterogeneous mixture of varying amounts of boulders, cobbles, gravel, and sand in a generally impervious matrix of fines. Gradation, type of rock, and mineral materials found in till vary considerably, depending on the geology of the terrain over which the ice moved and the degree of leaching and chemical weathering. Glacial tills usually produce impervious materials with satisfactory shear strength, but removal of boulders will be necessary in order for the soil to be compacted satisfactorily. Where morainal deposits have been overridden by ice, the resulting fairly high in-place density makes them satisfactory for foundations. However, shear zones developed in the process of overriding can complicate the conditions. Superimposition of more than one till separated by weathered zones can occur as a result of multiple advances of the glacier.

Typical landforms containing till are the ground moraine or till plain which has a flat to slightly undulating surface; the end (or terminal) moraine, a ridge at right angles to the direction of ice movement, which often curves so that its center is farther downstream than its ends; and lateral or medial moraines which occur as ridges parallel to the direction of ice movement. Low, cigar-shaped hills occurring on a ground moraine, with their long axis parallel to the direction of ice movement, are called drumlins. They commonly contain unstratified fine-grained soils. Glacial outwash deposits from the glacial melt water are of several types. Glacial outwash plains of continental glaciation and their alpine glaciation counterparts, the valley trains, commonly contain poorly stratified silt, sand, and gravel similar to the alluvial fans of torrential outwash which they resemble in mode of formation. Eskers are prominent winding ridges of sand and gravel which are the remnants of the beds of glacial streams that flowed under the ice. Eskers generally parallel the direction of ice movement, have an irregular crestline, are characterized by steep flanks (about 30°), and are 5 to 30 m high. Eskers usually contain clean sand and gravel with some boulders and silty strata which are in irregular, poor to fair stratification and are excellent sources of pervious materials and concrete aggregate. Kames are low hills of stratified sand and gravel deposited on or against glacial ice by melt water streams and are materially similar to eskers. Glacial lake deposits formed in temporary lakes during the Ice Age are generally similar in character and in engineering uses to fluvial lacustrine deposits; however, they are normally more coarsely and regularly stratified (varved) than are the recent lake deposits, and they may contain fine sand.

Eolian soils. Soils deposited by the wind are known as eolian deposits. The two principal classes that are readily identifiable are dune sands and loess. Dune sand deposits are recognizable as low elongated or crescent-shaped hills, with a flat slope windward and a steep slope leeward of the prevailing winds. Usually, these deposits have very little vegetative cover. The material is very rich in quartz and its characteristics are limited range of grain size usually in the range of fine to medium sand, no cohesive strength, moderately high permeability, and moderate compressibility. Eolian sands generally fall in the SP group of the USCS.

Deposits of windblown silt and fine sand cover extensive areas in the plains regions of the temperate zone and near the Mississippi, Missouri, Ohio, and Columbia Rivers. These deposits have a remarkable ability for standing in vertical walls. Loess consists mainly of particles of silt or fine sand, with a small amount of clay that binds the soil grains together. Loess deposits may contain very sandy portions which are lacking in binder and are pervious. Their recognition is important from an engineering standpoint. In its natural state, true loess has a characteristic structure formed by remnants of small vertical root holes that makes it moderately pervious in the vertical direction. Although of low density, naturally dry loess has a fairly high strength because of the clay binder, but the strength may decrease dramatically upon wetting and the structure may collapse. When remolded, loess is relatively impervious, moderately compressible, and of low cohesive strength. Loess usually falls in the ML group or the borderline ML-CL or ML-SP groups.

Eolian deposits are normally regarded with suspicion as foundations for structures and are avoided if practicable to do so. However, there are areas where no choice is available and these soils must be used. For these deposits, evaluation of subsurface conditions from surface indications is complex and uncertain; therefore, foundation exploration is initiated during the reconnaissance stage for important or costly structures, and the magnitude of the exploration is increased proportionately for later stages.

Volcanic ash and pumice. Ash and pumice deposits are widespread in many areas of the United States within and west of the Rocky Mountains where violent volcanic action has occurred. These deposits are sometimes concentrated in valley bottoms many kilometers from their source where they may offer troublesome foundations for bridges spanning the streams of the area. Generally, the deposits are stratified and cross-bedded with particle gradation ranging from clays to fine sands. The specific gravity of the material commonly falls in the range 2.60 to 2.68, but the cellular structure makes the deposits low in density and subject to irregular consolidation under concentrated loads and during saturation by flood water. The particles are angular but weak in shear strength, providing, for example, only a nominal driving resistance to piling.

Much volcanic material is expansive when wet, being high in smectite clay. Structures built upon these ashy beds have been damaged by differential upheavals of the foundation soils of as much as 15 cm over the structure area.

## Residual deposits

As weathering action on rock progresses, the rock fragments are gradually reduced in size until the total material has a soillike appearance. Residual soils are the result of in-place weathering of the underlying material and they have not been moved from the location where they were formed. It is sometimes difficult to define clearly the dividing line between rock and residual soil, but for engineering purposes a material may be considered soil if it can be removed by commonly accepted excavating methods. Some knowledge of the engineering characteristics of residual soils can be obtained from an understanding of the bedrock from which they are derived.

It is difficult to recognize and appraise residual soils on the basis of topographic forms. Their occurrence is quite general wherever none of the other types of deposits, with their characteristic shapes, are recognizable and where the material is not clearly rock in place. Also, erosional features may be helpful in evaluating a residual deposit. Since the type of parent rock has a very pronounced influence on the character of the residual soil, the rock type should always be determined in assembling data for the appraisal of a residual deposit. The degree to which alteration has progressed largely governs the strength characteristics. Laboratory testing is required if the material appears questionable or when very large structures are planned. Identification of the clay minerals in residual soils is often necessary for an understanding of their engineering properties.

A distinguishing feature of many residual soils is that individual particles in place are angular but soft. Handling of the material during construction may appreciably reduce the grain size so that the soil as used may have entirely different characteristics than shown by standard laboratory tests of the original soil. Special laboratory testing programs are often required to determine the changes in characteristics to be expected. Full-scale field tests are sometimes appropriate before proper decisions can be made regarding utilization of such soils.

Some residual soils are entirely satisfactory for foundations or as construction materials and, in some cases, may be superior to other local soils. Other residual soils, depending on parent rock type, have such poor engineering properties that they should be avoided if possible.

## Geological strata

Geological strata may be composed of any of the deposits described above but usually have the additional connotation of considerable age, i.e., a manifestation of a process well removed in the past. Frequently, the age is also reflected in consolidation, induration, and lithification of the deposit. One additional class of strata not included above is the marine deposits. While not to be expected among Holocene deposits at a LLW site (except for possible glacial marine deposits elevated by glacial rebound), older marine strata are potentially very important and can be expected to constitute the main containing medium at many promising sites.

Ocean or marine deposits may take several forms. Littoral deposits are formed along shore lines by the action of waves and currents on the shore line and on materials brought in by streams. The continuous action of the waves in moving the soil particles back and forth tends to separate them by size, and abrasive action tends to reduce their size. Upon deposition, the coarse gravel particles will be found on the high region of the beach away from the water line, and progressively smaller sand sizes will be found in the seaward direction. Both the gravel and sand particles are rounded and pitted.

Offshore deposits are similar to those described for lakes, but they have greater flocculation due to the salt water. Also the quartz content is commonly subordinate to the content of calcareous material. Thus, the clastic strata may be interbedded with partially cemented strata of shells, calcareous sand, and clay and be recognized as marl or calcareous shale or sandstone. Delineating the distinct types of deposits (facies) formed contemporaneously or in close association a relatively short distance apart--e.g., littoral versus offshore--is just one more part of stratigraphical documentation that can occupy a geologist in productive investigation.

## Strength

The triaxial compression test is used to measure the shear strength of a soil under controlled drainage conditions. A soil mass may be considered as a compressible skeleton of solid particles. In saturated soils the void spaces are completely filled with water; in partially saturated soils the void spaces are filled with both water and air. Shear stresses are carried only by the skeleton of solid particles; whereas, the normal stress on any plane is carried by both the solid particles and the pore water. In a series of triaxial tests, the shear strength is determined as a function of the total stress (intergranular stress plus pore water pressure), unless (a) complete drainage is provided during the test so that the pore pressure is equal to zero at failure, or (b) measurements of pore pressure are made during the test. When the pore pressure at failure is known, the shear strength can be computed in terms of the effective stress, i.e., that carried by the soil particles. Pore pressure measurements during testing are seldom required in routine investigations, as the basic triaxial tests are sufficient to furnish shear strengths for the limiting conditions of drainage. The types of triaxial compression, boundary conditions, and detailed test procedures are described in:

> "Triaxial Compression Tests," Appendix X, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp X-1 to X-53.

The unconfined compression test is also used to measure the unconfined compressive strength of a cohesive soil. This test is applicable only to coherent materials such as saturated clay or cemented soils that retain intrinsic strength after removal of confining pressure: it is not a substitute for a triaxial test. Dry or crumbly soils, fissured or varved materials, silts, and sand cannot be tested meaningfully in unconfined compression. The unconfined compression test can be viewed as a form of triaxial test in which the major principal stress is equal to the applied axial stress, and the intermediate and minor principal stresses are equal to zero. The undrained shear strength is assumed to be equal to one-half of the unconfined compressive strength. The unconfined compression test and data presentation forms are presented in:

> "Unconfined Compression Test," Appendix XI, Laboratory Soils Testing, Engineer Manual 1110-2-1906, U. S. Army Corps of Engineers, 1970, pp XI-1 to XI-11.

## Structure

### Bedding attitude

The dip and strike should be determined for all significant stratigraphic units at surface exposures if possible. For subsurface units, the dip and strike can be determined in a given boring by borehole camera or related techniques; attitude can also be determined from the elevations of stratigraphic contacts in three or more boreholes. Generally, since a number of borings will be made, dip and strike can be most easily determined from data displayed on structural contour maps. These maps are effective in revealing detailed variations as well as overall trends of horizons and lend themselves to the determination of potential pathways of fluid migration. Isopach maps are another tool for revealing structural as well as stratigraphic details of a stratum or sequence of beds.

### Fracture systems

The analysis of fracture systems should include: the identification of all significant joints, fracture zones and faults, the determination of the conditions on or along these features and the determination of attitude and spacing. Fracture systems can be identified by surface mapping as well as within test pits, trenches, and borings. The identification of fracture systems from borings includes observations of core samples and from indirect, down-the-hole techniques such as the borehole camera. The conditions along the fractures may be determined by indirect methods; however, the conditions can best be determined from direct observation and classification techniques. Dip and strike and spacing should be determined, if possible, for all fracture systems, and the principal fractures systems should be plotted on a geological map and cross sections. All identified fracture systems should also be plotted stereographically in order to identify potential directions of radionuclide migration and to facilitate statistical analysis. The age of surface faulting should be evaluated in terms of earthquake hazards.

## Suction Pressure Function

The suction pressure function can be determined in the laboratory using the following procedures for granular soil and for fine-textured soil, separately:

> ASTM D2325-68 (Reapproved 1981), "Standard Test Method for Capillary-Moisture Relationships for Coarse- and Medium-Textured Soils by Porous-Plate Apparatus," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 7 pp.
>
> ASTM D3152-72 (Reapproved 1977), "Standard Test Method for Capillary-Moisture Relationships for Fine-Textured Soils by Pressure-Membrane Apparatus," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 8 pp.

In each of these tests a small sample (about 25 g) is saturated and then allowed to drain under an applied air pressure until equilibrium is reached. The applied air pressure is assumed to be equal to the suction pressure at the equilibrium water content. This procedure is repeated to produce points that define the drying (desorption) curve. These tests can be performed on undisturbed, disturbed, or compacted soil.

Developments in making the measurements for the soil moisture characteristic (suction pressure function) in the field are reviewed in Giesel et al. (1970), but such field procedures are regarded as relatively advanced and should be carefully considered before being attempted.

### Reference

W. Giesel, S. Lorch, M. Renger, and O. Strebel, "Water-Flow Calculations by Means of Gamma-Absorption and Tensiometer Field Measurements in the Unsaturated Soil Profile," Isotope Hydrology 1970, International Atomic Energy Agency, Vienna, pp 663-672, 1970.

## Suction Pressures

In the field, suction pressures can be measured either directly using a manometer or vacuum gage or indirectly by measuring properties that can be associated with suction pressure. Direct measurement is restricted to small suction pressures (less than 0.8 atm) because greater negative pressure exceeds the air entry limits of the measurement system. Direct measurement instruments are called tensiometers. A tensiometer consists of a porous stone and a manometer or vacuum gage. Tensiometers are inexpensive and permit continuous readings, but their use is limited to nearly saturated cohesive soils and granular soils. Tensiometer systems are commonly used in agricultural research, irrigation system design, and watershed characterization. Guidance on the use of tensiometers is described in:

> "Soil Suction Measurements with Tensiometers," Chapter 9, Methods of Soil Analysis: Part 1 - Physical and Mineralogical Properties, Including Statistics of Measurement and Sampling. American Society of Agronomy, 1965, pp 153-164.

Indirect measurement of soil suction relies on the association of soil suction with other material properties that are more easily measured. The primary technique in indirect measurement uses the relative humidity as an indicator of suction pressure. Instruments that use this principle are called psychrometers. A detailed discussion of the accuracy and limitations of psychrometers is given by Johnson (1974) with emphasis on measuring suction in undisturbed samples of clay soils in the laboratory. Comments are also made regarding the use of psychrometers for field measurements and field use is also discussed by Wilson (1980).

A less frequently used technique uses a porous element such as filter paper that is placed in contact with the soil until the soil moisture equilibrium is reached. The water content of the element is correlated to the suction pressure of the soil. Details of the filter paper method are given in Snethen and Johnson (1980) and Hamblin (1981). The use of gypsum blocks for measuring in situ soil moisture via electrical resistance is discussed by Phene et al. (1971).

### References

A. P. Hamblin, "Filter-Paper Method for Routine Measurement of Field Water Potential," Journal of Hydrology, Vol. 53, pp 355-360, 1981.

L. D. Johnson, "An Evaluation of the Thermocouple Psychrometric Technique for the Measurement of Suction in Clay Soils," Technical Report S-74-1, U. S. Army Corps of Engineers, Waterways Experiment Station, 77 pp, 1974.

C. J. Phene, G. J. Hoffman, and S. L. Rawlins, "Measuring Soil Matrix Potential In Situ by Sensing Heat Dissipation Within a Porous Body: I, Theory and Sensor Construction," *Soil Science Society of America*, Proceedings, Vol. 35, pp 23-27, 1971.

D. R. Snethen and L. D. Johnson, "Evaluation of Soil Suction from Filter Paper," Miscellaneous Paper GL-80-4, U. S. Army Corps of Engineers, Waterways Experiment Station, 182 pp, 1980.

L. G. Wilson, "Monitoring in the Vadose Zone: A Review of Technical Elements and Methods," EPA-600/7-80-134, Environmental Monitoring Systems Laboratory, U. S. Environmental Protection Agency, Las Vegas, 1980.

## Surface Water Chemistry

Use the same methods and procedures as identified under Ground Water Chemistry.

## Surface Water System and Boundaries

The characterization of natural surface drainage is related to and is partially addressed under Geomorphology in which surface water catchments were described and related to fluvial conditions. Additional information which must be considered and which is addressed here is the collection and evaluation of surface slope data and the records of actual or representative stream gages at or near the LLW site. Stream gage information will be obtained, where possible, from literature sources or from Federal or State records and will be a basis for additional gaging conducted as a part of site investigations. Slope and terrain related data will be taken from existing topographic maps or imagery, if available, and if not, from an actual site survey.

## Transmissivity

Transmissivity is determined from the analysis of drawdown curves obtained during a field pumping test. Guidance on the procedures is included in:

> "Analysis of Discharging Well and Other Test Data," Chapter V, Ground Water Manual, U. S. Department of the Interior, Bureau of Reclamation, 1977 (revised reprint 1981), pp 85-173.
>
> "Aquifer-Test Design, Observation, and Data Analysis," Chapter B1, Book 3, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1971, 26 pp.

## Visual Description

Standard practice for describing soils, also applicable for most soft rocks, is available as follows:

> ASTM D2438-69 (Reapproved 1975), "Standard Recommended Practice for Description of Soils (Visual-Manual Procedure)," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 7 pp.

Samples collected at outcrops, from borings, and in test pits should be thoroughly examined and described in the field and in the laboratory.

The visual description of rock samples is ordinarily accomplished with the usual methods of geology. These methods are mostly covered under Lithology and Soils in this Appendix, but the methods also incorporate well established interpretations on origin such as reviewed under Stratigraphy.

## Water Content

Water content is expressed as the percentage ratio of the weight of water to the weight of solid particles for geotechnical purposes. In some other technical fields water content is expressed on a volumetric basis, and it is important that this distinction be fully appreciated since numerical values are of the same order of magnitude. The water in question is the free water and not that which is hydrated to the mineral surfaces. Therefore, measurements on materials containing significant amounts of hydrated water at in situ temperatures or less than 110°C can be misleading. The water content of materials containing extraneous matter such as cement, water-soluble salts, and organics typically require special treatment or a qualified definition of water content.

### Laboratory test

Characterization of potential LLW sites will usually require the laboratory determination of water content. The following standard is recommended:

> ASTM D2216-80, "Standard Method for Laboratory Determination of Water (Moisture) Content of Soil, Rock, and Soil-Aggregate Mixtures," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 4 pp.

Repeated laboratory determinations of water content, though desirable, may not be feasible since each test in time requires new soil and, therefore, a new sampling borehole at a slightly different location. It is generally preferred to avoid making excessive borings into a site.

### Field test

Water content of soil and soil-aggregate may be determined rapidly in situ with a nuclear gage. The nuclear gage method of determining water content has more application during the excavation of trenches and construction of required earthwork (such as covers). The test procedures and notes on the nuclear test are contained in:

> ASTM D3017-78, "Standard Test Method for Moisture Content of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)," Annual Book of ASTM Standards: Part 19 - Natural Building Stones; Soil and Rock, 6 pp.

Continuous records of water content above the water table can be obtained by neutron logging. Neutron logs can be obtained in cased or uncased boreholes, although it is essential that calibration is obtained in boreholes of the same diameter and condition (i.e., cased or uncased) as the boreholes being logged. Details of the necessary calibration procedures are given in the section on neutron log porosity determination and in Keys and MacCary (1971).

## Reference

W. S. Keys and L. M. MacCary, "Application of Borehole Geophysics to Water-Resources Investigations," Chapter E1, Book 2, Techniques of Water-Resources Investigations, U. S. Department of the Interior, Geological Survey, 1971.

## Water-Holding Parameters

The water-holding parameters--field capacity and wilting point--can be estimated accurately where a soil moisture characteristic curve has been obtained (see Suction Pressure Function). The values for these parameters are the volumetric water contents at suction pressures of 33.5 kPa and 1520 kPa, respectively.

For most purposes a satisfactory estimate of water-holding parameters can be made by correlation with material type, particularly on the basis of grain size. Figure A.12 provides one such correlation for the near-surface materials, but others may be found to be more accurate on a site-specific basis.

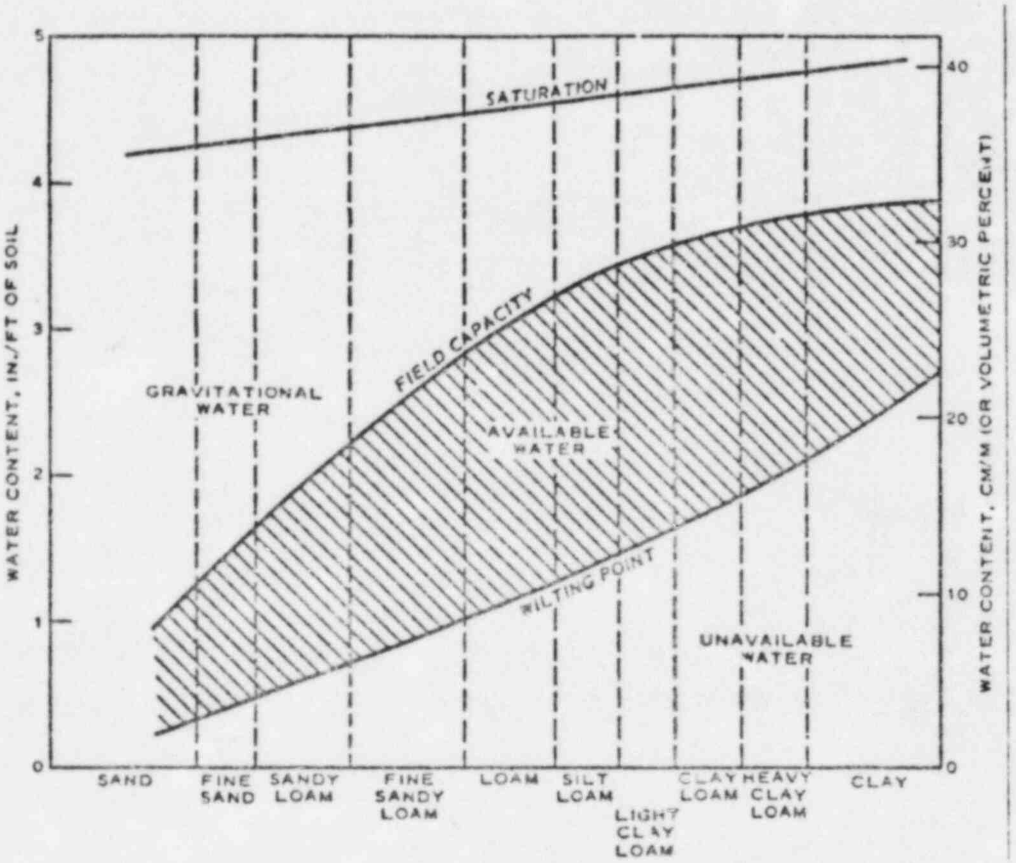


Figure A.12. Estimated water-holding parameters of textural classes of soil

The determination of specific retention, a similar water-holding parameter applicable below the near-surface zone, is best made on the basis of a series of water content determinations on borehole samples or by borehole logging (see <u>Water Content</u>). In periods of low rainfall and low infiltration the water contents should tend to approach a value representative of specific retention. Of course suitable allowance must be made for slow drainage in fine-grained soils. For example, clay beds can remain saturated and impede drainage of beds above, even where those above are composed of granular soils.

## Water Zone Boundaries

The delineation of boundaries between saturated and unsaturated zones (including perched zones of saturation) and for capillary subzones is accomplished through recognized methods of collecting field and laboratory data on ground water during subsurface investigations. Time-dependent aspects such as involved in defining the subzone of water table fluctuation are established from records compiled over a period of time in observation holes. Methods of investigating water conditions for a variety of purposes are quite similar among experienced organizations, but no step-by-step procedure has been recognized as the standard method, and it is unlikely that one will be or even should be.

### Background data

Accurately locating the position of the ground water table begins with the collection of background data from the region. This part of the investigations is reviewed under Ground Water System and Boundaries and Surface Water System and Boundaries but generally amounts to synthesizing data from wells and springs and detailed study of government agency files, hydrological reports, and records of wells. Some of this characterization is accomplished during studies for preliminary site selection.

### Use of observation wells and piezometers

The following discussion, mostly from the Bureau of Reclamation Ground Water Manual, summarizes practice in locating and characterizing the water table and its fluctuations with time. The methods are appropriate for LLW site investigations.

Frequency of measurements. Water level measurements may be made of the water table or the piezometric surface under numerous conditions. Records may be required of continuous measurements such as those supplied by a continuous water stage recorder or of periodic measurements with a time interval extending from less than 1 min (for a pump test) to 6 months. The frequency of measurement should be adjusted to the circumstances. In some instances, only a few measurements are possible or expedient to make, but in other instances frequent measurements over a long period of time may be required. The possibility of error in interpretation decreases as the frequency of measurement and length of record increase. Initially, measurements are made often until the annual regimen is established. The frequency may then be reduced to about four a year with the exception of a few carefully selected observation wells. These may be read 6 to 24 times a year or equipped with continuous recorders.

It is advisable to install a number of observation wells at least 2 years prior to construction (in any case 1 year prior to application for license) and to take measurements so frequently as to determine preexisting ground water conditions. Measurements as frequently as weekly may be necessary in unconfined aquifers expected to respond quickly to precipitation events. The program should be continued (during license review, construction, and full operation) to permit comparison of preexisting and postfacility conditions. Such data may be invaluable in the event of claims or suits for damage.

Water level measuring devices. Measurements may be made with a number of different devices and procedures. Probably the most common device for measuring static water levels is the chalked steel tape which has a weight attached on the lower end. The weight keeps the tape taut and aids in lowering it into the well. The tape is chalked with chalk or dry soil which changes shade upon becoming wet. The line of the color change denotes the length of tape immersed in water. Cascading water in a well may mask the mark of the true water level on the tape; however, this usually occurs only in a well that is being pumped. When this condition is encountered, another method of measuring may have to be used. In small-diameter wells, the volume of the weight may cause the water level to rise in the pipe, and the measurement may be somewhat inaccurate.

Electric sounders may also be used to measure the depth to water in wells. There are a number of commercial models available, none of which is entirely reliable. Many sounders use brass or other metal indicators clamped around a conductor wire at 5-ft (1.5-m) intervals to indicate the depth to water when the meter indicates contact. The spacing of these indicators should be checked periodically with a surveyor's tape to assure accurate and reliable readings.

Some electric sounders use a single-wire line and probe, and rely on grounding to the casing to complete the circuit; others use a two-wire line and double contacts on the electrode. Experience has shown the two-wire circuits with a battery are by far the most satisfactory. Electric sounders are generally more suitable than other devices for measuring the depth to water in wells that are being pumped because they generally do not require removal from the well for each reading. However, when there is oil on the water, water cascading into the well, or a turbulent water surface in the well, measuring with an electric sounder may be difficult. Oil not only insulates the contacts of the probe, but if there is a considerable thickness of oil, it will give an erroneous reading. In some instances, it may be necessary to insert a small pipe in the well between the column pipe and the casing from the ground surface to about 0.4 m above the top of the pump bowls. This pipe should be plugged at the bottom with a cork or similar seal which is blown out after the pipe is set. Measurements with the electric sounder can then be made in the smaller pipe where the disturbances are eliminated or dampened, the true water level is measured, and the insulating oil is absent.

A simple and reliable method for measuring the depth to water in observation holes (4 to 15 cm in diameter) is a steel tape with a popper. The popper is a metal cylinder with a concave undersurface and is fastened to the end of a steel tape. The popper is raised a few centimeters and then dropped to hit the water surface, where it makes a distinct "pop." By adjusting the length of tape, the point at which the popper just hits the surface is rapidly determined. Poppers generally are not satisfactory for measuring pumping wells because of the operating noise and lack of clearance.

Permanent pump installations should always be equipped with an access hole for probe insertion or an air line and gage, or preferably both, to measure drawdown during pumping. An air line is accurate only to about 0.5 ft (15 cm) unless calibrated against a tape for various drawdowns, but is sufficiently accurate for checking well performance.

Artesian wells with piezometric heads above the ground surface are conveniently measured by capping the well with a cap that has been drilled, tapped, and fitted with a plug which is removed for the insertion of a Bourdon gage or mercury manometer stem. The static level is determined from the gage or manometer reading after the pressure has stabilized. Figure A.13 illustrates a mercury gage that is particularly suited to field use, especially when running a recovery test after constant head tests of artesian aquifers. For continuous records, a recording pressure gage may be used.

*Records of measurements.* Accurate permanent records should be kept of all water level measurements and should include: (a) identification of the well by number and location; (b) location and elevation of reference point; (c) elevation of ground surface; (d) date of measurement; (e) measured depth to water or to the bottom of the hole, if dry; (f) computed elevation of the water table or piezometric surface; (g) for piezometers, the aquifer or other zone represented by the reading; and (h) a note whether the well was being pumped when measured, was pumped recently, or whether a nearby well was pumping during the measurement.

*Exploration holes and observation well and piezometer installation.* Areas may be encountered containing wells for which logs are not available, where well construction features preclude measurement of water levels, or where the wells have not been drilled. For investigations of any size or importance and even for many individual well installations in such areas, exploratory drilling is often necessary. Such drilling should be tailored to the needs of the investigation and gaps in available data. In many instances, holes drilled for stratigraphic or other data can be converted for use as observation wells or piezometers. The following types of holes are drilled:

a. Stratigraphic holes are drilled primarily for the purpose of determining the nature, depth, and thickness of the geologic formations.

① 1-$\frac{1}{4}$" Stainless steel stop cock.
② 4' Length of $\frac{3}{4}$" i.d. rubber hose.
③ 1-2" Dia. ink bottle.
④ 1-3 Holed No. 8 rubber stop.
⑤ 1-$\frac{3}{4}$" Hose coupling.
⑥ 48" Length of 2 mm i.d. glass tubing.
⑦ 45" Length of stainless steel strip with graduations which give readings in feet of water.
⑧ 1-4" Length of $\frac{1}{4}$" o.d. stainless steel tubing with fittings.
⑨ 1-$\frac{5}{16}$" Stainless steel stop cock.
⑩ 1-4" Length of $\frac{5}{16}$" o.d. stainless steel or plastic tubing with fitting.
Assorted lumber (marine plywood)
Assorted $\frac{1}{4}$" bolts with nuts.

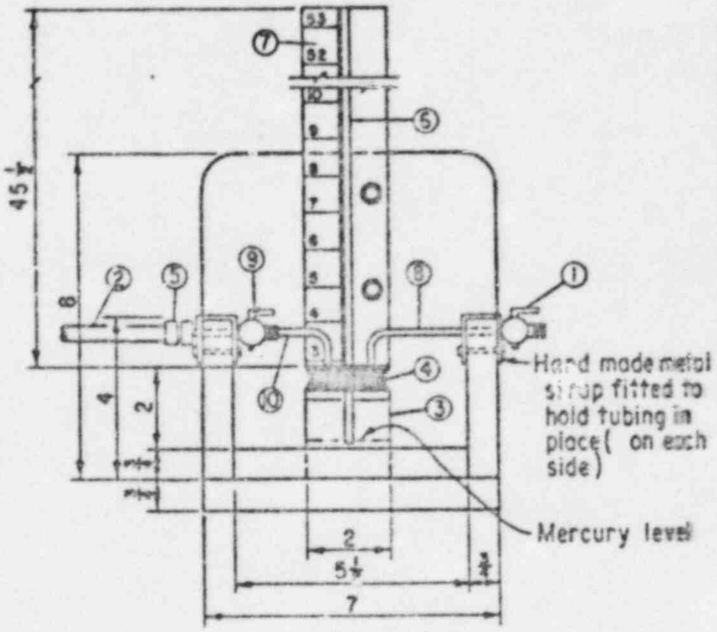


Figure A.13. Mercury manometer for measuring artesian heads (from Bureau of Reclamation)

b. Pilot holes are usually drilled to obtain data on which to base the design of wells.

c. Observation wells are usually constructed for the purpose of measuring water levels where subsurface conditions are relatively simple.

d. Piezometers are a special type of observation well so finished as to permit the measurement of the water level in a particular stratum or zone.

After exploratory or similar holes are completed, a permanent record should be made of each. This record should include an as-built drawing of the facility showing the elevation of the point from which measurements of the depth to water in the hole will be made; the elevation of the average ground surface in the vicinity of the well; the depth of hole; the length, size, and type of casing; location of seals and packers; and the location of the screen or perforations.

The record should also show subsurface geologic conditions, water level data, the location of the hole with respect to landlines or whatever land subdivision system is used in the area, and the identification number of the hole.

Drilling and installation. There are many methods and combinations of methods of drilling exploratory holes and wells. The most common holes are dug, drilled, bored, driven, or jetted (see Table 2).

Where conditions are uniform, it may be satisfactory to install observation holes on a grid with holes spaced at uniform intervals. Where conditions are not uniform, wells should be located to conform to the local variations in conditions. The magnitude and type of the study will also affect the spacing and location of holes. To obtain general information on an area, a wide spacing is satisfactory; for a detailed study, the spacing must be reduced to provide the necessary detail.

The holes should be deep enough to penetrate at least 3 m below the lowest water table of record or to the top of an artesian aquifer. If information on thickness of an aquifer is required, one or more holes should be drilled through the aquifer. An indication of the required hole depth can usually be obtained from an inventory of existing well records. Separate wells or piezometers may be required when two or more aquifers are involved.

Casing installed in observation wells should be sized to the purpose of the facility and means of obtaining data. Generally, if water levels are to be measured by a wetted tape or electric probe, a 3/4- to 1-1/2-in.- (2- to 4-cm-) diam steel or plastic pipe is suitable. However, if a standard water stage recorder is to be used or water samples taken from the facility, a minimum 4-in. (10-cm) casing may be required. Suitable perforations should be made opposite the saturated zone to assure reliable readings. Periodic collection of water samples may be one of several functions of the well, and this function may establish a determining limit on size of hole and casing.

Piezometer installations (Figure A.14) rather than simple observation wells, may be essential to a clear understanding of ground water conditions where subsurface conditions are complex. The presence of a confined zone or several zones each with a different water level requires use of piezometers to confine and separate each level. Observation of pumping test influence may especially require the use of piezometers, even in apparently homogeneous aquifers. Installation of piezometers, especially in slowly permeable materials, may require strict design considerations to minimize time lag and other similar problems.

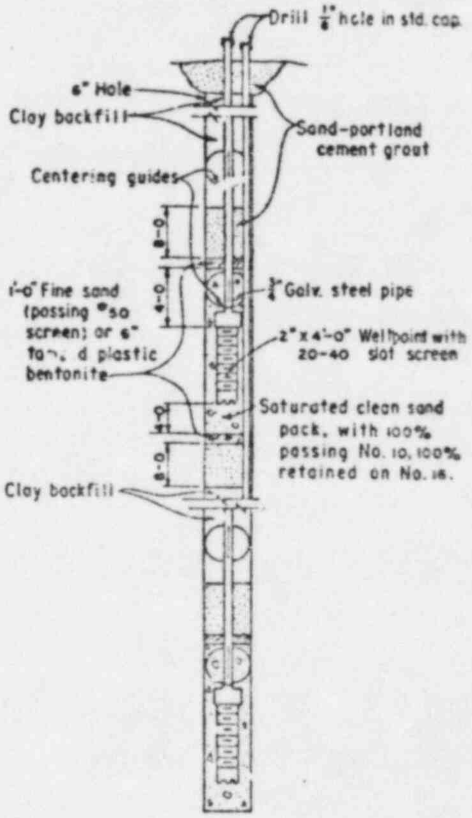


Figure A.14. Typical dual piezometer installation (from Bureau of Reclamation)

Each piezometer should consist of three essential components:

a. A watertight standpipe of the smallest possible diameter, consistent with the method of reading, attached to the tip and extending to the surface.

b. A tip consisting of a well screen, porous tube, or other similar feature, and in fine-grained materials, a surrounding zone of filter sand.

c. A seal consisting of cement grout, bentonite slurry, or other similar slowly permeable material placed between the standpipe and the hole to isolate the zone.

Where several piezometers are required at a given location, it may be possible, as a cost-saving feature, to install them in a single hole, as shown on Figure A.14.

In addition to the described standpipe-type piezometer, there are several commercially available instruments that are operated by hydraulic or pneumatic pressure, or by an electric signal. Such instruments may be especially valuable for unusual subsurface or monitoring conditions, such as in very slowly permeable materials.

The casing or pipes in an observation well or piezometer usually extend above the ground surface at least a foot unless pit installation is necessary. The top of the casing or each pipe should be fitted with a screwcap or locking cap containing a small hole to permit adjustment of air pressure in the pipe in response to water level fluctuations or barometric changes. Where artesian flow conditions are present, a tight-fitting cap which has been drilled and tapped for a Bourdon gage or mercury manometer should be used. If climatic conditions require protection against freezing, a suitable shelter equipped with heating facilities or replacement of the water in the upper portion of the piezometer by a nonfreezing fluid may be necessary.

Facilities should be protected against standing surface water and leakage alongside the casing by proper grading and placement of grout or clay seals at the surface. When an observation well or piezometer must be located in the open where damage by machinery may occur, it should be adequately identified and protected.

## Boundaries within the unsaturated zone

The delineation of the top of the capillary water subzone often requires exercise of technical judgment. Any variations in grain size and porosity of material zones upon which the capillary water subzone is superimposed complicate the choice of position and obscure it with some uncertainty. Changes taking place with time and hysteresis effects add more complication.

Degree of saturation. One technique that can be used to assure a thorough investigation is through expression of material water contents in terms of degree of saturation. Below the water table the saturation is 100 percent. At some predetermined degree of saturation, e.g., 90 percent, the boundary may be defined somewhat arbitrarily. This technique can also be useful for delineating other capillary water zones in perched configurations well above the water table. The calculation of degree of saturation on which to base boundaries of capillary water subzones is as follows:

$$\text{Degree of saturation (\%)} = \frac{\text{Volume of water (cc)}}{\text{Volume of wet specimen (cc)} - \text{Volume of solids (cc)}} \times 100$$

Determination of saturation in the laboratory is supplemental to the laboratory determination of water content (see Water Content and Porosities and Void Ratio).

Approximate capillary rise. In those cases where a reasonable approximation of the capillary zone is adequate, the thickness of the zone can be estimated according to soil type. Suction pressure and capillary rise are primarily dependent on grain and pore sizes of the soil. This method of zoning is particularly suitable in granular soils where the capillary subzone tends to be quite thin. Capillary rise may be approximated according to the following tabulation:

| USCS Soil Type | Capillary Rise, cm |
|---|---|
| GW | 6 |
| GM | 68 |
| SW | 60 |
| SM | 112 |
| ML | 180 |
| CL | 180 |
| CH | 200-400+ |

## Wind Speeds and Directions

Wind speeds and directions are routinely recorded at many stations of the National Weather Service. These records are often satisfactory for average regional conditions. If a local weather station is established, the instrumentation and procedures should be organized according to established guidance such as:

> "Measurement of Surface Wind," Chapter 6, Guide to Meteorological Instruments and Observing Practices, 2nd Ed., World Meteorological Organization, 1970, pp VI.1 to VI.6.
>
> "Surface Wind," Section 10.F., National Handbook of Recommended Methods for Water-Data Acquisition, U. S. Department of the Interior, Geological Survey, 1980, pp 10-45 to 10-51.

## ROUTING AND TRANSMITTAL SLIP

Date 3/16/83

| TO: (Name, office symbol, room number, building, Agency/Post) | Initials | Date |
|---|---|---|
| 1. Inez Bailey/Jeff Bartlett | | |
| 2. | | |
| 3. | | |
| 4. | | |
| 5. | | |

| | | | | | |
|---|---|---|---|---|---|
| ☐ | Action | ☐ | File | ☐ | Note and Return |
| ☐ | Approval | ☐ | For Clearance | ☐ | Per Conversation |
| ☐ | As Requested | ☐ | For Correction | ☐ | Prepare Reply |
| ☐ | Circulate | ☐ | For Your Information | ☐ | See Me |
| ☐ | Comment | ☐ | Investigate | ☐ | Signature |
| ☐ | Coordination | ☐ | Justify | ☐ | |

REMARKS

Attached is a master of microfiche for a waste management contract for your processing. Attached is correspondence which explains the fiche system regarding WM contracts. This arrangement was worked out with Steve Scott and John Skoczlas. Please let me know if you have any questions. Thank you.

**DO NOT use this form as a RECORD of approvals, concurrences, disposals, clearances, and similar actions**

FROM: (Name, org. symbol, Agency/Post)
Nancy Still, WM

Room No.—Bldg. 623-SS

Phone No. 74087

5041-102

**OPTIONAL FORM 41 (Rev. 7-76)**
Prescribed by GSA
FPMR (41 CFR) 101-11.206

☆ GPO : 1981 O - 341-529 (101)