

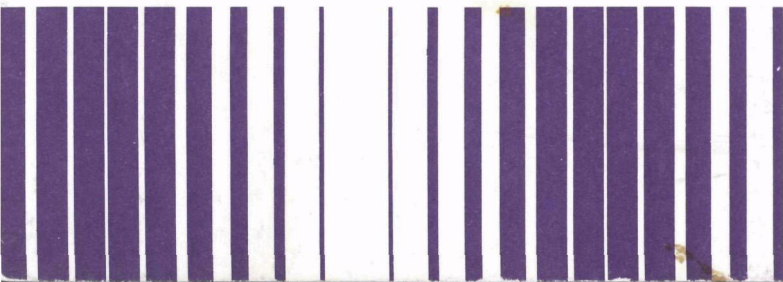
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Technology Transfer

Description and Sampling of Contaminated Soils

A Field Pocket Guide





Description and Sampling of Contaminated Soils: A Field Pocket Guide

Center for Environmental Research Information
U.S. Environmental Protection Agency
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Notice

This guide has been reviewed by the U.S. Environmental Protection Agency and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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How to Use This Guide

This guide describes many field methods and procedures that can be used for (1) preliminary site reconnaissance, (2) detailed site and contaminant characterization/sampling for transport/fate modeling and risk assessment, and (3) remediation selection and design.

All methods and procedures described in this guide are simple and inexpensive. When used early in site reconnaissance, site characterization, or remediation projects, the methods in the guide may reduce project costs by providing a basis for more efficient application of more complex and expensive field methods, when they are needed.

This guide has also been designed to serve as a companion to EPA's **Guide to Site and Soil Description for Hazardous Waste Site Characterization** (Cameron, 1991), which also serves as the basis for the site and soil components for metals of the Environmental Sampling Expert System (ESES) under development by EPA's Environmental Monitoring Systems Laboratory, Las Vegas.

Use for Preliminary Site Reconnaissance. If a soil survey prepared by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture is available for the site, this guide in combination with Cameron (1991) can be used to develop preliminary interpretations concerning the potential for site and soil conditions to facilitate or inhibit contaminant transport.

Use for Detailed Site and Contaminant Characterization:

1. To assist field personnel in preparing for a visit to a contaminated site by providing checklists to ensure that no documents or equipment are accidentally left behind (see Forms 1-2 and 1-3 in Chapter 1).

2. To provide a concise, but comprehensive, reference source for methods of describing and analyzing site and soil characteristics in the field that require only visual/tactile observation or very simple equipment. Chapter 2 provides this information for site characteristics. Chapter 3 provides this information for soil characteristics, placing special emphasis on soil description procedures of the U.S. Soil Conservation Service. Abbreviations and codes that can be used for specific soil features are suggested to facilitate notetaking. Where soil conditions favor use of a soil probe (no coarse fragments), description procedures outlined in Appendix A.1 may be useful for characterizing soils at a site prior to sampling for detailed chemical characterization.
3. To assist in selecting and obtaining alternative soil sampling equipment if unforeseen problems at the site prevent use of sampling procedures specified in the Soil Sampling and Quality Assurance Plans. Chapter 4 provides information on sampling equipment characteristics. A series of Appendices describe some standard soil sampling and handling protocols that may help address quality control concerns related to alternative procedures that may be required by unforeseen site conditions.
4. To facilitate use of EPA's Environmental Sampling Expert System (see Section 1.6).

Use for Modeling and Remediation Selection/Design. When site soil parameters that are required for modeling or remediation selection/design are known, the appropriate sections of this guide can be used for data collection. **Characterizing Soils for Hazardous Waste Site Assessments** (Breckenridge et al., 1991) and Cameron (1991) may assist in identifying soil parameters of interest.

Chapter 1

Field Methods, Equipment, and Documents

This chapter provides tables and checklists that can be used to help select specific field methods, and to identify equipment and documents that should be assembled prior to going into the field.

1.1 Nature of Soil Pollutants and Surface Pollution Situation

Before beginning field sampling and characterization, it is necessary to have some knowledge of the nature of soil pollutants at a site, whether they are heavy metals, toxic organics, or both, and of the areal extent of pollution. EPA's Environmental Sampling Expert System (ESES) defines two major types of surface pollution situations related to the areal distribution of the contaminants: (1) **large** (covers a wide area, primarily on the surface), and (2) **localized** (areas usually polluted near the source).

Once all available site information has been evaluated, an **exploratory** soil sampling program may be undertaken to further define the nature and extent of soil pollutants, before developing a detailed soil sampling plan. Soil descriptions of near-surface soil cores (1.5 to 2 m) taken on a grid at the site using procedures described in Appendix A.1 may provide valuable additional information at relatively low cost prior to developing either an exploratory or detailed soil sampling plan.

Existing data, or soil sampling results, will indicate the nature of pollutants. Specific contaminants of concern are broadly defined in EPA's ESES as relatively **mobile and toxic** (residence time in the solid phase is relatively short, enhancing toxicity) or relatively **nonmobile and nontoxic** (residence time in the solid phase is relatively long, decreasing potential toxicity).

1.2 Soil Parameters for Field Sampling and Characterization

This field guide assumes that:

1. Physical, hydrologic, and chemical/biological parameters of soils and contaminants have been selected for description and sampling prior to the field collection phase for characterization of a contaminated site.
2. These parameters and methods or protocols are contained in statistically sound and detailed Soil Sampling and Quality Assurance Plans for the site. Guidance for the preparation of such plans can be found in Mason (1983), Barth et al. (1989), van Ee et al. (1990), and U.S. EPA (1986, Vol. 2, Chap. 9).

Appendix D in a companion document to this field guide, **Guide to Site and Soil Description for Hazardous Waste Site Characterization** (Cameron, 1991), may provide assistance in selecting site and soil characterization parameters and in identifying available field, laboratory, and calculation or lookup methods for individual parameters.

This field guide is intended to assist in carrying out three major types of activities in the field:

- Description of site and soil features based on visual and tactile observation
- Field tests or measurements that involve relatively simple procedures and equipment
- Methods for collecting undisturbed or minimally disturbed samples for physical and microbiological characterization in the laboratory

Collection of samples for chemical characterization in the laboratory is not covered in detail in this guide, because it is assumed that this is defined in detail in the Sampling and Quality Assurance Plans for the site. However, general protocols for sample handling and preparation and for sampling with a spade and scoop, augers, or thin-walled tube samplers are contained in Appendices A.2 through A.4.

Specialized field procedures involving more complicated equipment, such as for measuring unsaturated hydraulic conductivity, are not covered in this field guide.

Procedures involving such methods should be described in the Sampling Plan.

1.3 Field Description of Soils

Multiple soil profile descriptions at a site can provide a great deal of information that may be useful in evaluating the variability of soil properties, and the directions and potential for transport of contaminants in the subsurface. Detailed soil profile descriptions have not been commonly used at contaminated sites. One purpose of this field guide is to encourage greater use of this relatively easy field method.

Table 1-1 summarizes the key features that should be noted in detailed soil profile descriptions and identifies the sections in this field guide that cover individual features. Preparation of a complete, detailed soil profile description requires the digging of a pit so that feature can be observed laterally as well as vertically. Although this method is time consuming, the ability to observe small-scale lateral variations in soil features associated with increased or reduced soil permeability, justifies, in most instances, a limited number of such soil profile descriptions at a site.

Where soils are not rocky, a thin-wall soil probe can be used to prepare a moderately detailed soil profile description in a sufficiently short time so that larger scale variations in soil characteristics can be identified. Appendix A.1 describes a general protocol for description of soil cores. Table 1-1 recommends that all the features used in preparing a pit soil profile description be observed. It should be recognized, however, that the soil core may be too small a sample of the subsurface to accurately describe a number of features, such as transitions between horizon boundaries, certain types of soil structure (columnar, for example), pore and root distribution, and genetic horizons (fragipans, for example). These features are indicated with an asterisk in Table 1-1.

Preparation of an accurate, detailed soil profile description requires training and experience, and such descriptions are best done under the supervision of someone familiar with procedures developed by the Soil Conservation Service in the U.S. Department of Agriculture.

Table 1-1. Suggested Soil Parameters for Field Description

Parameter	Section in Guide	Soil Profiles	Soil Samples
Horizons	3.1.1	R*	R
USDA Texture	3.1.2	R	R
Color	3.1.3	R	R
Porosity	3.1.4	R*	r
Zones of Increased Porosity/Permeability			
Soil structure	3.1.5a	R*	r
Extrastructural cracks	3.1.5b	r	r
Roots	3.1.5c	R*	r
Surface features	3.1.5d	R	
Sedimentary features	3.1.5e	R*	
Zones of Reduced Porosity/Permeability			
Genetic horizons	3.1.6a	R*	
Consistency	3.1.6b	R	
Root restricting layers	3.1.6d	R*	
Compaction	3.1.6e	r	
Moisture Condition	3.2.1	R	R
Water Table	3.2.2	R	R
Saturated Hydraulic Conductivity	3.2.4	R**	r
Clay Minerals	3.3.7	r	
Other Minerals	3.3.8	r	
Odor	3.3.2	r	

R = Recommended for all situations.

r = Recommended where climatic, geologic, and soil conditions make parameter significant.

* Soil pit may be required for accurate description of this soil feature.

** Estimation of K_{sat} class based on other observable features.

Soil samples for chemical characterization in the laboratory should generally not double as samples for detailed soil description, because exposure to the air before placement in sample containers should be minimized. However, abbreviated descriptions should be made to identify the samples and possibly help in relating sample results to other soil profile descriptions. Table 1-1 recommends that, at a minimum, soil horizon (or depth increments), color, texture, moisture condition, and relationship to the water table be observed. The table also identifies several other features (porosity, structure, and roots) for which observations would be useful, if the nature of the sample allows (soil core) and exposure to air is less of a concern (heavy metals in aerated soil).

1.4 Field Sampling and Testing

A number of tests involving relatively simple procedures and equipment can be used to measure or characterize soil physical and chemical properties. Such tests are generally not as accurate as laboratory tests but have the advantage of being inexpensive and may be used for preliminary screening or selection of samples for more accurate laboratory testing.

Form 1-1 provides a checklist of soil engineering, physical, and chemical parameters for which field tests are described in this field guide. Special sampling procedures for microbiological characterization are covered in Section 3.3.10.

Before going into the field, this checklist should be used to identify the specific tests that appear to be of value for the site of interest. This procedure will assist in locating the appropriate section of the field guide where specific procedures are described, and in identifying equipment needs (see next section).

1.5 Field Equipment and Documents

Form 1-2 is a checklist of over 90 items that may be required for field description, analysis, and sampling of soils. Major categories covered in this checklist include (1) documents, (2) protective equipment, (3) miscellaneous equipment, (4) site surface characterization, (5) soil description equipment/materials, (7) texture analysis and sample preparation equipment, (8) sample, equipment,

and waste containers and forms, and (9) field testing and analysis. Form 1-3 contains a checklist of around 20 items related to quality assurance and quality control of the sampling process, such as (1) QA/QC forms and samples, (2) material required for sample preservation and transport, and (3) decontamination equipment.

These checklists have two columns: the first is to identify those items that are needed for the site in question; the second column can be checked when the item has been obtained and packed. Required items can be identified by reviewing the site Soil Sampling Plan and Quality Assurance Plan and the checklist of field tests contained in this guide (Form 1-1).

1.6 Use of EPA's Environmental Systems Monitoring Laboratory

EPA's Environmental Systems Monitoring Laboratory is developing an Environmental Sampling Expert System (ESES) which ultimately will integrate a Geographic Information System and Site Description System (including data quality objectives, quality assurance and quality control, and site description) with a Knowledge Frame Manager (for analysis, interpretation of data, and report preparation) for contaminated sites.

The **Guide to Site and Soil Description for Hazardous Waste Site Characterization** (Cameron, 1991) provides the basis for the site and soil components for metals in the ESES. Site and soil parameters (called Object/Attributes in the ESES), are assigned "values" which have significance for contaminant transport and fate.

Form 3-1 (Soil Profile and Related Information) contains space to record observations related to all the site and soil knowledge frames in EPA's ESES. Data on this form can be coded on Forms 1-4 and 1-5 (Coding Sheet for Use of ESES Site and Soil Knowledge Frames) to aid in data interpretation using the ESES or Cameron (1991). These forms also indicate the section in this guide that covers description procedures and nomenclature. Where standard SCS descriptive procedures do not readily allow assignment of a "value" for the ESES, definitions used in the ESES are provided for use during field observations. Cameron (1991) provides additional definitions of terms.

Form 1-1. Checklist of Soil Physical and Chemical Property Sampling and Field Test Procedures

Soil Physical Properties

- ☐ Color ignition test (Section 3.1.3)
- ☐ Extrastructural crack tests (Section 3.1.5b)
- ☐ Fragipan identification (Section 3.1.6a)
- ☐ Cementation test (Section 3.1.6b)
- ☐ Bulk density (Section 3.1.6c)
- ☐ Pocket penetrometer test (Section 3.1.6e)
- ☐ Soil temperature regime characterization (Section 3.1.8)
- ☐ Soil moisture (Section 3.2.1)
- ☐ Water table estimation (Section 3.2.2)
- ☐ Available water capacity (Section 3.2.3)
- ☐ Saturated hydraulic conductivity class estimation (Section 3.2.4)
- ☐ Soil drainage class placement (Section 3.2.4)

Soil Engineering Properties

- ☐ Unified (ASTM) texture (Section 3.1.7a)
- ☐ Atterberg limits (Section 3.1.7b)
- ☐ Shear strength (Section 3.1.7c)
- ☐ Shrink-swell tests (Section 3.1.7d)
- ☐ Corrosivity characterization (Section 3.1.7e)

Soil Chemical Properties

- ☐ Organic matter ignition test (Section 3.3.1)
- ☐ Cation exchange capacity/exchangeable acidity (Section 3.3.3)
- ☐ pH (Section 3.3.4)
- ☐ Redox potential (Section 3.3.5)
- ☐ Electrical conductivity (Section 3.3.6)
- ☐ Clay minerals—nitrobenzene test (Section 3.3.7)
- ☐ Calcium carbonate—HCl test (Section 3.3.8)
- ☐ Soluble salts—chloride and sulfate (Section 3.3.8)
- ☐ Gypsum acetone test (Section 3.3.8)
- ☐ Iron oxides—ignition and streak tests (Section 3.3.8)
- ☐ Manganese—streak and hydrogen peroxide tests (Section 3.3.8)
- ☐ Sampling for soil microbiota (Section 3.3.10)

Form 1-2. Soil Description/Sampling Equipment and Documents Checklist

Check first column to identify needed items. Check second column when item has been obtained and packed prior to leaving for the field.

Documents

- | | | |
|-----|-----|------------------------|
| ___ | ___ | Sampling plan |
| ___ | ___ | Quality assurance plan |
| ___ | ___ | Health and safety plan |
| ___ | ___ | Log books |

Protective Equipment

- | | | |
|-----|-----|--|
| ___ | ___ | Protective suits |
| ___ | ___ | Boots |
| ___ | ___ | Gloves (inner/outer) |
| ___ | ___ | Duct tape |
| ___ | ___ | Respirators, respirator cartridges, and/or dust masks |
| ___ | ___ | Raingear and/or warm clothing |
| ___ | ___ | Insect repellent (should not contain chemicals that will be target analytes or in matrix spikes) |

Miscellaneous

- | | | |
|-----|-----|---|
| ___ | ___ | Keys for access to site, graphite lubricant for locks |
| ___ | ___ | Folding table |
| ___ | ___ | Camera and film |
| ___ | ___ | Flashlight and extra batteries |
| ___ | ___ | Toolbox, including hacksaw |
| ___ | ___ | Calculator |

Site Surface Characterization

- | | | |
|-----|-----|---|
| ___ | ___ | Max/min thermometer |
| ___ | ___ | Humidity gage or sling psychrometer |
| ___ | ___ | Hand-held anemometer |
| ___ | ___ | 4-ft staffs with flags or flagging (for wind direction indicators) |
| ___ | ___ | Clinometer for slope measurement |
| ___ | ___ | 6-ft rod and colored tape to mark eye level for clinometer readings |

(Continued)

Form 1-2. (Continued)

Soil Description Equipment/Materials

- ___ ___ Field notebook, pencils, ballpoints, and markers
- ___ ___ Clipboard with cover
- ___ ___ Microcassette recorder, spare microcassettes and batteries (optional for notetaking)
- ___ ___ Map of soil sampling locations
- ___ ___ Soil profile and related information forms (Form 3-1)
- ___ ___ Unified (ASTM) texture determination form (Form 3-2)
- ___ ___ Other soil data collection forms:
 - _____
 - _____
 - _____
- ___ ___ Carpenters rule (for measuring horizon depth) and/or steel tape
- ___ ___ 30-cm by 2-m plastic sheet for placing soil cores for description
- ___ ___ Munsell Soil Color book
- ___ ___ Knife (for cleaning exposed soil surfaces)
- ___ ___ Nails (for marking horizon boundaries)
- ___ ___ 10 power hand lens (surface features, mineral identification, carbonate test)
- ___ ___ Sand size and coarse fragment determination scales
- ___ ___ 1/2 in. mesh (for estimating areal distribution of features on excavated profile)
- ___ ___ Tile probe (soil depth determination in rocky soil)
- ___ ___ Stiff, 2-mm wire for crack depth measurement
- ___ ___ Graded sand of uniform color for crack characterization (excavation method)
- ___ ___ Stereoscopic microscope (5 to 6 in. working distance, 20 to 80 power)
- ___ ___ Small high intensity 6v flexible lamp (for illuminating microscope)

(Continued)

Form 1-2. (Continued)**Soil Sampling Equipment (specified in Sampling Plan)****Hand-held sampling devices**

(Check all items that may be required at the site.)

- ☐ ☐ Shovel/spade
- ☐ ☐ Spoons
- ☐ ☐ Scoops
- ☐ ☐ Screw-type auger
- ☐ ☐ Barrel/bucket auger (regular, sand, mud, stone, planer, in situ soil recovery)
- ☐ ☐ Thin-walled tube
- ☐ ☐ Chisel rock breakers
- ☐ ☐ Crescent wrenches, vice grips, pipe wrenches (for changing drill rod length and sampling tips)
- ☐ ☐ Weighted plastic mallet
- ☐ ☐ Tube sampler cleaning tool

Power-driven sampling devices

(Check types planned for use at the site.)

- ☐ ☐ Auger
- ☐ ☐ Split spoon
- ☐ ☐ Thin-walled tube samplers

Texture Analysis and Sample Preparation Equipment

- ☐ ☐ Sieves (3 in., 1/2 in., No. 10, for characterizing coarse fraction)
- ☐ ☐ Hanging spring scale with canvas sling or pail (for weighing coarse fragments)
- ☐ ☐ No. 10 mesh stainless steel screens (for TOC and semivolatile samples)
- ☐ ☐ No. 10 mesh Teflon[®] screens (for metals samples)
- ☐ ☐ Compositing bucket/mixing containers (stainless steel, glass, Teflon[®]-lined suitable for all contaminants; aluminum pans for any contaminant except Al; plastic for metals analysis only)
- ☐ ☐ 1-m square piece of suitable plastic, canvas, or rubber sheeting (for sample preparation)

(Continued)

Form 1-2. (Continued)

Sample, Equipment, and Waste Containers and Forms

- ___ ___ Brown plastic trash bags for dirty equipment
- ___ ___ White plastic trash bags for clean equipment
- ___ ___ Ziplock type plastic bags for protecting equipment that cannot be decontaminated (cameras, notebooks, etc.)
- ___ ___ Sample containers (sealed clean and labeled plus 20 percent)
- ___ ___ Plastic bags for sample containers
- ___ ___ Sample description/identification forms
- ___ ___ Sample labels/tags
- ___ ___ Soil moisture tins

Field Testing and Analysis

- ___ ___ Photoionization detector (PID) or flame ionization detector (FID)
- ___ ___ Calibration gases for meters
- ___ ___ Hydrogen gas for FID
- ___ ___ Specialty gas meters (HCN, etc.)
- ___ ___ Explosimeter
- ___ ___ Scale/balance (0.1 gram accuracy) for weighing of samples (moisture, bulk density, organic matter)
- ___ ___ Infrared lamp, or small oven, and thermometer scaled to at least 120°C (for drying samples for moisture, bulk density, and organic matter tests)
- ___ ___ Portable gas soldering torch and porcelain crucible or small tin (not Al) with wire bracket or tongs (for ignition tests)
- ___ ___ Saran-ketone mixture (bulk density clod method) or sand-measuring or rubber balloon apparatus (bulk density excavation method)
- ___ ___ pH measurement kit and standard solutions (spare batteries, if necessary), and/or color dyes, pH test strips
- ___ ___ Glass or plastic stirring rod (pH test)
- ___ ___ Small containers for mixing water and soil (pH, specific conductance tests)

(Continued)

Form 1-2. (Continued)

Field Testing and Analysis (Continued)

- ___ ___ Conductivity meter and specific conductance standards
- ___ ___ Quart container of distilled deionized water in squeeze bottle (for pH, texture, and carbonate tests)
- ___ ___ Common laboratory spatulas (for texture tests)
- ___ ___ Porcelain spot plate (carbonate test, iron oxide, manganese oxide scratch tests)
- ___ ___ Clean glass rod (carbonate test)
- ___ ___ 10-percent HCl in plastic squeeze bottle (carbonate test)
- ___ ___ Solution of malachite green in nitrobenzene (for clay minerals test)
- ___ ___ Hydrogen peroxide (manganese test, organic matter tests)
- ___ ___ Test tubes or plastic vials and 5-percent silver nitrate, and 5-percent barium chloride solutions (chloride and sulfate tests)
- ___ ___ Small stoppable bottle, filter paper, and acetone (gypsum test)
- ___ ___ Field sampling glove box and core paring tool (for aseptic core samples for microbiological analysis—see Section 3.3.10)

Form 1-3. Soil Sampling Quality Assurance/Quality Control Checklist

Check first column to identify needed items. Check second column when item has been obtained and packed prior to leaving for the field.

Forms

- | | | |
|-------|-------|--|
| _____ | _____ | List of sample locations where duplicates and other QA samples are to be taken |
| _____ | _____ | Sample alteration form (Form 3-1), multiple copies |
| _____ | _____ | Field audit checklist (Form 3-2) |
| _____ | _____ | Soil sample corrective action form (Form 3-3) |

QA Samples (check types specified in QA Plan)*

Double-Blind Samples

- | | | |
|-------|-------|---|
| _____ | _____ | Field evaluation samples (FES) |
| _____ | _____ | Low level field evaluation samples (LLFES) |
| _____ | _____ | External laboratory evaluation samples (ELES) |
| _____ | _____ | Low level external laboratory evaluation samples (LLELES) |
| _____ | _____ | Field matrix spike (FMS) |
| _____ | _____ | Field duplicate (FD) |
| _____ | _____ | Preparation split (PS) |

Single-Blind Samples

- | | | |
|-------|-------|---|
| _____ | _____ | Field rinsate blanks (FRB)—also called field blanks, decontamination blanks, equipment blanks, and dynamic blanks |
| _____ | _____ | Preparation rinsate blank (PRB)—also called sample bank blanks |
| _____ | _____ | Trip blank (TB)—also called field blank |

Sample Preservation and Transport

- | | | |
|-------|-------|---|
| _____ | _____ | Chest or 6-pack cooler |
| _____ | _____ | Ice |
| _____ | _____ | Max/Min thermometer |
| _____ | _____ | Chain-of-custody forms and seals |
| _____ | _____ | Shipping forms |
| _____ | _____ | Analytical analysis request forms, if different from chain-of-custody forms |

(Continued)

Form 1-3. (Continued)

Decontamination

- ___ ___ Decontamination vessel
- ___ ___ Wash solution(s)—should be specified in
 Sampling Plan.
- ___ ___ Garden spray cans for wash fluids
- ___ ___ Rinse solutions (acetone, deionized water)
- ___ Labels for containerized wastes (solid or liquid)

* See van Ee et al. (1990) for more detailed discussion of these types of samples.

Form 1-4. Coding Sheet for ESES Site Knowledge Frames

Object/Attribute	Source*	Value	
Nature of Heavy Metal Pollutants (enter elements concentrations—see Table 3-1 in Cameron [1991])	Test results	Mobile/ Toxic	Nonmobile/ Nontoxic
		_____	_____
		_____	_____
		_____	_____
		_____	_____
		_____	_____
Climate/Weather	Lookup	_____ Humid	
		_____ Temperate	
		_____ Dry	
Macrofauna and Mesofauna	2.6	_____ Many	
		_____ Common	
		_____ Few	
Slope	2.2	_____ Steep (>12%)	
		_____ Moderate (3-12%)	
		_____ Flat (<3%)	
Surface Erosion/Erodibility	2.3	_____ Severe	
		_____ Moderate	
		_____ Slight to none	
Surface Pollution Situations	1.1	_____ Large areas	
		_____ Localized areas	
Surface Runoff	2.4	_____ Rapid (H, VH)	
		_____ Medium (M)	
		_____ Slow (L, VL)	
		_____ Ponded (N)	
Vegetation	2.5	_____ Dense	
		_____ Scattered/Sparse	
		_____ Absent	
Wind Speed/Direction	2.1.2	_____ Gale	
		_____ Breezy	
		_____ Calm to light	

*Use observations recorded on Form 3-1 or refer to indicated section number in this guide. For lookup methods, refer to Appendix D in Cameron (1991).

Form 1-5. Coding Sheet for ESES Soil Knowledge Frames

Object/Attribute	Source*	Value
Bulk Density (g/cc)	3.1.6c Lab	<input type="checkbox"/> Low (<1.3)
		<input type="checkbox"/> Medium (1.3-1.6)
		<input type="checkbox"/> High (>1.6)
Cation Exchange Capacity (meq/100 g soil)	3.3.3 Lab	<input type="checkbox"/> Low (<12)
		<input type="checkbox"/> Medium (12-20)
		<input type="checkbox"/> High (>20)
Clay Minerals	3.1.2	<input type="checkbox"/> Abundant (>27%)
	3.3.7	<input type="checkbox"/> Mod/Slight(1-27%)
	Lab	<input type="checkbox"/> None/Neg. (<1%)
Color	3.1.3	<input type="checkbox"/> Dark
		<input type="checkbox"/> Red and Yellow
		<input type="checkbox"/> Brown
		<input type="checkbox"/> Gray/Whitish
		<input type="checkbox"/> Mottled
Compaction	3.1.6e	<input type="checkbox"/> High
		<input type="checkbox"/> Moderate
		<input type="checkbox"/> Low/Slight
Consistency	3.1.6b	<input type="checkbox"/> High
		<input type="checkbox"/> Moderate
		<input type="checkbox"/> Low/Weak
		<input type="checkbox"/> Cemented
Corrosivity	3.1.7e Lookup	<input type="checkbox"/> High
		<input type="checkbox"/> Moderate
		<input type="checkbox"/> Low
Electrical Conductivity (Salinity, mmhos/cm)	3.3.6 Lab	<input type="checkbox"/> Nonsaline (<2)
		<input type="checkbox"/> Slight (2-4)
		<input type="checkbox"/> Moderate (4-8)
		<input type="checkbox"/> Very (8-16)
		<input type="checkbox"/> Extremely (>16)
Fertility Potential	3.3.9 Lab	<input type="checkbox"/> High
		<input type="checkbox"/> Moderate
		<input type="checkbox"/> Low

(Continued)

Form 1-5. (Continued)

Object/Attribute	Source*	Value
Horizons	3.1.1	<input type="checkbox"/> Master Horizons <input type="checkbox"/> Transitional <input type="checkbox"/> Disturbed <input type="checkbox"/> Buried
Hydraulic Conductivity (micrometers/s)	3.2.4	<input type="checkbox"/> High (>10) <input type="checkbox"/> Moderate (0.1-10) <input type="checkbox"/> Low (0.01-0.1) <input type="checkbox"/> Inhibited (<0.01)
Infiltration/ Percolation (cm/hr)	3.2.5	<input type="checkbox"/> High (>5) <input type="checkbox"/> Medium (1.5-5.0) <input type="checkbox"/> Low (0.15-1.5) <input type="checkbox"/> Inhibited (<0.15)
Microbiota	3.3.10 Lab	<input type="checkbox"/> Abundant <input type="checkbox"/> Common <input type="checkbox"/> Few <input type="checkbox"/> None
Moisture Conditions	3.2.1 Lab	<input type="checkbox"/> Wet <input type="checkbox"/> Moist <input type="checkbox"/> Dry
Odor	3.3.2	<input type="checkbox"/> High <input type="checkbox"/> Mod/Slight <input type="checkbox"/> None
Organic Matter	3.3.1 Lab	<input type="checkbox"/> Abundant (>4%) <input type="checkbox"/> Moderate (2-4%) <input type="checkbox"/> Sparse (<2%)
Porosity	3.1.4	<input type="checkbox"/> Coarse (>5mm) <input type="checkbox"/> Medium (2-5mm) <input type="checkbox"/> Fine (0.5-2mm) <input type="checkbox"/> Very fine (<0.5mm)
Reaction (pH)	3.3.4	<input type="checkbox"/> Acid (<6.6) <input type="checkbox"/> Neutral (6.6-7.3) <input type="checkbox"/> Alkaline (>7.3)

(Continued)

Form 1-5. (Continued)

Object/Attribute	Source*	Value
Redox Potential	3.3.5	<input type="checkbox"/> High Oxidized <input type="checkbox"/> Intermediate <input type="checkbox"/> Highly Reduced
Roots	3.1.5c	<input type="checkbox"/> Many <input type="checkbox"/> Common <input type="checkbox"/> Few
Structure Grades	3.1.5a	<input type="checkbox"/> Structureless <input type="checkbox"/> Weak <input type="checkbox"/> Moderate <input type="checkbox"/> Strong
Surface Features	3.1.5d	<input type="checkbox"/> Prominent <input type="checkbox"/> Distinct <input type="checkbox"/> Faint
Temperature	3.1.8	<input type="checkbox"/> High <input type="checkbox"/> Medium <input type="checkbox"/> Low
Temperature Regimes	3.1.8 Lookup	<input type="checkbox"/> Pergelic <input type="checkbox"/> Cryic <input type="checkbox"/> Frigid-Isofrigid <input type="checkbox"/> Mesic-Isomesic <input type="checkbox"/> Thermic-Isothermic <input type="checkbox"/> Hyperthermic- <input type="checkbox"/> Isohyperthermic
Texture Classes	3.1.2	<input type="checkbox"/> Fragmental <input type="checkbox"/> Sandy <input type="checkbox"/> Silty <input type="checkbox"/> Loamy <input type="checkbox"/> Clayey <input type="checkbox"/> Organic soils

*Use observations recorded on Form 3-1 or refer to indicated section number in this guide. For laboratory and lookup methods, refer to Appendix D in Cameron (1991).

Chapter 2

Site Characteristics

This chapter covers a number of weather-related factors that affect the ease or difficulty of soil description and sampling in the field (Section 2.1) and other site surface features at locations where soils are described or sampled. These features include slope (Section 2.2), surface erosion (Section 2.3), surface runoff (Section 2.4), vegetation (Section 2.5), and macro- and mesofauna associated with the surface and subsurface (Section 2.6).

2.1 Climate and Weather

Climate exerts a profound influence on soil directly through soil forming and weathering processes such as precipitation, evapotranspiration, and temperature, and indirectly by its influence on vegetation. Climate is a known factor at a site that is usually evaluated by analysis of meteorologic records from nearby weather stations, although in some instances detailed monitoring of meteorologic parameters such as precipitation, temperature, and wind may be required as a part of site characterization and remediation. This guide does not cover methods for systematic monitoring of climatic factors.

Weather refers to the state of the atmosphere at a site during field investigation activities. Unusual weather conditions are usually noted during the sampling and description of soils. Weather usually doesn't become a concern during field work unless conditions, such as rain or snow, adversely affect the carrying out of field procedures or create health and safety concerns for field personnel. The major weather parameters to be monitored during field work include air temperature, wind speed and direction, and humidity. The site health and safety officer is primarily responsible for evaluating adverse weather conditions and pacing field activities accordingly, but field personnel should communicate their own feelings about working under adverse weather conditions.

2.1.1 Air Temperature

Air temperature is primarily a concern when it is at one extreme or the other. Heat becomes a special concern when protective clothing must be worn on site, because the impervious material used increases sweating and the possibility of heat stress from dehydration. Extreme cold makes sampling and notetaking difficult. Maximum thermometers are relatively inexpensive and daily extremes should be recorded along with periodic observations through the day, if appropriate. Wind speed (see Section 2.1.2) should be monitored when working in the winter to determine wind chill temperatures. Humidity (see Section 2.1.3) should be monitored when the climate is humid and temperatures are high.

2.1.2 Wind Speed and Direction

In winter, wind speed should be monitored to estimate wind chill temperature. Hand-held anemometers can be used for this purpose. High winds create unfavorable conditions for soil sampling, especially when soil is dry, because of the possibility of contamination from blowing surface soil and the mobilization of contaminated subsoil that is brought to the surface. When it is breezy, personnel should position themselves upwind during soil sampling, and avoid sampling in locations where contaminated soil might blow into the exclusion area. Four-foot staffs with flags or flagging placed around the site can serve as wind direction indicators. Wind speed and direction should be recorded at each location where soils are sampled.

EPA's ESES defines wind speed classes as follows:

Gale: >32 mph (>37 knots)

Breezy: 4 to 32 mph (3 to 37 knots)

Calm to light: <4 mph (<3 knots)

2.1.3 Humidity

Relative humidity, the ratio of measured atmospheric water vapor pressure to that which would prevail under saturated conditions, is the most commonly used measure of atmospheric moisture. For general field use, relative humidity can be measured using a humidity gage, but if very accurate measurements are desired, a sling psychrometer should be used.

Humidity is primarily a concern for field operations when it is very high or very low. Very high humidity associated with high temperatures increases the danger of heat stress in field personnel, especially when protective clothing must be used on site. When sampling for soil moisture when the humidity is low, special care should be taken to minimize exposure of soil to the air to avoid drying before the sample is sealed.

2.2 Slope

Slope is an important site feature that influences the distribution of precipitation between the soil and surface runoff, and the movement of soil water. Slope gradient is usually measured as a percentage, but may be measured in degrees. Both gradient and the length of the slope (to the point where surface runoff loses its energy and deposits suspended soil particles) are required for estimating erosion using the Universal Soil Loss Equation (see Section 2.3 below). Slope shape and topographic position influence the movement of water on the surface and in the subsurface. Slope aspect affects the moisture status of soil, with southern exposures usually drier than northern exposures due to increased evapotranspiration.

Soil surveys prepared by the U.S. Soil Conservation Service (SCS) differentiate soil map units in upland areas by the dominant soil series and a slope range (such as 0 to 2 percent, 2 to 6 percent, 6 to 12 percent, etc.) that is based on soil management considerations. Slope classes are based on slope gradient limits as follows (Soil Survey Staff, 1991):

Classes		Slope Gradient Limits (%)	
Simple Slopes	Complex Slopes	Lower	Upper
Nearly level	Nearly level	0	3
Gently sloping	Undulating	1	8
Strongly sloping	Rolling	4	16
Moderately steep	Hilly	10	30
Steep	Steep	20	60
Very steep	Very steep	>45	

Different SCS county soil surveys may specify different slope ranges for a slope class within the lower and upper limits identified above.

The following slope features should be observed when preparing a soil description:

Gradient (percent or degrees)—Measured using a clinometer and a rod with a marking at the observer's eye level. Siting through the clinometer up or downslope to the marker on the rod allows a direct reading in percent or degrees. Accurate readings require that (1) the line of siting is perpendicular to the contour of the slope, and (2) there is no change in slope gradient over the distance the siting is taken.

Length (if erosion potential is evaluated).

Shape—Convex, concave, or flat.

Topographic position—Summit, shoulder, back-slope, footslope, toeslope, or floodplain.

2.3 Surface Erosion and Erodibility

Field evaluation of surface erosion has two components: (1) assessment of soil loss or deposition that has occurred in the past, and (2) evaluation of the future erosion potential.

In upland soils, the amount of erosion can be inferred by comparing observed texture and color in the A and B horizons (see Section 3.1.1 for definitions of horizons) with a nearby undisturbed soil in a similar topographic setting (if available), or with a soil profile description prepared by the SCS for the soil series to which the soil belongs. The thickness of the A horizon is reduced in **moderately** eroded soils, and may show mixing with the B horizon if the soil has been cultivated. Rill erosion, the removal of soil through the cutting of many small, but conspicuous channels, may be evident on unvegetated soil. In **severely** eroded soils, most of the topsoil is missing and gully erosion (channels that cannot be obliterated by ordinary tillage) may be evident. Soils with **slight** to no erosion have fully developed A horizons and surface material showing little evidence of erosion.

In depressional areas, the thickness of soil that has accumulated as a result of accelerated erosion can be measured by finding the top of the natural A horizon, provided the eroded material can be differentiated by color, texture, and other soil features. Surface contaminated soil preferentially concentrates in such areas, and special sampling may be desirable.

Use of the Universal Soil Loss Equation (USLE) or its revised version (RUSLE) to estimate erosion potential from a site requires the following field observations: (1) slope gradient and length (see Section 2.2 above) and (2) vegetation (Section 2.5). The soil erodibility factor (K) can usually be obtained from SCS soil series interpretation sheets. If classification of a soil is uncertain, the K factor can be estimated using soil erodibility nomographs (SCS, 1983). The following soil properties must be described or estimated to use these soil nomographs: (1) percent silt plus very fine sand, (2) percent sand (0.10 to 2.0 mm), (3) percent organic matter (see Section 3.3.1), (4) soil structure (see Section 3.1.5a), and (5) permeability class (see Section 3.2.4).

EPA's ESES defines soil erodibility classes based on estimated annual soil loss, using the USLE or RUSLE, as follows:

Severe: >10 metric tons/hectare.

Moderate: 2.5 to 10 metric tons/hectare.

Slight: <2.5 metric tons/hectare.

2.4 Surface Runoff

Surface runoff potential is important for evaluating the potential for transport of contaminants at the soil surface to surface streams or water bodies.

SCS defines six runoff classes that can be used for qualitative comparison of runoff from different locations at a site (See Table 2-1). Placement requires measurement of the slope gradient (see Section 2.2) and measurement or estimation of the saturated hydraulic conductivity (see Section 3.2.4).

Computation of runoff by SCS's Curve Number Method requires placement of soils in hydrologic groups

based on saturated hydraulic conductivity (K_{sat} —see Section 3.2.4) and water table characteristics (Section 3.2.2). If the hydrologic class of the soil of interest is not known, it can be determined using Table 2-2.

2.5 Vegetation

Vegetation at a site serves as an indicator of site history and site productivity and is a major determinant in erosion potential at a site (see Section 2.3).

Features observed and noted should include the nature, kind, extent, and distribution of plants and plant cover. The charts in Figure 3-3 (Section 3.1.2) for estimating areal percentages of coarse fragments and mottles also can be used to estimate amount of vegetative cover. Vogel (1987) describes more precise methods for measuring vegetation cover such as the point-quadrant method, rated microplots, and line intercepts.

Stunted vegetation or discolored leaves may be an indication of toxic effects from contaminants in the soil. In heavy metal contaminated sites, sampling of vegetation along with soil may be desirable to assess exposure through bioaccumulation.

EPA's ESES defines qualitative vegetation classes as follows:

Dense: Site completely covered with vegetation of predominant forms or varying composition and species, usually with slow temporal variability.

Scattered to sparse: Plant cover, aerial, or soil surface vegetation, is intermittent or infrequent at site.

Absent: No visible macrovegetation can be observed, but some scattered soil vegetation cover (e.g., algal-lichen crusts or mosses) may be evident.

Table 2-1. Index Surface Runoff Classes

Slope Gradient (%)	Runoff Classes* K _{sat} Class**					
	VH	H	MH	ML	L	VL
Concave***	N	N	N	N	N	N
<1	N	N	N	L	M	H
1-5	N	VL	L	M	H	VH
5-10	VL	L	M	H	VH	VH
10-20	VL	L	M	H	VH	VH
>20	L	M	H	VH	VH	VH

* Abbreviations: Negligible-N; very low-VL; low-L; medium-M; high-H; and very high-VH. These classes are relative and not quantitative.

** See Section 3.2.4 for definitions. Assumes that the lowest value for the soil occurs at <0.5 m. If the lowest value occurs at 0.5 to 1 m, reduce runoff by one class. If it occurs at >1 m, then use the lowest saturated hydraulic conductivity <1 m. VL K_{sat} is assumed for soils with seasonal shallow or very shallow free water.

*** Areas from which no or very little water escapes by flow over the ground surface.

Table 2-2. Criteria for Placement of Hydrologic Soil Groups

Criteria*		
Soil Group*	K _{sat}	Free Water Depth/Duration
A	>55	DV** (>1.5 m)
B	5.5 to 55	D or DV (>1 m)
C	.55 to 5.5	>S (>0.5 cm)
D	<.55	S or SV (0 to 0.5 m); T through P

* The criteria are guidelines only. They are based on the assumption that the minimum saturated hydraulic conductivity occurs within the uppermost 0.5 m. If the minimum occurs between 0.5 and 1 m, then K_{sat} for the purpose of placement is increased one class. If the minimum occurs below 1 m, then the value for the soil is based on values above 1 m using the rules previously given.

** See Section 3.2.2 for meaning of abbreviations.

2.6 Macro- and Mesofauna

Soil macrofauna, such as burrowing animals, earthworms, and larger insects that can be measured in centimeters, and mesofauna, such as smaller mollusks and arthropods, affect soil profiles by mixing, changing, and moving soil material. The activities of soil macro- and mesofauna tend to increase the secondary permeability of soil horizons and thus provide preferential paths for sub-surface migrations of contaminants.

Surface features that animals produce include termite mounds, ant hills, heaps of excavated earth beside burrows, the openings of burrows, paths, feeding grounds, and earthworm or other castings.

These features can be described in terms of (1) number of structures per unit area, (2) proportionate area occupied, and (3) volume of aboveground structures. **Krotovinas**, irregular tubular streaks of soil material with contrasting color or texture, resulting from filling of tunnels made by burrowing animals, may be observed in soil pits.

Where soils are contaminated with heavy metals, collection of soil macro- or mesofauna for chemical analysis may provide evidence of bioaccumulation for exposure assessment, provided that similar species on nearby uncontaminated soils with similar characteristics can be obtained for comparison.

Macro- and mesofauna are described for EPA's ESES by species and abundance per unit area as follows:

Class	Number/m ²
Macrofauna	
Many	>10
Common	5-10
Few	1-5
None	0
Mesofauna	
Many	>100,000
Common	100-100,000
Few	10-100
None	<10

Chapter 3

Field Description and Analysis of Soils

This chapter presents field test and soil description procedures that can be done visually or with simple field equipment. Appendix D of Cameron (1991) identifies references where more detailed information can be found about more complex field procedures for measuring specific soil parameters.

For nonengineering applications, the soil taxonomy of the U.S. Soil Conservation Service is the most widely used system for describing and classifying soils. The basic reference on this system is **Soil Taxonomy**, Agricultural Handbook 436 (Soil Survey Staff, 1975). Revisions and amendments are periodically published in looseleaf form as **Soil Taxonomy Notes**. The most recent edition of the pocket-sized **Keys to Soil Taxonomy** (Soil Survey Staff, 1990) is the best concise reference source on classification of soils, and is recommended for use in the field (price and ordering information are given in the reference section).

Unfortunately, the most up-to-date reference for current SCS soil description procedures, a major revision of Agricultural Handbook 18, **Soil Survey Manual** (Soil Survey Staff, 1991), is not yet readily available. Most of the soil description procedures in this guide are taken from the latest version of the new manual. Other important references for field investigation procedures for noncontaminant parameters are published by SCS (1971 and 1984). Procedures from the geologic literature for description of unconsolidated material below the weathering zone are also included in this chapter.

3.1 Soil Physical Parameters

A number of soil physical parameters such as coarse fragments, pores, mottled colors, roots, lateral features, and mineral concentrations require area measurements on the ground surface or the wall of a pit for conversion to volume or weight percentages. Section 3.1.2 includes charts for estimating proportions of a feature at the surface, but if more accurate measurements are desired, traverses on an arbitrary grid can be used.

Coarse screening such as hardware cloth or rat wire with a 1/2-inch mesh makes a convenient and durable grid for small and medium objects as large as 2 to 4 inches (5 to 10 cm). A screen 1 foot square is suitable for most situations. Marking every fifth, tenth, or twentieth wire in each direction, or at intersections, with paint makes counting easier. When the screen is tacked over the area to be measured, a small wire pointer pushed into the soil at the intersection of each wire allows the most accurate counting of features in the grid. SCS (1971, Section 12.7) provides additional guidance on making linear and volume measurements.

Form 3-1 provides a sample form for description of a soil profile. This form follows the sequence of features for description of soil horizons in this chapter. Standard forms used by SCS and coding sheets for computer programs, which automatically prepare narrative soil profile descriptions, can also be used.

A dug pit that provides a lateral view of soil horizons is best for accurate and detailed soil profile description. Thin-walled tube samplers are the next best alternative. Appendix A.1 outlines procedures for soil descriptions using tube samplers and augers. Comprehensive descriptions using one or two pits, along with less detailed tube/auger sampler descriptions at each sampling site, would probably provide the maximum amount of useful data.

Form 3-1. Soil Profile and Related Information

Soil Type or Designation _____

Date _____ ID No. _____

Described by _____

Location _____

_____ Elevation _____

Wind Speed/Direction (2.1.1) _____

Other Weather Conditions (2.1) _____

Parent Material _____

Topographic Position (2.2) _____

Slope Gradient _____ Slope Length _____

Slope Shape _____ Slope Aspect _____

Erosion (2.3) _____

Surface Runoff Class (2.4) _____

Vegetation (2.5) _____

Macro- and Mesofauna (2.6) _____

Engineering Properties (3.1.7) _____

USCS Texture _____

Shear Strength _____ Corrosivity _____

Soil Temperature/Regime (3.1.8) _____

Water Table (3.3.3) _____

Depth (Max/Min) _____

Thickness, if Perched _____

Duration _____

Drainage Class (3.2.4) _____

Infiltration (3.2.5) _____

Redox Potential (3.3.5) _____

Electrical Conductivity (3.3.6) _____

Fertility Potential (3.3.9) _____

Soil Classification _____

Additional Notes _____

(Continued)

Form 3-1. (Continued)

Horizon (3.1.1)*	_____	_____	_____
Depth	_____	_____	_____
Boundary	_____	_____	_____
Texture (3.1.2)	_____	_____	_____
Fines (<2 mm)	_____	_____	_____
>2 mm %	_____	_____	_____
>2 mm description	_____	_____	_____
Color (3.1.3)	_____	_____	_____
Moist	_____	_____	_____
Dry	_____	_____	_____
Mottles (3.1.3)	_____	_____	_____
Color	_____	_____	_____
Description	_____	_____	_____
Pores (3.1.4)	_____	_____	_____
Structure (3.1.5a)	_____	_____	_____
Roots (3.1.5c)	_____	_____	_____
Surface Features (3.1.5d)	_____	_____	_____
Sedimentary Features (3.1.5e)	_____	_____	_____
Consistency (3.1.6b)	_____	_____	_____
Moist/Dry	_____	_____	_____
Cementation	_____	_____	_____
Bulk Density (3.1.6c)	_____	_____	_____
Compaction (3.1.6e)	_____	_____	_____
Water State (3.2.1)	_____	_____	_____
AWC (3.2.3)	_____	_____	_____
K _{sat} (3.2.4)	_____	_____	_____
OM (3.3.1)	_____	_____	_____
Odor (3.3.2)	_____	_____	_____
CEC (3.3.3)	_____	_____	_____
pH (3.3.4)	_____	_____	_____
Clay Minerals (3.3.7)	_____	_____	_____
Carbonates (3.3.8)	_____	_____	_____
Other Minerals (3.3.8)	_____	_____	_____
Microbiota (3.3.10)	_____	_____	_____

3.1.1 Soil Horizons

Table 3-1 provides a key to SCS's 1981 system for designating **master horizons**, **layers**, and **transitional horizons**, along with the lower case letters that are used for subordinate distinctions within horizons. If an SCS soil survey of the site is available, the soil series descriptions should be reviewed for a general idea of the types of horizons likely to be encountered. SCS soil surveys published prior to around 1984 contain soil profile descriptions using the 1962 system. Table 3-2 compares the 1962 and 1981 systems and provides approximate equivalencies where nomenclature has changed.

In glaciated areas, it may be useful to make more precise designations for the C horizon. Table 3-3 shows subdivisions and diagnostic characteristics of four types of C horizons recognized by the Illinois State Geological Survey. If this notation is used in the description, it should be clearly noted on the field sheet.

Key features to record are the depth and characteristics of the boundary between horizons. The following notation can be used to describe horizon boundaries or contacts:

Distinctness

- a — abrupt (<2 cm)
- c — clear (2-5 cm)
- g — gradual (5-15 cm)
- d — diffuse (>5 cm)

Topography

- s — smooth (nearly a plain)
- c — clear (pockets with width > depth)
- i — irregular (pockets with depth > width)
- b — broken (discontinuous)

A **disturbed** soil has been truncated or manipulated to the extent that its principle pedogenic characteristics have been severely altered or can no longer be recognized.

A **buried** soil, or paleosol, is covered by an alluvial, loessial, or other depositional surface mantle of more recent material, and usually lies below the weathering profile of the soil at the land surface. As noted in Section 3.1.5, buried soils may have high secondary porosity compared to materials above and below it, forming a potential zone for preferential movement of contaminants.

Table 3-1. Definitions and Designation Nomenclature for USDA Soil Horizons and Layers (Adapted from SSSA, 1987)**Master Horizons and Layers**

O Horizons—Layers dominated by organic material, except limnic layers that are organic.

A Horizons—Mineral horizons that formed at the surface or below an O horizon and (1) are characterized by an accumulation of humified organic matter intimately mixed with the mineral fraction and not dominated by properties characteristic of E or B horizons; or (2) have properties resulting from cultivation, pasturing, or similar kinds of disturbance.

E Horizons—Mineral horizons in which the main feature is loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles of quartz or other resistant materials.

B Horizons—Horizons that formed below an A, E, or O horizon and are dominated by (1) carbonates, gypsum, or silica, alone or in combination; (2) evidence of removal of carbonates; (3) concentrations of sesquioxides; (4) alterations that form silicate clay; (5) formation of granular, blocky, or prismatic structure; or (6) a combination of these.

C Horizons—Horizons or layers, excluding hard bedrock, that are little affected by pedogenic processes and lack properties of O, A, E, or B horizons. Most are mineral layers, but limnic layers, whether organic or inorganic are included.

R Layers—Hard bedrock including granite, basalt, quartzite, and indurated limestone or sandstone that is sufficiently coherent to make hand digging impractical.

Transitional Horizons

Two kinds of transitional horizons occur. In one, the properties of an overlying or underlying horizon are superimposed on properties of the other horizon throughout the transition zone (i.e., AB, BC, etc.). In the other, distinct parts that are characteristic of one master horizon are recognizable and enclose parts characteristic of a second recognizable master horizon (i.e., E/B, B/E, and B/C).

Alphabetical Designation of Horizons

Capital letters designate master horizons (see definitions above).

Lowercase letters are used as suffixes to indicate specific characteristics of the master horizon (see definitions below). The lowercase letter immediately follows the capital letter designation.

(Continued)

Table 3-1. (Continued)

Numeric Designation of Horizons

Arabic numerals are used as (1) suffixes to indicate vertical subdivisions within a horizon and (2) prefixes to indicate discontinuities.

Prime Symbol

The prime symbol (') is used to identify the lower of two horizons having identical letter designations that are separated by a horizon of a different kind. If three horizons have identical designations, a double prime (") is used to indicate the lowest.

Subordinate Distinctions within Horizons and Layers

- a — Highly decomposed organic material where rubbed fiber content averages $<1/6$ of the volume.
- b — Identifiable buried genetic horizons in a mineral soil.
- c — Concretions or hard nonconcretionary nodules of iron, aluminum, manganese, or titanium cement.
- e — Organic material of intermediate decomposition in which rubbed fiber content is $1/6$ to $2/5$ of the volume.
- f — Frozen soil in which the horizon or layer contains permanent ice.
- g — Strong gleying in which iron has been reduced and removed during soil formation or in which iron has been preserved in a reduced state because of saturation with stagnant water.
- h — Illuvial accumulation of organic matter in the form of amorphous, dispersible organic matter-sesquioxide complexes, where sesquioxides are in very small quantities and the value and chroma of the horizons are <3 .
- i — Slightly decomposed organic material in which rubbed fiber content is more than about $2/5$ of the volume.
- k — Accumulation of pedogenic carbonates, commonly calcium carbonate.
- m — Continuous or nearly continuous cementation or induration of the soil matrix by carbonates (km), silica (qm), iron (sm), gypsum (ym), carbonates and silica (kqm), or salts more soluble than gypsum (zm).
- n — Accumulation of sodium on the exchange complex sufficient to yield a morphological appearance of a natric horizon.

(Continued)

Table 3-1. (Continued)

-
- o — Residual accumulation of sesquioxides.
 - p — Plowing or other disturbance of the surface layers by cultivation, pasturing, or similar uses.
 - q — Accumulation of secondary silica.
 - r — Weathered or soft bedrock including saprolite; partly consolidated soft sandstone, siltstone, or shale; or dense till that roots penetrate only along joint planes and which is sufficiently incoherent to permit hand digging with a spade.
 - s — Illuvial accumulation of sesquioxides and organic matter in the form of illuvial, amorphous dispersible organic matter-sesquioxide complexes, if **both** organic matter and sesquioxide components are significant and the value and chroma of the horizon are >3 .
 - t — Accumulation of silicate clay that either has formed in the horizon and is subsequently translocated or has been moved into it by illuviation.
 - v — Plinthite which is composed of iron-rich, humus-poor, reddish material that is firm or very firm when moist and that hardens irreversibly when exposed to the atmosphere under repeated wetting and drying.
 - w — Development of color or structure in a horizon but with little or no apparent illuvial accumulation of materials.
 - x — Fragic or fragipan characteristics that result in genetically developed firmness, brittleness, or high bulk density.
 - y — Accumulation of gypsum.
 - z — Accumulation of salts more soluble than gypsum.
-

Table 3-2. Comparison of the 1962 and 1981 USDA Soil Horizon Designation Systems

Alphabetical Designation of Horizons

Capital letters designate master horizons in **both** systems, but there are some changes in specific letter designations (see below).

Lowercase letters are used as suffixes to indicate specific characteristics of the master horizon in both systems, but there are some changes in specific letter designations (see below). In the 1981 system, the lowercase letter always immediately follows the capital letter designation.

Numeric Designation of Horizons

1962 System: Arabic numerals used as suffixes to (1) indicate kind of O, A, or B horizon, and (2) indicate vertical subdivisions of a horizon; Roman numerals used as prefixes to indicate lithologic discontinuities.

1981 System: Arabic numerals used as suffixes to indicate vertical subdivisions **within** a horizon **and** as prefixes to indicate discontinuities. Their use to indicate kind of O, A, or B horizon has been eliminated.

Prime Symbol

1962 System: The prime used to identify the lower sequum of a soil having two sequa (horizon sequences), although not for a buried soil.

1981 System: The prime used to identify the lower of two horizons having identical letter designations that are separated by a horizon of a different kind. If three horizons have identical designations, a double prime is used on the lowest.

(Continued)

Table 3-2. (Continued)

Comparisons of Horizon Designations (see Table 3-1 for definitions)

Master Horizons Distinctions		Subordinate Horizon	
1962	1981	1962	1981
O	O	—	a
O1	Oi,Oe	b	b
O2	Oa,Oe	cn	c
A	A	—	e
A1	A	f	f
A2	E	g	g
A3	AB or EB	h	h
AB	—	—	i
A&B	E/B	ca	k
AC	AC	m	m
B	B	sa	n
B1	BA or BE	—	o
B&A	B/E	p	p
B2	B or Bw	si	q
B3	BC or CB	r	r
C	C	ir	s
R	R	t	t
		—	v
IIB23t	2Bt3	—	w
		x	x
		cs	y
		sa	z

Source: Adapted from Guthrie and Witty (1982).

Table 3-3. Subdivisions of the C Horizon Used in Illinois

Horizon	Mineralogy	Carbonates	Color	Structure
C1	Strongly altered	Leached	Uniform, mottled or stained	Some soil structure, peds with clay films; structure of parent material—blocky; layered, or massive—dominant; often porous
C2	Altered	Unleached	Uniform, mottled, or stained	Less soil, structure, clay films along joints; structure of parent material—blocky; layered, or massive—dominant; often porous
C3	Partly altered	Unleached	Uniform; rare stained	Massive, layered, or very large blocky; conchoidal fractures; dense
C4	Unaltered	Unleached	Uniform	Massive or layered, conchoidal fractures; dense

Source: Follmer et al. (1979).

3.1.2 Soil Texture Classes

Soil texture, the relative proportions of silt-, sand-, and clay-sized particles (also called particle-size distribution), is an important property from which many other soil parameters can be estimated or inferred. This section focuses on the USDA soil texture classification system. Many other classification systems have been developed, but of these, only the ASTM (Unified) system, which is oriented toward soil engineering applications, is covered in this field guide (see Section 3.1.7a).

Figure 3-1 shows the USDA soil texture triangle. Classification is based on the fine fraction (less than 2 mm), with modifiers applied where coarse fragments are more than 15 percent by volume. For example, a sample that plots on the texture triangle as a sand, contains 40 percent rock fragments, which are mostly around 30 mm in diameter. Using Table 3-4, the adjective modifier for 35 to 60 percent coarse fragments is the dominant rock plus the word "very." The SCS adjective for coarse fragments around 30 mm is gravelly or coarse gravelly. Thus, the full texture description would be "very coarse gravelly sand." The noun used to describe the coarse fragments is pebbles or coarse pebbles. Table 3-4 also shows simplified descriptors for the >2 mm fraction based on the Wentworth scale, which is more commonly used by geologists.

Sandy soil classes are often divided into subclasses according to the coarseness of the sand grains. Figure 3-2 shows the criteria for subclasses of sandy soils. Table 3-4 summarizes abbreviations and designations for recording USDA soil texture in the field. Figure 3-3 provides charts for estimating percentages of coarse fragments in a soil horizon. Field determinations based on estimated percentages of clay and sand should be verified by laboratory analysis of samples.

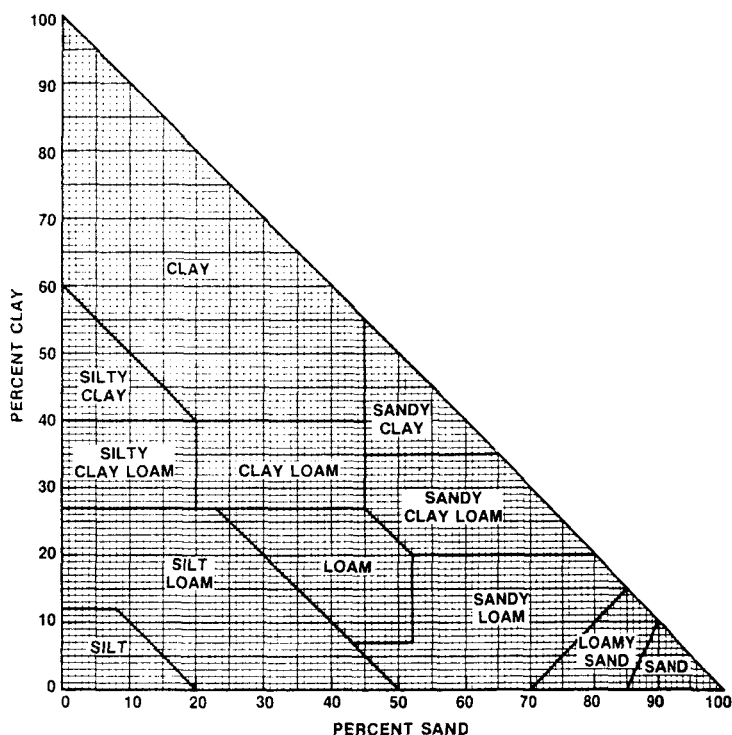
The following general groupings of texture classes are sometimes used (see Table 3-4 for abbreviations):

Sandy (light or coarse)—s, ls

Silty (medium)—si, sil, sicl

Loamy (medium)—sl, l, cl, scl (sil, si, sicl may be included in this category)

Clayey (heavy or fine)—sc, sic, c



Using Materials Less Than 2.0 mm in Size. If approximately 20% or more of the soil material is larger than 2.0 mm, the texture term includes a modifier. Example: gravelly sandy loam.

Example of Use: A soil material with 35% clay, 30% silt, and 35% sand is a clay loam.

Figure 3-1. USDA soil texture triangle.

Table 3-4. Abbreviations and Designations for USDA Soil Texture Classes (including coarse fraction)

<2 mm Fraction		>2 mm Fraction (SCS)	
(See texture triangle, Figure 3-1)		Adjective modifier (see text explanation)	
		<15%	none
s	— sand	<15-35%	dominant rock
ls	— loamy sand	35-60%	dominant rock + very
sl	— sandy loam	>60%	(>5% fines) dominant
l	— loam		rock + extremely
si	— silt	>60%	(<5% fines) dominant
sil	— silt loam		rock adjective
cl	— clay loam	Other Descriptive Features	
sicl	— silty clay	of >2 mm fraction	
	loam	Percent	
sc	— sandy clay	Roundness	
sic	— silty clay	Mineralogy/rock type	
c	— clay	Sorting	

Rock Descriptors for >2 mm Fraction (SCS)

Adjective/Noun		Shape/Size rounded, subrounded, angular, or irregular (diameter, mm)
g	— gravelly/pebbles	2-76
fg	— fine gravelly/fine pebbles	2-5
mg	— medium gravelly/medium pebbles	5-20
cg	— coarse gravelly/coarse pebbles	20-76
k	— cobbly/cobbles	76-250
st	— stony/stones	250-600
b	— bouldery/boulders	>600
		Flat (long, mm)
st	— stony/stones	280-600
b	— bouldery/boulders	>600
ch	— channery/channers	2-150
flg	— flaggy/flagstones	150-380

(Continued)

Table 3-4. (Continued)

Simplified Descriptors for >2 mm Fraction (IDEM)

gn	— granules	2-4
pb	— pebbles	4-64
fpb	— fine pebbles	4-16
cpb	— coarse pebbles	16-64
cb	— cobbles	64-256
b	— boulders	>256

Source: Soil Survey Staff (1991) and IDEM (1988).

The USDA soil taxonomy defines particle-size classes for differentiation of the soils at the family level (Soil Survey Staff 1975, 1990) as described below:

Fragmental—Stones, cobbles, gravel, and very coarse sand particles with too little fine earth to fill some of the interstices larger than 1 mm in diameter.

Skeletal—Rock fragments make up 35 percent or more by volume. The dominant fine earth fraction (sandy, loamy, or clayey) is used as a modifier.

Sandy—Texture of fine earth is sand or loamy sand with <50 percent very fine sand; <35 percent clay; <35 percent rocks.

Loamy—Texture of fine earth is very fine sand or finer; <35 percent clay; <35 percent rocks. Subdivisions include coarse-loamy, fine-loamy, coarse-silty, and fine-silty.

Clayey—Texture of fine earth is >35 percent clay; <35 percent rocks. Subdivisions include fine and very fine.

3.1.3 Soil Color

Soil color is described using Munsell Soil Color charts (available from Munsell Color Company, 2441 N. Calvert St., Baltimore, MD 21218). Color is usually a good indicator of the redox status (see Section 3.3.5) of a horizon (uniform high chroma colors indicate oxidizing conditions; uniform low chroma colors usually indicate reducing conditions; mixed chromas indicate variable

		Soil separates				
Basic soil class	Subclass	Very coarse sand, 2.0-1.0 mm.	Coarse sand, 1.0-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.1 mm.	Very fine sand, 0.1-0.05 mm.
Sands	Coarse sand	25% or more		Less than 50%	Less than 50%	Less than 50%
	Sand	25% or more			Less than 50%	Less than 50%
	Fine sand	Less than 25%			50% or more	Less than 50%
	Very fine sand					50% or more
Loamy Sands	Loamy coarse sand	25% or more		Less than 50%	Less than 50%	Less than 50%
	Loamy sand	25% or more			Less than 50%	Less than 50%
	Loamy fine sand	Less than 25%			50% or more	Less than 50%
	Loamy very fine sand					50% or more
Sandy Loams	Coarse sandy loam	25% or more		Less than 50%	Less than 50%	Less than 50%
	Sandy loam	Less than 25%	30% or more			Less than 30%
	Fine sandy loam	Between 15 and 30%			30% or more	Less than 30%
	Very fine sandy loam	Less than 15%			More than 40%	30% or more

*Half of fine sand and very fine sand must be very fine sand.

Figure 3-2. Percentage of sand sizes in subclasses of sand, loamy sand, and sandy loam basic texture classes (Source: Portland Cement Association, 1973).

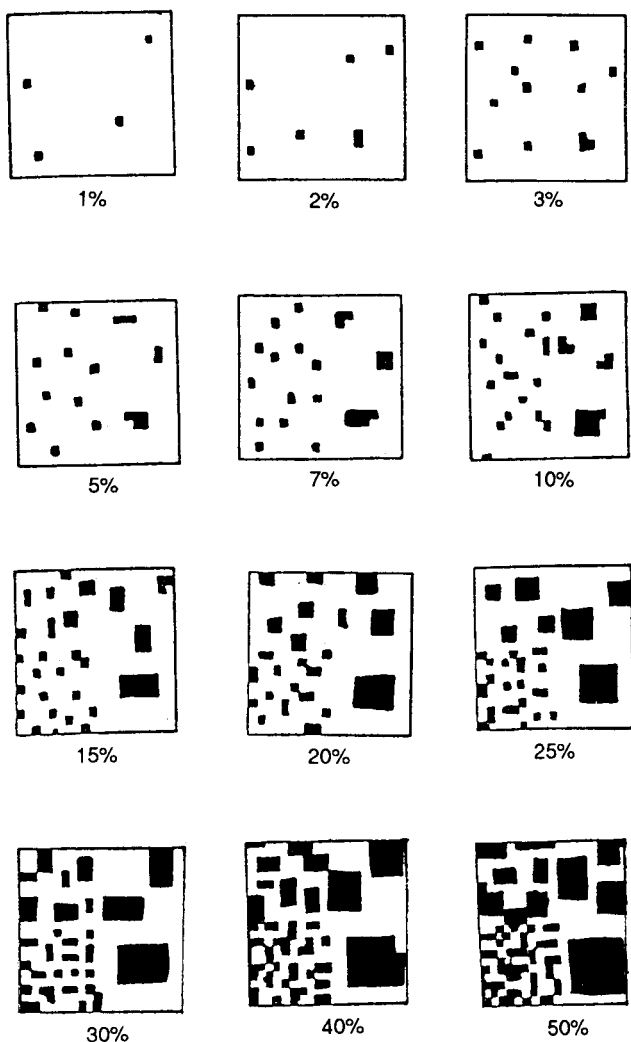


Figure 3-3. Charts for estimating proportions of coarse fragments and mottles (each fourth of any one square has the same amount of black).

saturation). In addition, low chroma, low value colors are often indicative of high organic matter content.

Dark colors have low value (generally <3) and low chroma (generally <2). **Red** colors generally have hues of 10YR or 2.5YR, and values and chromas >3 . **Yellow** colors generally have values and chromas >6 and hues of 7.5YR, 10YR, or 2.5Y. **Brown** colors typically have values from 3 to 6, chroma from 3 to 5, and hues of 7.5YR or 10YR. **Gray or whitish** colors may be of any hue with chromas <2 and values generally >3 . The Munsell Soil Color charts provide precise descriptors for any soil color reading.

The following data should be recorded in field description of color:

Color name.

Color notation (chroma, hue, value).

Water state (*moist* or *dry*).

Physical state (*broken* through ped is the standard state. Others are *rubbed* between fingers (*moist*), or *crushed/crushed and smoothed* (*dry*)).

Soil mottling is usually an indication of variable saturation, and is described according to abundance, size, and color contrast. Figure 3-3 provides charts that may help in estimating mottle abundance, and Figure 3-4 provides guidance in identifying contrast.

Abbreviations, descriptors, and criteria for description of mottles are:

Abundance

- f — few ($<2\%$)
- c — common (2-20%)
- m — many ($>20\%$)

Size

- 1 — fine (<5 mm)
- 2 — medium (5-15 mm)
- 3 — coarse (>15 mm)

Contrast (see Figure 3-4)

- f — faint (1 or 2 units H,C,V)
- d — distinct (2-4 units H,C,V)
- p — prominent (4-5 units H,C,V)

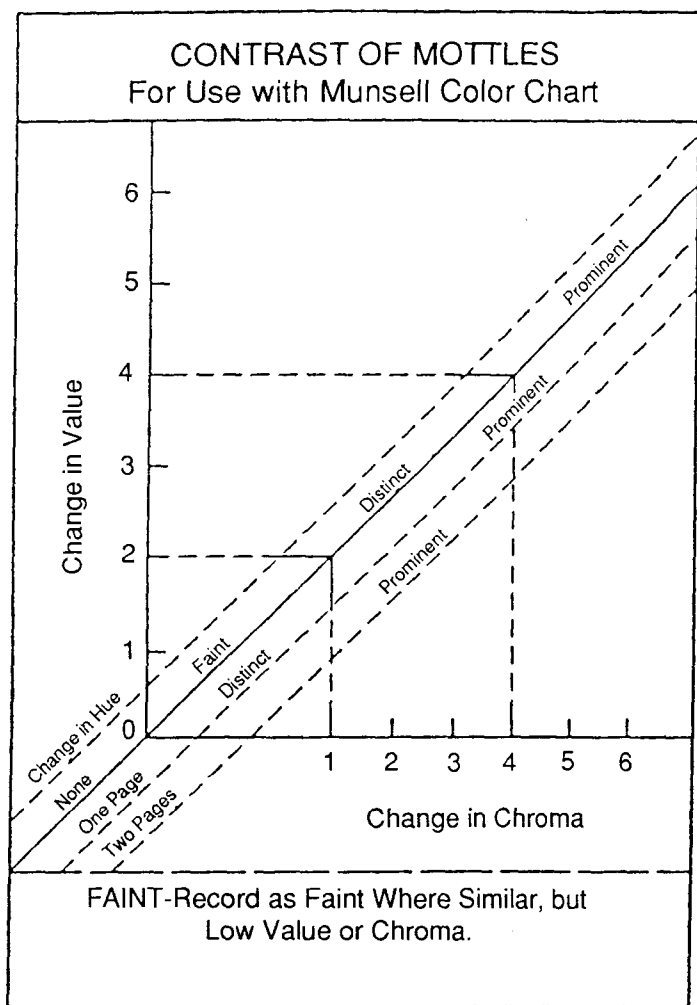


CHART DIRECTIONS:

- A. Select Change in HUE (None Ref. to Same Page).
- B. Record Greatest of VALUE or CHROMA at
HUE Line Intercept (Faint, Distinct, or Prominent).

Figure 3-4. Guide for designation of mottle contrast.

Shape (spots, streaks, bands, tongues, tubes)

Location (inped, exped)

Boundaries (sharp—like a knife edge; clear—colors grade over <2 mm; diffuse—colors grade over >2 mm)

Color Ignition Test

An ignition test using 2 or 3 grams of soil can provide useful information for interpretation of natural soil colors. The equipment and procedures described in Section 3.3.1 for organic matter should be used, except that weighing of the samples is not required. The following provides some guidance for interpreting colors:

Organic matter contributes black, brown, reddish (spodic horizons), and grayish colors. It burns away, leaving a whitish residue if it is the only colored material.

Minerals such as quartz, which make up the bulk of sand and silt-sized particles, are mostly colorless or pale colored to gray. These particles will not change color with ignition. Mineral grains may be cemented with lime or silica or stained with iron oxide, especially in dry regions. SCS (1971, Section 17.1) describes procedures for cleaning mineral surfaces of cement and stains.

Iron oxides are red, brown, or yellow. If browns and yellows become redder and brighter with ignition, highly hydrated iron oxide (goethite) is present.

Ferrous (reduced) iron is indicated by gray, blue, or green colors, and turns red when ignited to form hematite.

Manganese oxides form black and purple bodies and effervesce vigorously in a 5 percent solution of hydrogen peroxide (See Section 3.3.8). Dark reddish brown and dark brown surface soils in the southeastern United States usually contain enough manganese oxides to give a positive reaction to peroxide.

3.1.4 Soil Porosity

Laboratory analysis is required for accurate determination of soil porosity, but field description of soil pores can provide useful qualitative data for estimating permeability and characterization of soil variability at a site. Johnson et al. (1960) provides more detailed guidance on classification and description of soil pores.

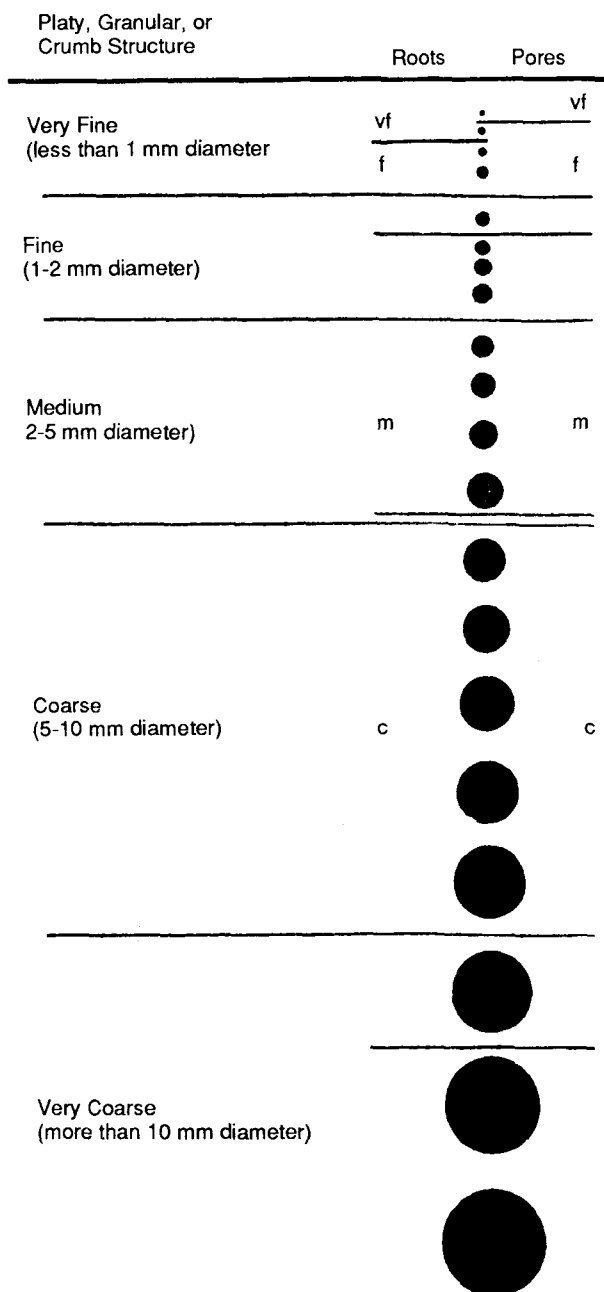


Figure 3-5. Charts for estimating pore and root size.

SCS describes pores according to (1) abundance, (2) size, (3) distribution within the horizon, and (4) type. Figure 3-5 can be used to estimate pore size in the field. Below are abbreviations, descriptors, and criteria for describing pores in the field:

Abundance Classes		No./Unit Area	
1	— few	<1	
2	— common	1-5	
3	— many	>5	
Size Classes		Diameter	Unit Area
vf	— very fine	<0.5 mm	1 cm ²
f	— fine	0.5-2 mm	1 cm ²
m	— medium	2-5 mm	10 cm ²
cos	— coarse	5-10 mm	10 cm ²
vcos	— very coarse	>10 mm	1 m ²

Distribution within Horizons

- in — inped (most roots and pores are within peds)
- ex — exped (most roots and pores follow interfaces between peds)

Types of Pores

- v — vesicular (approximately spherical or elliptical)
- t — tubular (approximately cylindrical and elongated)
- i — irregular

3.1.5 Zones of Increased Porosity/Permeability

Weathering and other soil-forming processes often increase the secondary porosity and permeability of unconsolidated materials. In addition, the mode of deposition of unweathered materials may create vertical and lateral variations in permeability that should be described. Increased secondary porosity is usually confined to the zone of soil weathering near the surface. Buried soils (paleosols) in glaciated areas represent zones of potential lateral movement of contaminants due to increased secondary porosity, if underlain by less permeable material.

3.1.5a Soil Structure Grades

Soil structure is an important feature that affects the movement of contaminants in soil. Contaminants often move preferentially along the interfaces between soil structure units. SCS describes soil structure according to shape (see Figure 3-6 for illustrations), grade, and size (see Figure 3-7 for charts). Below are abbreviations, descriptors, and criteria for describing soil structure in the field:

Grade

- 0 — structureless (massive or single grain)
- 1 — weak (poorly defined individual peds)
- 2 — moderate (well formed peds, but not distinct)
- 3 — strong (durable peds, quite evident in place; will stand displacement)

Size	Shape			
	pl-platy gr-granular cr-crumb	abk-angular blocky sbk-subangular blocky	cl-columnar pr-prismatic	
vf — very fine	<1 mm	<5 mm	<10 mm	
f — fine	1-2 mm	5-10 mm	10-20 mm	
m — medium	2-5 mm	10-20 mm	20-50 mm	
c — coarse	5-10 mm	20-50 mm	50-100 mm	
vc — very coarse	>10 mm	>50 mm	>100 mm	

Accurate identification of columnar or prismatic structure generally requires a soil pit. Blocky structure can usually be identified in cores taken from thin-walled samplers, but size class cannot always be accurately identified. Augers disturb the soil too much to allow accurate description of soil structure.

3.1.5b Extrastructural Cracks

Cracks are macroscopic vertical planar voids with a width much smaller than length and depth, which result from soil drying. Extrastructural cracks extend beyond the planar surfaces between soil structural units and represent

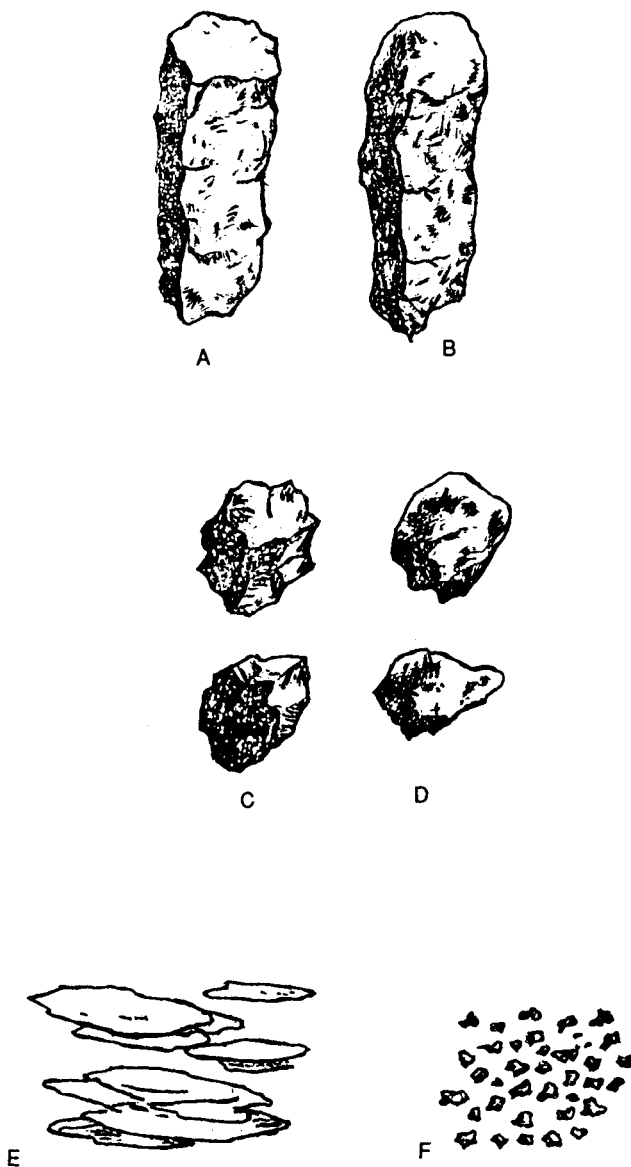


Figure 3-6. Drawings illustrating some of the types of soil structure: A, prismatic; B, columnar; C, angular blocky; D, subangular blocky; E, platy; and F, granular.

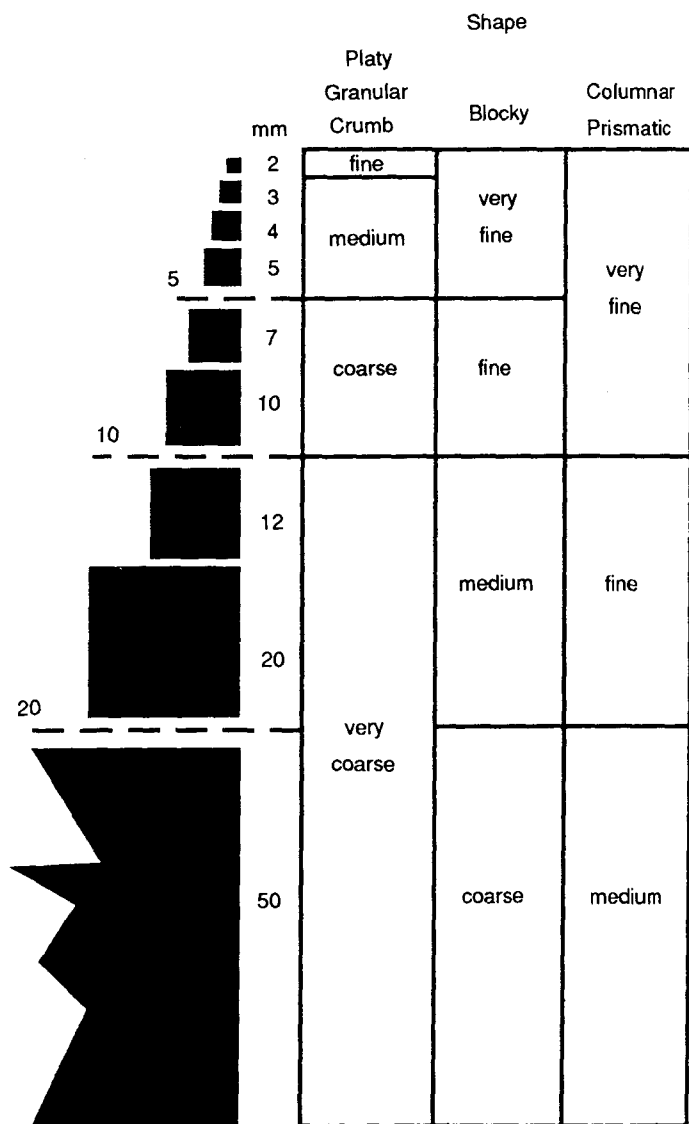


Figure 3-7. Charts for estimating size class of different structural units (see also Figure 3-5 for platy, granular, and crumb structures).

major potential channels for increasing infiltration of water during precipitation and preferential contaminant movement into the soil. The presence of irreversible cracks in the soil increases ponded infiltration (see Section 3.2.5).

SCS define four major types of extra-structural cracks:

Surface-initiated reversible cracks form as a result of drying from the surface downward. They close after relatively slight surficial wetting and have little influence on ponded infiltration rates.

Surface-initiated irreversible cracks form from freeze-thaw action and other processes, and do not close completely when rewet. They extend to the depth that frost action has occurred, and act to increase the ponded infiltration rates.

Subsurface-initiated reversible cracks form in subsoils with a high shrink-swell potential as the soil dries from field capacity. They close in a matter of days if the horizon becomes moderately moist or wet. They extend to the surface (unless the surface horizon does not permit the propagation of cracks), and increase ponded infiltration and rates of soil evaporation.

Subsurface-initiated irreversible cracks are permanently present in the subsurface.

Tests for Crack Characterization

A crack index value may be obtained by using a blunt wire, approximately 2 mm in diameter. More detailed characterization of cracks can be accomplished by pouring loose sand into the crack and excavating after wetting and after the crack has closed.

Penetrant cracks are 15 cm or more in depth as measured by an inserted wire. **Surface-connected** cracks occur at the ground surface or are covered by up to 10 to 15 cm of soil material that has very high or high saturated hydraulic conductivity with soft, very friable, or loose consistency. Surface connected cracks increase ponded infiltration.

Crack development is primarily associated with clayey soils and is most pronounced in high shrink-swell soils (see Section 3.1.7d).

3.1.5c Roots

The penetration of plant roots into the soil increases the secondary porosity of soil, and, after the plant dies and the root decomposes, leaves channels for more rapid flow of water through the soil. The absence of roots in the near surface is also an indication of reduced porosity/permeability.

A soil pit is required to accurately describe soil roots. SCS conventions for describing roots in soil are similar to those for soil pore description, although the criteria for abundance and size classes are different from those for pores. These classes are described below:

Abundance Classes	No./Unit Area
1 — few	<1
v1 — very few	<0.2
m1 — moderately few	0.2-1
2 — common	1-5
3 — many	>5

Size Classes	Diameter	Unit Area
vf — very fine	<0.5 mm	1 cm ²
f — fine	0.5-2 mm	1 cm ²
m — medium	2-5 mm	10 cm ²
cos — coarse	5-10 mm	10 cm ²
vcos — very coarse	>10 mm	1 m ²

Distribution within Horizons

- in — inped (most roots are within peds)
- ex — exped (most roots follow interfaces between peds)

Figure 3-5 provides charts for estimating root size.

3.1.5d Surface Features

Surface or lateral features such as clay films and silt coatings are often indicators of areas of increased permeability in the soil. Stress formations, on the other hand, are good indicators of active shrinking and swelling of clays in the soil. SCS describes lateral features according to (1) kind, (2) amount, (3) distinctness, and (4) location. Section 13.1 in SCS (1971) provides more detailed guidance on the observation of features on ped faces. A

stereoscopic microscope illuminated by a high-intensity lamp is useful for more detailed observation of lateral features. Criteria for descriptors of lateral features are as follows:

Kind	Amount
Coatings	vf — very few (<5%)
Clay films	f — few (5-25%)
Clay bridges	c — common (25-50%)
Sand	m — many (>50%)
Silt	
Other	
Stress formations	
Pressure faces	
Slickensides	

Distinctness

Faint—Requires 10 power magnification; little contrast in properties with material.

Distinct—Detectable without magnification although magnifier or other tests may be required for positive identification. Contrast in properties with adjacent material evident.

Prominent—Conspicuous without magnifier; properties contrast sharply with adjacent material.

Location

Surfaces of peds, channels, pores, primary particles or grains, soil fragments, rock fragments, nodules, or concretions.

3.1.5e Sedimentary Features

Sedimentary features in unweathered unconsolidated materials often allow inferences to be made about the depositional history of the material and, when combined with particle-size distribution data, assist in the location of zones of more rapid lateral movement of contaminants. The main features described are type and orientation. The following types and orientations are taken from the Indiana Department of Environmental Management guidelines for description of unconsolidated material at hazardous waste sites (IDEM, 1988):

Type (describe thickness)	Orientation
1 — bedding/lamination	ver — vertical
2 — cross-stratification	hor — horizontal
3 — deformation in bedding	obl — oblique
4 — bedding/surface structures	
5 — fossils/bioturbation	
6 — massive (no structure)	

3.1.6 Zones of Reduced Porosity/Permeability

Low-permeability soil or other horizons in unconsolidated material inhibit the downward movement of contaminants. Ground water tends to perch above such zones and transport contaminants laterally. Soil features indicating such zones include (1) slowly permeable genetic horizons, (2) very firm and very hard consistency classes, (3) high bulk density, (4) root restricting layers, and (5) high penetration resistance.

3.1.6a Genetic Horizons

Fragipans and cemented or indurated horizons formed by the precipitation of carbonates, silica, iron oxides, or other minerals are distinctive features of certain soil series. Determination of degree of cementation requires wetting the sample for at least an hour (see 3.1.6b).

There are substantial problems in the field identification of fragipans. Witty and Knox (1989) suggest the following essential characteristics of a fragipan:

1. One or more of the subhorizons are brittle at or near field capacity throughout the subhorizon or at least in any large prismatic structural units that have horizontal dimensions of 10 cm or more and constitute 60 percent or more of the volume.
2. Air-dried fragments of 5 to 10 cm in size from any part of the horizon slake or fracture when placed in water.

3. Roots are virtually absent, except in vertical streaks, between any large prismatic structural units that have horizontal dimensions of 10 cm or more and that constitute 60 percent or more of the volume.
4. There is evidence of pedogenesis in the form of mottles, clay films, or vertical streaks that define large prisms.

Many or all fragipans also exhibit one or more of the following characteristics:

1. Relatively low vertical saturated hydraulic conductivity (slow or very slow permeability), as measured or as revealed by evidence of perched water in the form of mottles, an E horizon, or seasonal seepage immediately above the pan.
2. High bulk density (commonly <35 percent porosity of the fine-earth fraction) relative to overlying horizons.
3. Large prisms defined by vertical streaks that are arranged in a polygonal pattern on a horizontal exposure.

Both vertical and horizontal exposure of the horizon is required for complete description of a fragipan.

3.1.6b Rupture Resistance (Consistency)

Rupture resistance, also called consistence or consistency, is a readily observed feature in the field. Terms used to describe rupture resistance vary depending on the moisture content of the sample tested (see Table 3-5). The very firm (moist) and very hard (dry) classes, and those that are firmer or harder, are indicative of reduced porosity/permeability. The footnotes to Table 3-5 describe the procedure for estimating rupture resistance classes. SCS recommends practice with scales to gain a more precise tactile sense of the transition between the different classes.

Cementation Test. Degree of cementation can be estimated by applying the rupture resistance tests in Table 3-5 to an air-dried specimen that has then been placed in water for at least an hour. Terms used to describe

Table 3-5. Rupture Resistance (Consistency) Classes

Moist (\geq DS*)	Dry (DM, DV*)	Conditions of Failure**	Stress Applied***
Loose	Loose	Specimen not obtainable	—
Very friable	Soft	Fails under very slight force applied slowly between thumb and forefinger	<8N
Friable	Slightly hard	Fails under slight force applied slowly between thumb and forefinger	8-20N
Firm	Hard	Fails under moderate force applied slowly between thumb and forefinger	20-40N
Very firm	"	Fails under strong force applied slowly between thumb and forefinger	40-80N
Extremely firm	Very hard	Cannot be failed between thumb and forefinger but can be by applying <i>pressure slowly with hands</i> ; fails if placed on a hard surface and gentle force applied underfoot	80-160N
"	Extremely hard	Cannot be failed in hand, but can be crushed or broken underfoot by the full body weight applied slowly	160-800N
Rigid	Rigid	Cannot be failed underfoot by full body weight but can be by <3J blow	800N-3J
Very rigid	Very rigid	Cannot be failed by blow of 3J	>3J

Source: Adapted from Soil Survey Staff (1991).

*See Table 3-8 for definitions of abbreviations.

**Standard specimens should be block-like and 25 to 30 mm on edge. If specimens smaller than the standard size must be used, corrections should be made for class estimates (i.e., a 10-cm block will require about one-third the force to rupture as will a 30-cm block). Stress is applied along the vertical in-place axis of

(Continued)

Table 3-5. (Continued)

the specimen by compressing it between extended thumb and forefinger, between both hands, or between the foot and a non-resilient flat surface. If the specimen resists compression, a 1-kg weight is dropped from progressively greater heights up to 30 cm, until rupture.

***Both force (newtons; N) and energy (joules; J) are employed. One newton is equivalent to the force necessary to accelerate a 1-kg mass 1 meter per second per second. One joule is the energy delivered by dropping a 1-kg weight 10 cm. A tactile sense of class limits may be learned by applying pressure through the tips of the fingers or ball of the foot to postal or bathroom scales.

cementation are as follows (use Table 3-5 to estimate stress applied):

Class	Stress Applied
Uncemented	<8N
Weakly cemented	8-80N
Moderately cemented	80-800N
Strongly cemented	800N-3J
Indurated	>3J

Other consistence classes used in the field are plasticity and stickiness. These are a function of clay content and are covered in Section 3.1.7a.

EPA's ESES defines the following consistency classes:

High: A soil when wet that shows high cohesion of soil particles, or adhesion of soil particles to other substances.

Moderate: A soil when moist that shows moderate cohesion or adhesion.

Low to Weak: A soil, usually dry, that shows reduced or poor cohesion or adhesion.

Cemented: A type of soil that remains hard or brittle after an air-dried specimen has been placed in water for at least 1 hour.

3.1.6c Bulk Density

Accurate measurement of bulk density, expressed as g/cc, requires weighing a known volume of soil or determining both the weight and volume of an undisturbed

soil sample. Some commonly used methods are described below.

Core Method. This method involves collecting a core of a known volume using a thin-walled sampler (to minimize disturbance of the soil sample), and transporting the core to the laboratory for weighing. Inserting a sampling cylinder inside the sampling tube allows other measurements to be made in the laboratory such as pore-size distribution, hydraulic conductivity, and water retention. Core samples should be placed in moisture-proof containers to maintain field moisture content.

Hole or Excavation Method. Bulk density can be determined directly in the field by excavating a quantity of soil, drying and weighing it (in the field or laboratory), and determining the volume of the excavation. This volume can be determined by measuring the volume of sand required to fill the excavation, or placing a rubber balloon in the excavation and measuring the amount of water or some other liquid required to fill the space. SCS (1971) and Blake and Hartge (1986) describe equipment and field procedures for these methods.

Coated-Clod Method. Bulk density of cohesive soils can be measured by coating a clod with a saran-ketone mixture and comparing the weights of the clod in air and water. Blake and Hartge (1986) describe this procedure in detail. This procedure can be done in a field laboratory with a scale that weighs accurately to 1 gram in a range of 500 to 1,000 grams. SCS (1971) describes procedures for determining the field-moist density and dry density of a clod. With these measurements, one can determine the minimum and maximum density, field moisture capacity, percentage of volume change, and ratio of moist and dry volumes for calculation of the coefficient of linear extensibility (COLE—see Section 3.1.7d).

The bulk density at which resistance to root penetration is high varies with texture as follows (SCS, 1983):

Family Texture	Bulk Density
Sandy	>1.85
Coarse-Loamy	>1.80
Fine-Loamy	>1.70
Coarse-Silty	>1.60
Fine-Silty	>1.50
Fine	>1.35

3.1.6d Root Restricting Layers

Root restricting layers are an indicator that contaminants will tend to move laterally along the top of the restrictive layer rather than vertically in the soil profile.

SCS classifies root restricting soil layers, whether they are genetic horizons or not, based on a combination of other soil properties as follows (the sections that describe specific features are indicated in parentheses).

Root depth observations are the most reliable indicator, with horizons incapable of supporting more than a few fine or very fine roots (see Section 3.1.5c) considered root restricting.

Continuously cemented zones (see Section 3.1.6b) of any thickness are considered root restricting.

Zones >10 cm below the rooting zone are considered root restricting if they exhibit the following characteristics when water state is very moist or wet (Section 3.2.1): (1) structure is massive, platy, or is weak of any type for a vertical repeat distance of <10 cm (Section 3.1.5a); and (2) rupture resistance is very firm (firm, if sandy) or extremely firm (Section 3.1.6b), or has a large penetration resistance (Section 3.1.6e).

When a root restricting layer is present, soils are classified according to the following depth classes:

Very shallow	<25 cm
Shallow	25 to 50 cm
Moderately deep	50 to 100 cm
Deep	100 to 150 cm
Very deep	>150 cm

3.1.6e Penetration Resistance (Compaction)

Penetration resistance is the capacity of the soil in its confined state to resist penetration by a rigid object. It is usually reported as megapascals (1 MPa = 10 bars or 9.9 atmospheres of pressure). Large penetration resistance is an indicator of compaction or other soil features that impede vertical flow of contaminants (see Section 3.1.6a and d). Truck or tractor-mounted cone penetrometers are commonly used in engineering investigations and are increasingly being used to characterize the subsurface at contaminated sites.

For soil descriptions, the pocket penetrometer, a hand-operated, calibrated-spring penetrometer, is a useful tool for helping identify root restricting layers. It is simple to operate, and can be pushed into the soil surface, core samples, or soil exposed in an open pit investigation.

Penetration resistance depends strongly on water state (Section 3.2.1), which should be specified. Orientation of the axis of insertion should also be specified. SCS defines penetration resistance classes based on the pressure required to push a pocket penetrometer with a diameter of 6.4 mm a distance of 6.4 mm into the soil in about 1 second, as follows:

Classes	Penetration Resistance (MPa)	
Small	<0.1	
Extremely low	<0.01	
Very low	0.01-0.1	
Intermediate	0.1-2	
Low	0.1-1	
Moderate	1-2	
Large	>2	
High	2-4	
Very high	4-8	
Extremely high	>8	

Compacted near-surface zones resulting from equipment traffic or tillage will have large penetration resistance, and higher rupture resistance (Section 3.1.6b) and bulk densities (Section 3.1.6c) than undisturbed near-surface horizons.

Soil Survey Staff (1991) and Bradford (1986) provide further guidance on use and interpretation of pocket penetrometer readings.

EPA's ESES uses the following soil compaction classes:

High: Surface soils have been subject to high compaction and consequent effects on soil structure, such as by vehicular and foot traffic, or livestock.

Moderate: Surface soils have been less subjected to compaction, either through reduced applications and frequency of pressure on surface soils or because the soil structure is more resistant to compaction.

Low to Slight: Surface soils are only slightly affected by compaction, either because of resistance to compaction or because they are less subject to application of compacting stressor.

3.1.7 Soil Engineering Parameters and Properties

Texture, clay content (amount and types of clays), and strength behavior at different moisture contents are the key properties affecting soil engineering. A number of classification systems have been developed for the selection of soil materials and design of foundations and earthen structures. The ASTM (Unified) soil classification is the most widely used at contaminated sites and is the only one covered in this guide.

Only field procedures for preliminary estimation of soil engineering properties are covered here. Laboratory tests are required for accurate determination of soil engineering properties. Once the Unified soil class has been identified, other properties such as permeability and suitability for different types of engineering applications can be estimated using Figure 4-14 in SCS (1990).

3.1.7a Unified (ASTM) Texture

Form 3-2 can be used to record the results of 11 tests for field classification of soil texture for engineering uses. These tests are drawn from Brown et al. (1991), SCS (1990), and Soil Survey Staff (1991). Figure 3-8 summarizes how the results of these tests are used to estimate texture in the Unified soil classification system. Procedures for specific tests identified in Figure 3-8 are described below, along with some alternative versions described by Soil Survey Staff (1991):

Test 1 - Coarse-Grained Soil Test

- a. Spread a sample of soil on a flat surface (clipboard) and examine the particles.
- b. Approximate the grain size by visual inspection.
- c. If **more** than 50 percent of the grains are easily distinguished by the unaided eye, the material is a coarse soil; if **less** than 50 percent of the grains are easily distinguished by the unaided eye, the material is a fine soil.

**Form 3-2. Unified (ASTM) Field Texture Determination Form
(adapted from Brown et al., 1991)**

Sample No. _____ Site: _____ Date: _____

Sampling Location: _____

Person(s) Performing Test: _____

SANDS AND GRAVELS

Test 1 (coarse grained) _____

Test 2 (gravel) _____

Test 3 (fine grained) _____

COMMENTS: _____

SILTS AND CLAYS

Test 4 (plasticity) _____

Test 5 (ribbon) _____

Test 6 (liquid limit) _____

Test 7 (clod strength) _____

Test 8 (dilatancy) _____

Test 9 (toughness) _____

Test 10 (stickiness) _____

Test 11 (organic soils) _____

COMMENTS: _____

- d. If some of the particles could be aggregates of fine particles, saturate a small sample of the soil with water.
- e. Rub a large marble-sized (2 cm) sample between the thumb and forefinger. Sand grains (coarse material) will feel rough and gritty, whereas aggregates of fine materials will break down and feel silky.

Alternative Jar Method (Soil Survey Staff, 1991)

- f. Thoroughly shake a mixture of soil and water in a straight-sided jar or test tube, and allow the mixture to settle.
- g. Sand sizes will fall out first, in 20 to 30 seconds; successively finer particles will follow. Estimate the proportions of sand and fines from their relative volumes.

Test 2 - Sand/Gravel Tests

2.a Gravel/Sand

- a. Spread a representative sample of soil on a flat surface.
- b. If more than one-half of the visible grains are greater than 2 mm, the material is gravel; if they are not, it is a sand.

2.b Clean/Dirty Test

- c. Remove any coarse material greater than 2 mm in diameter.
- d. Saturate the remaining materials with water and work it with your hands.
- e. Hands will not be stained when fines are less than 5 percent (GW or GP; SW or SP); hands will be stained when there is more than 12 percent fines, and weak casts can be formed (GM or GC; SM or SC).

2.c Sorting Test

- f. Take a second sample of soil and place it on a flat surface. Spread it out and observe the grain size distribution.
- g. If coarse materials consist of evenly distributed particle sizes, the material is well graded (GW or SW); if they are chiefly of one size particle or large

and small particles without intermediate sizes, the material is poorly graded (GP or SP).

Test 3 - Fine-Grained Test

- a. When Test 1 indicates fine-grained soils, complete Tests 4 through 7 to determine if the material is clayey or silty.
- b. If Test 2b indicates dirty sands or gravels (>12 percent fines), complete Test 4 to determine whether fines are plastic or nonplastic.

Test 4 - Plasticity Test

- a. Wet and mold a small 2 x 2 x 2 cm (3 teaspoons) soil sample so that it can be rolled into a thread without crumbling. The material will not stick to the hands if the correct amount of water is added.
- b. Roll the moist soil with the palm of the hand on any clean, smooth surface, such as a piece of paper or clipboard, to form a coarse thread and pull it apart.
- c. Observe difficulty of pulling thread apart: GC, SC, CH, or CL = tough (hard to pull apart); GM, SM, or MH = medium tough; GM, SM, or ML = weak (easily pulled apart).

Alternative Plasticity Test (from Soil Survey Staff, 1991)

- d. Find the minimum thickness a 4-cm long roll must have to support its own weight: nonplastic = >6 mm; slightly plastic = 4-6 mm; moderately plastic = 2-4 mm; very plastic = <2 mm.

Test 5 - Ribbon Test

- a. Take a quantity of soil measuring at least 2 x 2 x 2 cm (3 teaspoons). Square and wet it with water until it reaches a plastic state. This condition prevails when the soil contains just enough moisture so that it can be rolled into 3-mm diameter threads. These threads or ribbons are formed by squeezing and working the sample between the thumb and forefinger. Plastic limit is governed by clay content.
- b. Observe properties of ribbon: ML = weak (breaks easily); MH = hard (does not break easily); CL = flexible with medium strength; CH = strong and flexible.

Test 6 - Liquid Limit Test (from SCS, 1990)

- a. Take a pat of moist soil with a volume of about 8 cc (1.2 in.³) and add enough water to make the soil soft but not sticky.
- b. Rapidly add enough water to cover the outer surface, and break the pat open immediately.
- c. A positive reaction has occurred when the water has penetrated through the surface layer: LL = low, if water has penetrated (ML, CL); LL = high, if the water has not penetrated (MH, CH). [Note: direct sunlight facilitates observation of this phenomena].

Test 7 - Dry Crushing/Clod Strength Test

- a. Obtain a dry block of soil at least 2 cm (3/4 in.) in its smallest dimension.
- b. Crush the clod between fingers and observe the effort required: ML = easily crushed; CL or MH = medium-hard to break; CH = almost impossible to break.

Test 8 - Dilatancy Test (from SCS, 1990)

- a. Mold material into a ball about 15 mm (1/2 in.) in diameter. Add water, if needed, until it has a soft but not sticky consistency.
- b. Smooth the soil in the palm of one hand with the blade of a knife or spatula.
- c. Shake horizontally, striking the side of the hand against the other several times. Note the appearance of water on the surface. Squeeze the sample and note the disappearance of water.
- d. Describe the reaction: none = no visible change (CH); slow = water appears slowly on the surface during the shaking and does not disappear or disappears slowly when squeezed (CL, MH); rapid = water appears quickly on the surface during shaking and disappears quickly when squeezed (ML).

Test 9 - Toughness Test (from SCS, 1990)

- a. Take the specimen for the dilatancy test and shape it into an elongated pat and roll it on a hard surface or between hands into a thread about 3 mm (1/8 in.) in diameter. (If it is too wet to roll, spread it out and let it dry.)

- b. Fold the thread and reroll repeatedly until the thread crumbles at a diameter of 3 mm (1/8 in.). The soil has reached its plastic limit.
- c. Note the pressure required to roll the thread and the strength of the thread: circumferential breaks = CH or CL material; longitudinal cracks and diagonal breaks = MH.
- d. After the thread crumbles, lump the pieces together and knead until the lump crumbles.
- e. Note the toughness of the material during kneading. Describe toughness: low = only slight pressure required to roll the thread near the plastic limit, the thread and lump are weak and soft (ML); medium = medium pressure is required to roll the thread near the plastic limit, the thread and lump have medium stiffness (CL, MH); high = considerable pressure required to roll the thread near the plastic limit, the thread and lump are very stiff (CL, CH); nonplastic = thread cannot be rolled (CL, CH).

Test 10 - Stickiness Test

- a. Saturate a sample of the soil and let it dry on the hands.
- b. Observe ease with which soil is rubbed off: ML is brushed off with little effort; CL or MH require moderate effort to brush off; CH requires rewetting to completely remove.

Alternative Stickiness Test (from Soil Survey Staff, 1991)

- c. Saturate a sample of the soil and press between thumb and forefinger.
- d. Observe the adhesion to thumb and forefinger when they are pulled apart: nonsticky = practically no adhesion (ML); slightly sticky = sticks to thumb or forefinger (MH); sticky = adheres to both, stretches slightly before breaking (CL); very sticky = adheres to both, stretches decidedly (CH).

Test 11 - Organic Soils Test

- a. Smell soils suspected of having a high organic matter content.
- b. A distinctive, pungent musty odor is indicative of organic soils.

- c. Feel texture of soil: PT = spongy or fibrous texture; OL or OH = nonfibrous.
- d. If nonfibrous, do plasticity test (Test 6): OL = low plasticity; OH = high plasticity.

3.1.7b Atterberg Limits

Atterberg limits define various states of fine-grained soil material ranging from dry to liquid. The **shrinkage limit** (SL) is the water content at which a further reduction in water does not cause a decrease in the volume of the soil mass. The **plastic limit** (PL) is the water content at which soil changes from a semi-solid to a plastic state. At the plastic limit, a fine-grained soil will just begin to crumble when rolled into a thread approximately 3 mm (1/8 in.) in diameter. The **liquid limit** is the water content at which soil consistency changes from a plastic to a liquid state. This is the water content at which a pat of soil, cut by a groove 2 mm wide will flow together for a distance of 13 mm (1/2 in.) under the impact of 25 blows in a standard liquid limit apparatus.

Accurate determination of Atterberg limits requires collection of samples for laboratory analysis.

3.1.7c Shear Strength

Shear strength can be estimated approximately in the field by the ease with which a sample can be penetrated by the thumb, as described in Table 3-6.

Table 3-6. Field Estimation of Soil Shear Strength

Consistency	Identification Procedure	Shear Strength (tons/ft ² or kg/cm ²)
Soft	Easily penetrated several inches by thumb	<0.25
Firm	Penetrated several inches by thumb with moderate effort	0.25 to 0.50
Stiff	Readily indented by thumb, but penetrated only with great effort	0.50 to 1.00
Very Stiff	Readily indented with thumbnail	1.00 to 2.00
Hard	Indented with difficulty by thumbnail	>2.00

Source: SCS (1990).

3.1.7d Shrink-Swell

Certain clays shrink when pore water is lost during drying and subsequently swell during wetting. High shrink-swell clays are of concern at contaminated sites because deeply penetrating cracks create pathways for contaminant movement during the early stages of the wetting phase. Where sodium rich clays with high dispersivity exist in the subsurface, a form of erosion called piping is also a concern.

SCS defines shrink-swell potential classes based on linear extensibility ($LE (\%) = 100 \times \text{moist length} - \text{dry length} / \text{dry length}$) or the coefficient of linear extensibility ($COLE = LE/100$), as follows:

Class	LE (%)	COLE	Dbd/Mdb
Low	<3	<0.03	<1.1
Medium	3-6	0.03-0.06	1.1-1.2
High	6-9	0.06-0.09	1.2-1.3
Very high	>9	>0.09	>1.3

LE can be measured by collecting a core from a wet or moist soil, carefully measuring its wet length, and setting it upright in a dry place. If the sample shrinks in a symmetrical shape without excessive cracking or crumbling, its length should be measured and LE calculated. If the core crumbles or cracks, the coated clod method for bulk density measurement (see Section 3.1.6c) and the ratio of dry bulk density (Dbd) to moist bulk density (Mbd) should be used to place samples in shrink-swell classes (see table above). SCS (1971, Section 14.3) and SCS (1983) provide additional information on these procedures. SCS (1971) also describes a simple test for rough determination of maximum potential shrinkage and density of disturbed soils.

3.1.7e Corrosivity

SCS soil series interpretation sheets give separate corrosion potential ratings for uncoated steel and for concrete. If classification of a soil is uncertain, corrosivity can be estimated using the following field and laboratory-measured parameters:

Uncoated steel — Texture (Section 3.1.2), water table (Section 3.2.2), drainage class (Section 3.2.4), total acidity or extractable acidity as a rough equivalent to total acidity (Section 3.3.3), resistivity

at field capacity, and conductivity of saturated extract (Section 3.3.6).

Concrete — Texture (Section 3.1.2), reaction (Section 3.3.4), and laboratory analysis of sodium and/or magnesium sulfate (ppm) and sodium chloride (ppm).

Table 3-7 shows criteria for soils with **high**, **moderate**, and **low** corrosion potential for uncoated steel. Table 603-8 in SCS (1983) provides criteria to estimate corrosion potential for concrete.

3.1.8 Soil Temperature/Temperature Regime

Soil temperature affects evaporation rates of water and volatile contaminants and influences the amount of microbiological activity in the soil. In soil classification, mean annual or summer soil temperature and the relationship between mean summer and mean winter soil temperature are used for placement in soil temperature regimes.

Ground-water temperature gives a close estimate of mean annual soil temperature if monitoring wells are available with water at a depth of 10 to 20 meters. Alternatively, the average of four temperature measurements taken at a depth of about 50 cm equally spaced throughout the year gives a good estimate of mean annual soil temperature. For mean summer temperature, readings may be taken on June 15, July 15, and August 15, and for mean winter temperature, on December 15, January 15, and February 15.

SCS (1971, Section 14.4) and Smith et al. (1960) describe more detailed procedures for soil temperature regime measurement, including special procedures where ground water or bedrock is shallow. Taylor and Jackson (1986) discuss types of thermometers and methods for measuring soil temperature for other applications.

EPA's ESES defines the following soil temperature classes based on point thermal measurements taken on the surface or with depth of soil at a point in time, or over a period of time:

High: 38°C (100.4°F)

Medium: 8-38°C (46.4 to 100.4°F)

Low: <8°C (46.4°F)

Table 3-7. Guide for Estimating Risk of Soil Corrosion Potential of Uncoated Steel

Class	Drainage Class and Texture	Total Acidity* (meq/100g)	Resis- tivity* (Ohm/cm)	Conduc- tivity* (mmhos/cm)
Low	Excessively drained coarse-textured or well-drained coarse- to medium-textured soils; or, moderately well drained, coarse-textured soils; or, somewhat poorly drained coarse-textured soils	<8	>5,000	<0.3
Moderate	Well-drained, moderately fine-textured soils; or moderately well drained, coarse- and medium-textured soils; or somewhat poorly drained, moderately coarse-textured soils; or, very poorly drained soils with stable high water table	8-12	2,000 to 5,000	0.3 to 0.8
High	Well drained, fine-textured, or stratified soils; or, moderately well drained fine- and moderately fine-textured or stratified soils; or, somewhat poorly drained, medium- to fine-textured or stratified soils; or poorly drained soil with fluctuating water table	>12	<2,000	>0.8

* See Table 603-7 in SCS (1983) for further guidance on how measurements should be made and interpreted.

3.2 Soil Hydrologic Parameters

3.2.1 *Moisture Conditions (Soil Water State)*

The terms used to describe soil properties may vary depending on the soil moisture content of the sample being observed. Soil water state is a more precise term for moisture conditions (Soil Science Society of America, 1987). Soil water state should be noted for any observations of properties that may vary with moisture content, such as color and consistency.

Table 3-8 describes three main soil water state classes (dry, moist, and wet) and eight subclasses within these categories, as defined by SCS. The water state classification of a particular soil sample will depend on (1) texture (whether it is coarse or not), (2) how strongly water is held by the soil (suction), and (3) the amount of gravimetric water held by the soil in relation to the amount held at specified reference suction pressures (i.e., 1,500 kPa for dry soils).

Referring to Table 3-8, the following can be used as guidelines for field estimation of soil water state:

Dry (VD) — Very little visual or tactile change between field observation and after air-dried samples.

Moist (MD) — Visual or tactile change between field observation and after air drying.

Wet — Water films evident, but no free water (WN); free water present (WA).

Between moist/wet and moderately dry/very dry separations, Soil Survey Staff (1991) describes four field water state tests: (1) color value test, (2) ball test, (3) rod test, and (4) ribbon test. These tests require calibration with the results of tests on similar soils that have been conducted at different known points on the moisture retention curve.

The following rules of thumb can be used to estimate actual percentages of water at different points on the moisture characteristic curve:

Water (%) at 1,500 Kpa = $0.4 \times$ estimated clay content

Water (%) of air dry soil = $0.1 \times$ estimated clay content

Table 3-8. Water State Classes

Class	Suction (kPa)*	Criteria
		Retention (% gravimetric moisture)
Dry (D)	>1500	
Very dry (DV)		<.35 x % water at 1500 kPa
Moderately dry (DM)		.35 - 0.8 x % water at 1500 kPa
Slightly dry (DS)		0.8 to 1.0 % water at kPa
Moist (M)	>1-1500	
Slightly moist (MS)		% water at 1500 kPa to MWR
Moderately moist (MM)		MWR** to UWR**
Very moist (MV)		UWR** to 1 or 0.5 kPa
Wet (W)	1	
Nonsaturated (WN)		No free water
Saturated (WA)		Free water present

Source: Soil Survey Staff (1991).

*Coarse soil material is considered wet at 0.5 kPa suction and moist from 0.5 to 1500 kPa if it meets the following criteria: (1) sand or sandy-skeletal family particle-size criteria, (2) coarser than loamy fine sand, (3) <2 percent organic carbon, (4) <5 percent water at 1500 kPa, and (5) computed total porosity of the <2 mm fabric exceeding 35 percent.

**UWR = upper water retention = % water at 5 Kpa (coarse soil) = % water at 10 KPa (other soil). MWR = midpoint water retention = halfway between UWR and % water at 1500 Kpa.

Methods for accurately measuring moisture content in the field require relatively sophisticated equipment and are not discussed further here (see Appendix D in Cameron (1991), for information on field methods). The same is true for accurate measurement of water retention at different matric potentials (moisture characteristic curves).

Moisture content and moisture characteristic curves are most commonly measured in the laboratory from samples collected in the field. Soil moisture tins with a capacity for about 250 grams of soil, filled to the brim and sealed with tape or plastic bags with any extra air removed before sealing, are best for determining field moisture content at the time of sampling. Undisturbed core samples are best for laboratory measurement of moisture characteristic curves.

SCS (1971, Section 14.1) describes procedures for determining water content that can be done in a field laboratory with the following equipment: balance accurate to 0.1 g; oven with thermometer or thermostat, or stove, hot plate, or infrared lamp; and thermometer with scale up to 150° C.

3.2.2 Water Table (Internal Free Water Occurrence)

SCS does not define a class for saturation (i.e., zero air-filled porosity) because the term implies that all of the pore space is filled with water, a situation which cannot be readily evaluated in the field. Free water develops positive pressure when its depth is below the top of a wet satiated zone (the top of water in an unlined borehole after equilibrium has been reached).

SCS classifies free water occurrence (perched or regional water table) into classes depending on (1) thickness (if perched), (2) depth, and (3) duration as follows:

Classes	Criteria
Thickness if perched	
Extremely thin (TE)	<10 cm
Very thin (TV)	10 to 30 cm
Thin (T)	30 cm to 1 m
Thick (TK)	>1 m

Depth

Very deep (DV)	>1.5 m
Deep (D)	1.5 to 1 m
Moderately deep (DM)	1 to 0.5 m
Shallow (S)	0.5 m to 25 cm
Very shallow (SV)	<25 cm

Cumulative Annual Duration

Absent (A)	Not observed
Very transitory (TV)	Present <1 month
Transitory (T)	Present 1 to 3 months
Common (C)	Present 3 to 6 months
Persistent (PS)	Present 6 to 12 months
Permanent (P)	Present continuously

3.2.3 Available Water Capacity

Available water capacity (AWC) is the amount of plant-available soil moisture, usually expressed as inches of water per inch of soil depth. It is commonly defined as the amount of water held between field capacity and the wilting point. AWC is important in developing water budgets and designing drainage systems.

Determination of AWC requires sampling of soil for moisture content when it is at field capacity. This requires sampling just after the soil has drained after a period of rain and humid weather, after a spring thaw, or after heavy irrigation. SCS (1971, Section 14.1) describes several other procedures for bringing a plot to field capacity by wetting, and several methods for wetting clods or cores to approximate field capacity. SCS (1983) provides further guidance on calculation and estimation of AWC.

3.2.4 Saturated Hydraulic Conductivity and Soil Drainage Class

The terms permeability and saturated hydraulic conductivity are often used interchangeably to refer to the ease with which water moves through the soil under saturated conditions. Permeability rates are typically reported in units of in./hr based on percolation tests; saturated hydraulic conductivity may be reported in units of $\mu\text{m/s}$, m/s , cm/day , in./hr , or cm/hr . Accurate field measurement of both saturated (K_{sat}) and unsaturated hydraulic

conductivity requires relatively complex instruments and procedures that are not covered here (see Appendix D in Cameron (1991) for information on these methods).

SCS currently defines six classes for describing soils based on saturated hydraulic conductivity:

Class	Saturated Hydraulic Conductivity	
	($\mu\text{m/s}$)	(in./hr)
Very low (VL)	<0.01	<0.001
Low (L)	0.01-0.1	0.001-0.01
Moderately low (ML)	0.1-1	0.01-0.14
Moderately high (MH)	1-10	0.14-1.4
High (H)	10-100	1.4-14.2
Very high (VH)	>100	>14.2

Class placement is based on geometric mean of multiple measurements.

Various methods have been developed for obtaining rough estimates of K_{sat} based on various soil properties. Table 3-9 provides a basis for estimating K_{sat} based on field observations of structure, texture, and pores. See Section 3.1.2 for identification of textural classes, Section 3.1.4 for pore definitions, and Section 3.1.5a for definitions of structural units.

O'Neal (1952) describes a procedure for somewhat more precise estimation of soil permeability classes (which are defined slightly differently from those listed above) based on (1) structure, (2) shape and overlap of aggregates, (3) visible pores, and (4) texture. Soil Survey Staff (1991, Chapter 3) provides figures for K_{sat} class placement based on soil bulk density and texture.

Soil drainage class refers to the frequency and duration of wet periods for the water regime associated with undisturbed soil conditions. Table 3-10 summarizes SCS criteria for seven soil drainage classes.

3.2.5 Infiltration

The amount of precipitation reaching the ground surface that enters the soil is determined by the **infiltration capacity**. In a dry soil, infiltration is usually rapid, unless there is an impervious crust at the surface. As time passes, infiltration slows until the **ponded infiltration** rate is attained, which is determined by the saturated hydraulic

Table 3-9. Guide for Estimating the Class of Saturated Vertical Hydraulic Conductivity from Soil Properties

Name	Class Rate*	Soil Properties**
Very High	<100	–Fragmental –Sandy with coarse sand or sand texture, and loose consistence –More than 0.5 percent medium or coarser vertical pores with high continuity
High	100-10	–Other sandy, sandy-skeletal, or coarse-loamy soil materials that are very friable, friable, soft, or loose –When very moist or wet has moderate or strong granular structure; or strong blocky structure of any size or prismatic structure finer than very coarse, and many surface features except stress surfaces or slickensides on vertical surfaces of structural units –0.5 to 0.2 percent medium or coarser vertical pores with high continuity
Moderate	10-1	–Sandy in other consistence classes except extremely firm or cemented –10 to 35 percent clay with moderate structure, except platy, or strong very coarse prismatic structure; and with common surface features except stress surfaces or slickensides on vertical surfaces of structural units –0.1 to 0.2 percent medium or coarser vertical pores with high continuity
Mod. Low	1-0.1	–Other sandy classes that are extremely firm or cemented –18 to 35 percent clay with other structures and surface conditions except pressure or stress surfaces –Greater than 35 percent clay and moderate structure except if platy or very coarse prismatic; and with common vertical surface features except stress surfaces or slickensides –Medium or coarser vertical pores with high continuity, but <0.01 percent

(Continued)

Table 3-9. (Continued)

Name	Class	Soil Properties**
	Rate*	
Low	0.1-0.01	<p>—Continuous moderate or weak cementation</p> <p>—Greater than 35 percent clay and meets one of the following: weak structure; weak structure with few or no vertical surface features; platy structure; common or many stress surfaces or slickensides</p>
Very Low	<0.01	<p>—Continuously indurated or strongly cemented and with less than common roots</p> <p>—Greater than 35 percent clay and massive or exhibits horizontal depositional strata and less than common roots</p>

Source: SCS (1983).

*Micrometers/second.

**A given soil profile would have most, but not necessarily all, of the soil properties associated with a particular class.

Table 3-10. Criteria for SCS Soil Drainage Classes

Excessively drained. Water is removed very rapidly. Internal free water occurrence commonly is very deep; annual duration is not specified. The soils are commonly very coarse textured, rocky, or shallow. Some are steep. All are free of mottling related to wetness.

Somewhat excessively drained. Water is removed from the soil rapidly. Internal free water occurrence commonly is very deep; annual duration is not specified. The soils are usually sandy and rapidly pervious. Some are shallow. A portion of the soils are so steep that a considerable part of the precipitation received is lost as runoff. All are free of the mottling related to wetness.

(Continued)

Table 3-10. (Continued)

Well drained. Water is removed from the soil readily but not rapidly. Internal free water occurrence commonly is deep or very deep; annual duration is not specified. Water is available to plants throughout most of the growing season in humid regions. Wetness does not inhibit growth of roots for significant periods during most growing seasons. Well drained soils are commonly medium textured. They are mainly free of the mottling related to wetness.

Moderately well drained. Water is removed from the soil somewhat slowly during some periods of the year. Internal free water occurrence commonly is moderately deep and transitory through permanent (Section 3.2.2). The soils are wet for only a short time during the growing season, but long enough that most mesophytic crops are affected. They commonly have a slowly pervious layer within the upper 1 m, periodically receive high rainfall, or both.

Somewhat poorly drained. Water is removed slowly enough that the soil is wet at shallow depth for significant periods during the growing season. Internal free water occurrence commonly is shallow and transitory or common. Wetness markedly restricts the growth of mesophytic crops unless artificial drainage is provided. The soils commonly have one or more of the following characteristics: contain a slowly pervious layer, have a high water table, receive additional water from seepage, or occur under nearly continuous rainfall.

Poorly drained. Water is removed so slowly that the soil is wet at shallow depths periodically during the growing season, or remains wet for long periods. Internal free water occurrence is shallow or very shallow and common or persistent. Free water is commonly at or near the surface for long enough during the growing season that most mesophytic crops cannot be grown unless the soil is artificially drained. The soil, however, is not continuously wet directly below plow-depth. Free water at shallow depth is usually present. This water table is commonly the result of a shallow, slowly pervious layer within the soil, of seepage, of nearly continuous rainfall, or of a combination of these.

Very poorly drained. Water is removed from the soil so slowly that free water remains at or very near the ground surface during much of the growing season. Internal free water occurrence is very shallow and persistent or permanent (Section 3.2.2). Unless the soil is artificially drained, most mesophytic crops cannot be grown. The soils are commonly level or depressed and frequently ponded. If rainfall is high or nearly continuous, slope gradients can be moderate or high.

conductivity of the soil. Infiltration rate is usually measured in rates of in./hr or cm/hr. Extrastructural cracks (Section 3.1.5b) may greatly increase infiltration rates compared to soils with similar texture that do not have cracks.

SCS's permeability classification system (SCS, 1983) can be used to describe infiltration classes:

Class	Permeability	
	(in./hr)	(cm/hr)
Very slow	<0.06	<0.15
Slow	0.06-0.2	0.15-0.5
Moderately slow	0.2-0.6	0.5-1.5
Moderate	0.6-2.0	1.5-5.0
Moderately rapid	2.0-6.0	5.0-15.2
Rapid	6.0-20	15.2-50.8
Very rapid	>20	>50.8

3.3 Soil Chemistry and Biology

Most procedures for characterization of soil chemistry require collection of samples for laboratory analysis. This section focuses on pH and mineralogical parameters that can be tested in the field using relatively simple equipment and procedures. Most of these tests are drawn from SCS (1971).

3.3.1 *Organic Matter*

Organic matter (more precisely measured in the laboratory as organic carbon) affects contaminant mobility primarily by its high sorptive capacity. Accurate determination of total organic carbon (TOC) requires collection of samples for laboratory analysis.

In the field, black or dark colors generally indicate high organic matter content in near-surface horizons. In most mineral soils, organic matter is moderately low to high in the A horizon, and low in the subsoil. Severely eroded soils, where the topsoil has been completely removed; alluvial soils, where flooding deposits topsoil; and buried soils may not follow this pattern. SCS defines the following classes for organic matter:

Class	% Organic Matter
Very low (VL)	<0.5
Low (LL)	0.5-1.0
Moderately low (ML)	1.0-2.0
Medium (MM)	2.0-4.0
High (HH)	>4.0

Note that organic matter content is generally 1.7 to 2.0 times the TOC. An ignition test can be used in the field to approximate organic matter content and check its contribution to soil color. Equipment for this test includes (1) thermometer and heat lamp, (2) portable gas soldering torch, (3) a porcelain crucible or small tin can (not aluminum), (4) wire brackets or tongs to hold the container, and (5) a balance accurate to 0.1 grams.

Ignition Test Procedure (adapted from SCS, 1971)

1. Dry about 30 grams of soil to 110°C under a heat lamp.
2. Weigh as accurately as possible about 10 grams of dried soil and place in a crucible or tin, supporting it with tongs or wire bracket.
3. Apply the flame of the torch to the bottom and lower walls of the outside of the container. Porcelain and metal glow red at 500°C. At this temperature, organic matter is completely burned and the water of hydration is removed from the common oxide and clay minerals.
4. Observe changes in color in the specimen. Apply heat more than once until there is no more change apparent in the specimen. Do not apply the flame directly to the sample if burning or oxidation are the purpose of the test, because unpredictable reducing conditions exist in parts of the torch flame. If organic matter is the only material giving color to the soil, it burns away leaving a whitish residue. See Section 3.1.3 for interpretation of other color changes.
5. When no more change is apparent, cool and weigh sample again. The loss in weight divided by the original weight times 100 equals the organic matter in sandy soils and materials high in organic matter.

If much clay is present, the loss also includes water of hydration in the minerals.

Organic matter also reacts with hydrogen peroxide. In contrast to manganese oxides (see Section 3.3.8), the reaction starts slowly, builds up, and continues. Organic matter reactions decrease with depth, whereas manganese oxide reactions remain constant.

Test No. 11 in Section 3.1.7a describes procedures for classifying organic soils in the Unified soil classification system. SCS uses a number of tests for classification of organic soils (histosols) including sodium pyrophosphate color, fiber percentages, and pH in 0.01 M calcium chloride. Since organic soils do not commonly occur at hazardous waste sites, these tests are not described here. If organic soils are present at a site and more detailed characterization is required, refer to Lynn et al. (1974) and Appendix III in Soil Survey Staff (1975).

3.3.2 Odor

High organic matter content in soil is associated with a distinctive, pungent musty odor (see Test 11 in Section 3.1.7a). Organic rich topsoil in mineral soils can also be distinguished from subsoil that is low in organic matter by this odor.

Volatile organic contaminants can impart distinctive odors to soil. Gasoline has an odor familiar to most people; aging gives petroleum a musty odor. Some other contaminants that may give soil a noticeable odor include halogens, ammonia, turpentine, phenols and cresol, picrates, various hydrocarbons, and unsaturated organic pesticides.

Caution should be exercised in observing soil odors. They should not be vigorously inhaled from any soil, since even natural soils may contain potentially harmful microorganisms. Soils where noticeable artificial odors are present should be checked for volatile concentrations using a detection instrument (HNU, organic vapor analyzer, etc.). The health and safety officer should be consulted to determine whether special protective equip-

ment, such as a respirator, should be used by individuals who are working close to the soil surface taking samples.

EPA's ESES uses the following odor classes:

High: A distinct odor, from naturally occurring soil organic materials with a distinctive pungent, musty odor, or sharp distinct odor from chemical contaminants.

Moderate to slight: A less distinct to faint odor, from naturally occurring soil organic materials, or from various odor-producing chemical contaminants.

None: No detectable odor by olfactory means.

3.3.3 Cation Exchange Capacity (CEC)

Cation exchange capacity, measured in milliequivalents per 100 grams (meq/100 g) or centimoles per kilogram (cmol/kg), is a measure of the soil's ability to absorb (and release) cations. It is an especially important parameter at sites contaminated by heavy metals, because heavy metals will often replace exchangeable ions such as sodium, potassium, calcium, and magnesium that exist in natural soil. Measurement of CEC requires collection of samples for laboratory analysis. SCS (1971, Section I9.7 and I9.8) describes relatively simple chemical tests that can be carried out in the field to estimate exchangeable calcium and exchangeable sodium.

The measurement of **extractable acidity**, also called exchangeable acidity or extractable hydrogen because it measures exchangeable ions that contribute to soil acidity, is required for evaluation of soil corrosivity (see Section 3.1.7e). Section 6H in SCS (1984) describes specific procedures for determining extractable acidity in the laboratory.

EPA's ESES uses the following CEC classes (expressed as meq/100 g soil): **high** (>20), **medium** (12-20), **low** (<12).

3.3.4 Reaction (pH)

A variety of methods are available for field measurement of pH (colorimetric, paper test strips, pH meter). Specific procedures and instructions accompanying equipment for the method used should be followed. For RCRA sites, EPA Method 9045A Revision 1, November 1990, should be used (U.S. EPA, 1986).

Soil Survey Staff (1991) defines 13 pH classes for soil as follows:

Class	pH
Ultra acid (UA)	<3.5
Extremely acid (EA)	3.5 - 4.5
Very strongly acid (VS)	4.5 - 5.0
Strongly acid (SA)	5.1 - 5.5
Medium acid (MA)	5.6 - 6.0
Slightly acid (SA)	6.1 - 6.5
Neutral (NA)	6.6 - 7.3
Mildly alkaline (MA)	7.4 - 7.8
Moderately alkaline (MO)	7.9 - 8.4
Strongly alkaline (SA)	8.5 - 9.0
Very strongly alkaline (VA)	>9.0

3.3.5 Redox Potential (Eh)

Redox, or oxidation-reduction potential (Eh), is measured in volts or millivolts (mV) as the potential difference in a solution between a working electrode and the standard hydrogen electrode. Whether soil conditions are oxidizing (aerobic) or reducing (anaerobic) will strongly affect the types of microbiological activity and contaminant transformation and degradation processes that may occur. The mobility of many heavy metals varies with oxidation state. In unsaturated soil, aerobic conditions prevail, and measurement of Eh requires collection of soil water samples using a suction lysimeter. The Eh of saturated soil should be measured using ground-water samples from properly purged monitoring wells.

EPA's ESES uses the following redox potential classes: **highly oxidized** (>+400 mV), **intermediate** (+400 to -100 mV), and **highly reduced** (<-100 mV).

3.3.6 Electrical Conductivity (Salinity)

In arid and semi-arid areas, soluble salts may accumulate in the soil and are called saline. The electrical conductivity of a saturation extract is the standard measure of salinity. Electrical conductivity is commonly reported in units of decisiemens/meter or millimhos/centimeter (1 dS/m = 1 mmho/cm). Electrical conductivity

measurement or estimation is required for evaluation of soil corrosivity (see Section 3.1.7e).

Salinity classes, based on electrical conductivity of a saturation extract, are defined in EPA's ESES as follows:

Class	Electrical Conductivity (dS/m or mmho/cm)
Nonsaline	0-2
Slightly saline	2-4
Moderately saline	4-8
Very saline	8-16
Extremely saline	>16

Note that Soil Survey Staff (1991) uses slightly different terms for these classes.

SCS (1971, Section 19.6) describes a relatively simple procedure for water extraction that can be used in the field or a field laboratory for measuring approximate soluble salt percentage. Accurate determination requires laboratory preparation of soil samples. SCS (1984, Section 8A) describes procedures for preparing a saturated paste and obtaining a saturation extract for electrical conductivity measurement. Measurement of the resistivity of the saturated paste (SCS, 1984, Section 8E) is required for evaluating soil corrosion potential for uncoated steel.

Richards (1954) and Richards et al. (1956) describe procedures for testing saline soils in more detail and provide charts and graphs for estimating total salt from electrical conductivity measurements. Rhoades and Oster (1986) describe more complex instrumentation for collecting soil water using in situ samplers and measuring soluble salts with in situ or remote monitors.

The electrical conductivity, also termed specific conductance, of ground-water samples can be readily measured in the field using a conductivity meter. Electrical conductivity is a measure of the total dissolved solids in the ground water and should not be confused with the soil salinity test described above.

3.3.7 Clay Minerals

The following procedures can be used to identify the dominant mineralogy of the clay size-fraction:

Clay Mineral Test

1. Prepare a saturated solution of malachite green in nitrobenzene to use as an indicator solution (follow prescribed safety procedures when handling nitrobenzene).
2. Add several drops of the indicator to a small sample (1 g) of soil and observe color of wetted soil as follows: blue or green-blue = kaolinite; yellow-red = montmorillonite; purple-red = illite.

Mica Shine Test

Rub a small clod of air-dried soil with a knife blade. A shiny surface indicates a micaceous soil with high plasticity.

EPA's ESES defines the following clay mineral abundance classes (see Section 3.1.2 for estimation of texture): **abundant** (>27 percent), **moderate to slight** (1 to 27 percent), **none to negligible** (<1 percent).

3.3.8 Other Minerals

Concentrations of minerals may form in soil horizons as a result of dissolution and precipitation processes. These concentrations are described by SCS according to (1) type, (2) amount or quantity, (3) size, (4) shape, and (5) composition. The following are abbreviations of descriptors and criteria for describing concentrations in soil:

Types

- m — masses (soft, no clearly defined boundaries)
- n — nodules and concretions (hard, clearly defined boundaries)
- c — crystals (single or complex clusters)
- srf — soft rock fragments (weakly cemented or noncemented)

Amount/Quantity

- f — few (<2%)
- c — common (2-20%)
- m — many (>20%)

Size

fine (<2 mm)

medium (2-5 mm)

coarse (5-20 mm)

very coarse (20-76 mm)

extremely coarse (>76 mm)

Shape

rnd — rounded

cyl — cylindrical

pl — platelike

ir — irregular

fe — ferruginous

mn — manganiferous

sal — saline

Composition

calc — calcareous

arg — argillaceous

yp — gypsiferous

sil — siliceous

The following features and tests can be used to identify major non-clay minerals in the field.

Carbonates (calcareous)

The presence of free calcium carbonate in soil can be readily determined based on effervescence in dilute hydrochloric acid. The test procedure is as follows:

1. Place 1 g of soil material (about the size of a marble) in the well of a porcelain spot plate. Thoroughly moisten the soil with a few drops of deionized water; stir with a clean glass rod to remove entrapped air.
2. Add three drops of dilute 10 percent (4 N) cold HCl from a plastic squeeze bottle and immediately observe for effervescence of the treated sample under a hand lens if possible.
3. If effervescence is observed, record intensity as follows:
vse—very slightly effervescent (few bubbles seen)
sle—slightly effervescent (bubbles readily seen)

ste—strongly effervescent (bubbles form low foam)
ve—violently effervescent (thick foam forms quickly)

4. Repeat procedure on a second 1-g sample.

Dolomite (calcium-magnesium carbonate) effervesces slowly in cold acid unless the mineral is very finely divided. If dolomite is suspected, place the sample in a container and warm it for 15 minutes after covering it with the acid solution.

Soluble Salts (saline, gypsiferous)

White incrustations that do not effervesce can be separated and checked for water solubility and taste. Chlorides, nitrates, and sulfates of sodium and potassium are very water soluble. **Chloride salts** can be tested by shaking a sample of soil in distilled water, placing about 10 mL of the supernatant solution (after the solids have settled) in a test tube, and adding a few drops of 5 percent sodium nitrate solution. Chlorides are indicated by the formation of a thick, milky precipitate of silver chloride. The formation of a heavy white precipitate after adding a 5 percent barium chloride solution to a separate supernatant sample indicates **sulfate** ions. SCS (1971, Section I9.6) provides further details for these tests.

Crystals of gypsum, which may occur as a white incrustation in voids, are rhombic plates, laths, or sometimes fibers. Gypsum crystals can be scratched with the fingernail, do not effervesce in acid, and are very slowly soluble in water.

Gypsum Acetone Test. Place 1 part soil and 10 parts water (by weight) in a small bottle. Seal the bottle and shake by hand at 15-minute intervals. Filter the extract through filter paper. Mix a 50-50 solution of the filtrate and acetone. The formation of a milky precipitate indicates the presence of gypsum. SCS (1971, Section I9.6) describes a somewhat more complex semi-quantitative test for gypsum using acetone which can be used in the field.

Iron Oxides (ferruginous)

Goethite and hematite commonly occur as segregated bodies in soils. Hematite is red; solid bodies, such as nodules or sheets may be dark brown or almost

black but have a red streak if rubbed on a rough porcelain surface or a tough paper. Goethite bodies commonly are red but may be yellow or brown and are generally softer than hematite bodies. In an ignition test (see Section 3.1.3), hematite will show little color change; the duller colors of goethite will brighten when it changes to hematite. If gray, blue, or green materials turn red when ignited, ferrous iron is present.

Manganese Oxide (manganiferous)

Black and very dark brown concretions and coatings on cleavage planes are likely to be the manganese oxide pyrolusite or a closely related mineral. It has a dark brown streak and is very soft, producing the streak even on paper. A procedure similar to the carbonate test using a dilute (5 percent) solution of hydrogen peroxide instead of HCl will result in the rapid evolution of small bubbles with a usually rapid consumption of the hydrogen peroxide if manganese oxides are present. See Section 3.3.1 for further guidance in differentiating possible reactions with organic matter.

SCS (1971, Section 17.2) discusses in more detail the identification of minerals and mineral groups in the field.

3.3.9 Fertility Potential

Soil fertility is the ability or status of a soil to supply water and nutrients necessary for plant growth. Inherent physical characteristics, such as soil structure and available water capacity, provide the basic elements of fertility potential, and are not easily modified. The nutrient status of a soil, on the other hand, can be improved by fertilization.

Nutrient status is evaluated by analyzing samples in the laboratory for nutrients essential for plant growth such as nitrogen, potassium, and phosphorus. Soil reaction (pH) is an important chemical parameter, because it strongly influences the availability of nutrients.

The key physical parameters affecting fertility potential are aeration and water availability, because plant roots require both air and a ready supply of moisture for optimum growth. These factors can be evaluated by observing soil properties such as soil texture (Section 3.1.2),

depth to water table (Section 3.2.2), available water capacity (Section 3.2.3), and soil drainage class (Section 3.2.4). Deep, well-drained soils with a high available water capacity have the greatest fertility potential, provided nutrient status is favorable. Shallow soils with low available water capacity have low fertility potential even if nutrient status is favorable.

EPA's ESES defines the following soil fertility potential or status classes:

High: Nutrients necessary for plant growth readily supplied.

Moderate: Nutrients necessary for plant growth in moderate supply.

Low: Nutrients necessary for plant growth in low supply.

3.3.10 Soil Microbiota

Microorganisms in soil and ground water are now recognized as being of major importance in affecting the transformation and fate of many organic contaminants and heavy metals. The study of soil microbiota from soil samples requires carefully controlled laboratory conditions. The major concern in the field is that procedures used to collect soil samples do not allow contamination by microorganisms from other sources. Soil samples must be collected using sterilized tools and placed in sterilized containers. Samples of near-surface soils for microbiological study should be taken from a soil pit. Scoops or trowels used to collect samples from each soil horizon should go through usual decontamination procedures. As a final step, they should be heated with a blow torch and cooled by being stuck into the horizon to be sampled before soil material is dug out and placed into containers.

Samples for microbiological study taken from greater depths where oxygen is low require special aseptic handling procedures to prevent oxygen from harming anaerobic microorganisms. Leach et al. (1988) describes in detail procedures for collecting such samples, which involve preparing nitrogen-filled sampling containers in the laboratory, and using a field sampling glove box that has been purged with nitrogen gas to reduce the oxygen level below detectable limits.

EPA's ESES defines the following abundance classes for soil microorganisms (as number per gram of soil): **abundant** (>1,000,000), **common** (10,000-1,000,000), **few** (100-10,000), **none** (<100).

3.4 Soil Contaminants

Visual identification of zones of soil contamination is sometimes possible when the contaminants are in an immiscible liquid phase or a solid phase. Iridescence of an oily phase in water may indicate contamination from synthetic organics. Solid phases should be described by color and consistency (granular, tarry, etc.). Possible contamination by heavy metals from artificial pigments is evident from bright colors. Toxic effects of contaminants on surface vegetation also may be evident. In any event, the presence of contaminants must be confirmed by laboratory analysis of samples.

Organic vapor detectors are relatively simple instruments that are used to identify the presence of volatile organics. The way in which readings are taken (distance from sample being checked, location in borehole, length of reading) should be recorded along with the readings themselves. Procedures should be performed consistently, and any departures from usual procedures noted.

Increasingly sophisticated field equipment in mobile laboratories is being used for onsite contaminant analysis. Use of such equipment is not covered in this guide. Ford et al. (1984) describe methods for monitoring toxic gases and vapors with portable field instruments.

Chapter 4

Soil Sampling and Quality Assurance

Sample design, sample location, equipment and sampling methods, and quality assurance/quality control (QA/QC) procedures should all be determined before sampling begins and be recorded in the Soil Sampling and Quality Assurance Plans for the site. Mason (1983) and Barth et al. (1989) provide detailed guidance on statistical aspects of sampling design and quality assurance. These documents will outline the specific procedures that will be required during field sampling.

This chapter has two purposes: (1) to provide information that may be useful if unforeseen conditions require modification of the procedures specified in the sampling plan, and (2) to provide forms that may be useful in carrying out QA/QC procedures.

4.1 Changes in Soil Sampling Procedures

Soil description, use of field analytical equipment, and soil sampling should be conducted in a uniform and consistent manner, following procedures specified in the Soil Sampling and Quality Assurance Plans. If unforeseen conditions arise at the site during the field investigation and sampling that prevent carrying out the specified procedures, it may be necessary to develop alternative approaches at the site. Any such changes must be documented and approved (see Section 4.2).

One situation requiring departure from specified procedures is when soil conditions are unfavorable for the equipment being used to collect samples. If this situation occurs, the following tables may help identify alternative sampling tools:

Table 4-1 summarizes information on applications and limitations for use of 15 types of hand-operated soil sampling devices.

Table 4-2 summarizes information on applications and limitations for use of 10 common types of power-driven tube samplers.

Appendix B provides the names and addresses of 24 manufacturers and distributors of manually operated and power-driven soil sampling equipment.

If the use of different sampling equipment requires altering the standard sampling protocol, the new protocol should be clearly specified. Appendices A.2 to A.4 provide some general soil handling and sampling protocols that can be used for guidance if revised protocols must be developed at the site.

4.2 Quality Assurance/Quality Control

Any change in standard procedures for field collection of soil samples must be justified, described, and approved by the appropriate project personnel. Form 4-1 (Sample Alteration) can be used for this purpose. Multiple copies of this form should be available for use.

Soil sampling personnel should be aware that their work may be subject to a field audit to ensure that soil sampling and other QA/QC procedures are being followed. Form 4-2 contains a checklist of major items that should be covered in a field audit. Field personnel would do well to review this checklist periodically as a reminder of areas in which they would be held accountable in the event of a field audit.

The results of a field audit, or review of analytical results, may identify problems areas requiring corrective action. If the need for corrective action is identified during a field audit, it should be implemented immediately. Resampling may be required if analytical results fall outside the acceptable limits specified in the Quality Assurance Plan. Form 4-3 (Soil Sample Corrective Action Form) can be used to identify problem areas and specify measures required to correct the problems. When resampling is required, this form should be taken into the field and the specified procedures carefully followed.

Table 4-1. Summary of Hand-Held Soil Sampling Devices

Sampling Device	Applications	Limitations
Spoons and Scoops	Surface soil samples or the sides of pits or trenches	Limited to relatively shallow depths; distributed samples
Shovels and Picks	A wide variety of soil conditions	Limited to relatively shallow depths
Augers*		
Screw Auger	Cohesive, soft, or hard soils or residue	Will not retain dry, loose, or granular, material
Standard Bucket Auger	General soil or residue	May not retain dry, loose, or granular material
Sand Bucket Auger	Bit designed to retain dry, loose, or granular material (silt, sand, and gravel)	Difficult to advance boring in cohesive soils
Mud Bucket Auger	Bit and bucket designed for wet silt and clay soil or residue	Will not retain dry, loose, or granular material
Dutch Auger	Designed specifically for wet, fibrous, or rooted soils (marshes)	
In Situ Soil Recovery Auger	Collection of soil samples in reusable liners; closed top reduces contamination from caving sidewalls	Similar to standard bucket auger
Eijkelcamp Stoney Soil Auger	Stoney soils and asphalt	
Planer Auger	Clean out and flatten the bottom of predrilled holes	

(Continued)

Table 4-1. (Continued)

Sampling Device	Applications	Limitations
Tube Samplers**		
Soil Probe	Cohesive, soft soils or residue; representative samples in soft to medium cohesive soils and silts	Sampling depth generally limited to less than 1 meter
Thin-Walled Tubes	Cohesive, soft soils or residue; special tips for wet or dry soils available	Similar to Veihmeyer tube
Soil Recovery Probe	Similar to thin-walled tube; cores are collected in reusable liners, minimizing contact with the air	Similar to Veihmeyer tube
Veihmeyer Tube	Cohesive soils or residue to depth of 3 meters	Difficult to drive into dense or hard material; will not retain dry, loose, or granular material; may be difficult to pull from ground
Peat Sampler	Wet, fibrous, organic soils	

*Suitable for soils with limited coarse fragments; only the stoney soil auger will work well in very gravelly soil.

**Not suitable for soils with coarse fragments.

Source: Adapted from Brown et al. (1991) and Rehm et al. (1985).

Table 4-2. Summary of Major Types of Power-Driven Tube Samplers

Sampling Device	Applications	Limitations
Split Spoon Sampler	Disturbed samples from cohesive soils	Ineffective in cohesionless sands; not suitable for collection of samples for laboratory tests requiring undisturbed soil
Thin-Walled Samplers		
Fixed-Piston Sampler	Undisturbed samples in cohesive soils, silt, and sand above or below water table	Ineffective in cohesionless sands
Hydraulic Piston Sampler (Osterberg)	Similar to fixed-piston sampler	Not possible to limit the length of push or to determine amount of partial sampler penetration during push
Stationary Piston Sampler	Undisturbed samples in stiff, cohesive soils; representative samples in soft to medium cohesive soils, silts, and some sands	
Wireline Piston Sampler	Undisturbed samples in cohesive soils and noncohesive sands; used with clamshell device on hollow-stem auger	In heaving sands only one sample per borehole can be collected because clamshell remains open after sampling
Free Piston Sampler	Similar to stationary piston sampler	Not suitable for cohesionless soils
Open Drive Sampler	Similar to stationary piston sampler	Not suitable for cohesionless soils

(Continued)

Table 4-2. (Continued)

Sampling Device	Applications	Limitations
Pitcher Sampler	Undisturbed samples in hard, brittle, cohesive soils and cemented sands; representative samples in soft to medium cohesive soils, silts, and some sands; variable success with cohesionless soils	Frequently ineffective in cohesionless soils
Denison Sampler	Undisturbed samples in stiff to hard cohesive soils, cemented sands, and soft rocks; variable success with cohesionless materials	Not suitable for undisturbed sampling of loose, cohesionless soils or soft cohesive soils
Vicksburg Sampler	Similar to Denison sampler except takes wider diameter samples	

Source: Adapted from Rehm et al. (1985) and Aller et al. (1989).

Form 4-1. Sample Alteration Form

Project Name and Number: _____

Material to Be Sampled: _____

Measurement Parameter: _____

Standard Procedure for Field Collection and Laboratory Analysis
(cite references):

Reason for Change in Field Procedure:

Variation for Field Procedure:

Special Equipment, Materials, or Personnel Required:

Initiator's Name: _____ Date: _____

Project Approval _____ Date: _____

Laboratory Approval: _____ Date: _____

QA Officer/Reviewer: _____ Date: _____

Sample Control Center: _____ Date: _____

Form 4-2. Field Audit Checklist

Records to Inspect

- _____ Chain-of-custody forms
- _____ Analytical analysis request forms
(if different from chain-of-custody forms)
- _____ Sample tags
- _____ Site description forms
- _____ Log books

Sampling Procedures to Inspect

- _____ Equipment
- _____ Techniques
- _____ Decontamination
- _____ Collection of duplicate and field blank samples
- _____ Security
- _____ Sample storage and transportation
- _____ Containers
- _____ Contaminated waste storage and disposal
- _____ Site description form entries

Form 4-3. Sample Corrective Action Form

Project Name and Number: _____

Sample Data Involved: _____

Measurement Parameter(s): _____

Acceptable Data Range: _____

Problem Areas Requiring Corrective Action:

Measures Required to Correct Problems:

Means of Detecting Problems and Verifying Correction:

Initiator's Name: _____ Date: _____

Project Approval: _____ Date: _____

Laboratory Approval: _____ Date: _____

QA Officer/Reviewer: _____ Date: _____

Sample Control Center: _____ Date: _____

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Appendix A.1

General Protocol for Description of Soil Cores

Careful description of soil conditions at sampling locations can provide valuable information for interpreting soil analyses. Soil cores, which provide relatively undisturbed cross sections of the soil, are best for soil description. A few major features like texture, color (but not accurate description of mottling or variations in color), and potential zones of contamination can be described from auger samples, but not much more.

At the outset, it should be decided whether soil descriptions will be made from the actual samples to be analyzed or from separate cores taken at the site. Describing actual samples has the advantage of allowing direct correlation of analyses with observed features, but will result in longer exposure of the sample to the air before it is placed in the sample container. This may not be desirable, even for samples taken for analysis of semi-volatiles and metals. Table 1-1 contains an abbreviated list of suggested features to be described from soil samples.

Taking separate cores allows more leisurely and detailed observation of soil features. The soil can also be handled as necessary without concern about affecting its integrity for analyses. When equipment is being used just to describe soil features, decontamination procedures between locations also may be less rigorous, provided that there is no danger that contaminants with very low detection limits could be spread to uncontaminated areas.

The upper 1.5 to 2 meters, which have been affected by soil weathering processes, should receive the most careful attention for description because this is where the most complex features are likely to be en-

countered. Weathering may extend below 2 m in older landscapes formed in temperate to humid climates. Below the zone of weathering, the more simplified descriptions typical of geologic drill logs are appropriate. General procedures for describing both types of cores are outlined below.

Soil Cores (weathered zone, usually 1.5 to 2 m)

1. Near the location where the core is to be taken, spread a plastic sheet about 30 cm wide and 2 meters long on the ground, and place on it a fully extended carpenters rule or range pole marked with gradations that match the depth increments on the tube sampler to be used (i.e., in./ft or cm/meter).
2. Clear any litter away from the ground surface and take the first core. An open tube sampler that exposes most of the core when it is pulled out is easiest to use for this purpose. Remove the core and place it on the sheet at the zero end of the rule. If the presence of volatile contaminants is suspected, take the reading of the core as soon as it is brought to the surface with field instrumentation (photoionization or flame ionization detector). Also take a reading near the top of the core hole and record the measurements.
3. Repeat coring process trying to take equal increments (12-in. increments are usually possible in the upper 2 or 3 ft; 6-in. increments when the soil is very dry and in deeper, denser horizons), placing each core on the sheet at the appropriate depth interval until the desired maximum depth has been reached. If the presence of volatile contaminants is suspected, readings with field instruments should be made of each core as soon as it is brought to the surface, and near the top of the hole before taking the next increment.
4. If penetration is difficult in very dense or very dry soils, a weighted plastic mallet can be used to drive a sampler with a T-handle into the ground. If such conditions are typical, consider using samplers with specially designed weighted drivers.

5. If rock fragments prevent further penetration of the tube sampler before the desired depth has been obtained, an auger (screw or bucket) can be used. If the diameter of the auger is larger than that of the tube sampler (usually the case), discard the soil material brought up by the auger for the depth increments already sampled.
6. When the depth of interest is reached, pull up the auger at regular intervals and place soil by the rule on the sheet at the appropriate depth location. To prevent mixing of loose soil material from different depth increments, place material at chosen increments (e.g., 12 in.) on opposite sides of the rule.
7. Once the complete soil is laid out on the sheet, visually examine the cores and place nails or some other kind of marker at the places where color changes indicate transitions between horizons.
8. Carefully split the cores. A knife may be used to create a shallow groove, but the core should not be sliced all the way through because this will disturb structural features. Place one-half with the interior side facing up, and the other half with the interior side facing down (exposing the surface that was used for the initial visual inspection).
9. Visually examine the interior face of the cores for transitions in structural units, texture, or other features. Adjust the locations of initially placed horizon markers on the sheet, if appropriate, and add additional markers for subhorizons, if required.
10. Describe each soil horizon using Form 3-1. Refer to the appropriate sections of Chapter 3 for procedures and abbreviated codes for descriptors of soil parameters.

Cores below Weathered Zone (usually 1.5 to 2 m)

Cores from greater depths can be described using essentially the same procedures as described above, except that the greater length requires placement of cores in holders where depth increments are side-by-side rather than end-on-end, and that generally fewer features are described. Most drillers and consultants have their own drill log forms. At a minimum, the following information

should be recorded when describing cores below the weathering horizon:

1. Type of sample (split spoon, shelly tube, etc.)
2. Thickness driven/thickness recovered
3. Blow count (per 6 in.), if driven
4. Depth interval

Descriptions of depth intervals tend to be more abbreviated than near-surface soil profile descriptions and apply to regular depth intervals rather than transitions between horizons (although such transitions should be noted and described). Features should be described in a consistent sequence. The following features, when present, should be described:

1. Texture (USDA and Unified estimated textures, coarse fragments)
2. Sorting and roundness
3. Moisture condition (moist, wet, dry, presence of water table)
4. Color and mottling
5. Consistency (rupture resistance, cementation)
6. Secondary porosity features
7. Sedimentary structures
8. Presence of organic matter
9. Effervescence in dilute, 10 percent cold HCl (calcareous parent material)
10. Visible presence of synthetic chemicals (oil, gasoline, solvents)
11. Reading from field instrumentation (photoionization or flame ionization detector)

Appendix A.2

General Protocol for Soil Sample Handling and Preparation

If questions arise in the field concerning sample handling and preparation procedures as specified in the Soil Sampling Plan for the site, this general protocol can be used. Any departures from procedures contained in the site Soil Sampling Plan should be documented and justified (see Form 4-1). The procedures described here generally apply to any type of soil sampling. They have been compiled primarily from procedures described in Brown et al. (1991). Specific procedures for different types of sampling tools are described in Appendices A.3 and A.4.

A.2.1 Soil Sample Collection Procedures for Volatiles

1. Tube samplers are preferred when collecting for volatiles. Augers should be used only if soil conditions make collection of undisturbed cores impossible. Soil recovery probes and augers, with dedicated or reusable liners (see Table 4-1), will minimize contact of the sample with the atmosphere.
2. Place the first adequate grab sample, maintaining and handling the sample in as undisturbed a state as possible, in 40-mL septum vials or in a 1-L glass wide mouth bottle with a Teflon[®]-lined cap. *Do not mix or sieve soil samples.*
3. Ensure the 40-mL containers are filled to the top to minimize volatile loss. Secure the cap tightly.
4. Examine the hole from which the sample was taken with an organic vapor instrument after each

sample increment. Record any instrument readings.

5. Label and tag sample containers, and record appropriate data on soil sample data sheets (depth, location, etc.).
6. Place glass sample containers in sealable plastic bags, if required, and place containers in iced shipping container. Samples should be cooled to 4°C as soon as possible.
7. Complete chain-of-custody forms and ship as soon as possible to minimize sample holding time (see Table A.1 for maximum holding times for various constituents).
8. Follow required decontamination and disposal procedures (see A.2.3).

A.2.2 Soil Sample Collection and Mixing Procedures for Semivolatiles and Metals

1. Collect samples.
2. If required, composite the grab samples, or use discrete grab samples.
3. If possible, screen the soils in the field through a precleaned O-mesh (No. 10, 2 mm) stainless steel screen for semivolatiles, or Teflon[®]-lined screen for metals (some metals in stainless steel could contaminate the sample).
4. Mix the sample in a stainless steel, aluminum (not suitable when testing for Al), or glass mixing container using the appropriate tool (stainless steel spoon, trowel, or pestle).
5. After thorough mixing, place the sample in the middle of a relatively inexpensive 1-m square piece of suitable plastic, canvas, or rubber sheeting.
6. Roll the sample backward and forward on the sheet while alternately lifting and releasing opposite sides or corners of the sheet.
7. After thorough mixing, spread the soil out evenly on the sheet with a stainless steel spoon, trowel, spatula, or large knife.

8. Take sample container and check that a Teflon[®] liner is present in the cap, if required (see Table A-1 for recommended sample containers for different contaminants).
9. Divide the sample into quarters, and take samples from each quarter in a consecutive manner until appropriate sampling volume is collected for each required container. Separate sample containers would be required for semivolatiles, metals, duplicate samples, triplicate samples (split), and spiked samples.
10. Secure the cap tightly. The chemical preservation of solids is generally not recommended.
11. Label and tag sample containers, and record appropriate data on soil sample data sheets (depth, location, other observations).
12. Place glass sample containers in sealable plastic bags, if required, and place containers in an iced shipping container. Samples should be cooled to 4°C as soon as possible.
13. Complete chain-of-custody forms and ship as soon as possible to minimize sample holding time (see Table A-1 for maximum holding times for various constituents). Scheduled arrival time at the analytical laboratory should give as much holding time as possible for scheduling of sample analyses.
14. Follow required decontamination and disposal procedures (see A.2.3).

A.2.3 Equipment Decontamination/Disposal

Decontamination procedures may vary from state to state and site to site. Detailed procedures should be specified in the Soil Sampling Plan. A very general procedure is outlined here:

1. Any disposable solid contaminated equipment (plastic sheets, screens, etc.) should be placed in plastic bags for temporary storage and sealed in metal barrels for final transport/disposal.
2. Reusable equipment should be washed and rinsed using decontamination procedures specified in the Soil Sampling Plan.

3. Collect swipes and decontamination blanks, if required, to evaluate the possibility of cross-contamination.

A.2.4 Air Drying

Samples collected for chemical analysis in the laboratory do not normally need to be air dried. However, air drying may be desired in the field for evaluation of soil physical and hydrologic properties. In some instances, air drying of contaminated samples involving semivolatiles and metals may be desired before sending samples to the analytical laboratory.

1. Weigh sample and record weight if percent moisture is required.
2. Spread out the soil sample on a stainless steel sheet and allow to air dry. This may take 3 days or more. If samples are to be analyzed for possible contaminants, samples should be placed so as to prevent possible cross-contamination. If they are to be analyzed for microbiological activity, samples should be placed in containers through which filtered air can be passed.
3. When dry, weigh and record weight if percent moisture is required.
4. Break up soil aggregates and pull apart vegetation and root mat, if present. Weigh nonsoil vegetation fraction, and archive or discard, as required.
5. Remove large rocks and weigh. Archive for possible analysis.
6. Crush the entire soil sample with a rolling pin, stainless steel spoon, or some similar tool. Blend with stainless steel spoon for 30 minutes.
7. Sieve through an O-mesh (No. 10, 2 mm) screen. Any type of screen is acceptable, if soils are not contaminated. Use disposable stainless steel (semivolatile contamination) or Teflon[®] (metal contamination) if soil samples are contaminated and the chemical integrity of the sample must be maintained.
8. Spread out the sample, mark off quarters, and take sample from each quarter in a consecutive manner until appropriate sample volume is collected.

- Archive remaining sample for future analysis, if needed.
9. When ready for shipment to the analytical laboratory, shake the sample to mix thoroughly.
 10. Follow required decontamination and disposal procedures (see A.2.3).

Table A-1. EPA Recommended Sampling Containers, Preservation Requirements, and Holding Times for Soil Samples

Contaminant	Container* Preservation**	Holding Time***
Acidity	P,G	14 days
Alkalinity	P,G	14 days
Ammonia	P,G	28 days
Sulfate	P,G	28 days
Sulfide	P,G	28 days
Sulfite	P,G	48 hours
Nitrate	P,G	48 hours
Nitrate-Nitrite	P,G	28 days
Nitrite	P,G	48 hours
Oil and Grease	G	28 days
Organic Carbon	P,G	28 days
Metals		
Chromium VI	P,G	48 hours
Mercury	P,G	28 days
Other Metals	P,G	6 months
Cyanide	P,G	28 days
Organic Compounds		
Extractables Including Phthalates, Nitrosamines, Organo- chlorine Pesticides, PCBs, Nitroaromatics, Isophorone, Polynuclear Aromatic Hydrocarbons, Haloethers, Chlorinated Hydrocarbons, and TCDD	G, Teflon®- lined cap	7 days until extraction 30 days after extraction

(Continued)

Table A-1. (Continued)

Contaminant	Container* Preservation**	Holding Time***
Extractables (Phenols)	G, Teflon®- lined cap	7 days until extraction 30 days after extraction
Purgables		
Halocarbons and Aromatics	G, Teflon®- lined septum	14 days
Acrolein and Acrylonitrile	G, Teflon®- lined septum	3 days
Orthophosphate	P,G	48 hours
Pesticides	G, Teflon®- lined cap	7 days until extraction 30 days after extraction
Phenols	G	28 days
Phosphorus	G	48 hours
Phosphorus, Total	P,G	28 days
Chlorinated Organic Compounds	G, Teflon®- lined cap	7 days

*P = polyethylene, G = glass.

**All samples cooled to 4°C. Sample preservation should be performed immediately upon sample collection. For composite samples, each aliquot should be preserved at the time of collection. When impossible to preserve each aliquot, then samples may be preserved by maintaining 4°C until compositing and sample splitting is completed.

***Samples should be analyzed as soon as possible after collection. The times listed are the maximum times that samples may be held before analysis and still be considered valid. Samples may be held for longer periods only if the analytical laboratory has data on file to show that the specific types of samples under study are stable for the longer time.

Source: Barth et al., (1989); for additional information, see Mason (1983).

Appendix A.3

General Protocol for Soil Sampling with a Spade and Scoop

The simplest and most direct method of collecting soil samples for subsequent analysis is with a spade and scoop. A normal lawn or garden spade can be used to remove the top cover of soil to the required depth, and then a smaller stainless steel scoop can be used to collect the sample.

This method can be used in most soil types, but is limited to sampling the near surface. Samples from depths greater than 50 cm become extremely labor intensive in most soil types. Very accurate, representative samples can be collected with this procedure depending on the care and precision demonstrated by the sampler. A flat, pointed mason trowel can be used to cut a block of soil when relatively undisturbed samples are desired. A stainless steel scoop or lab spoon will suffice in most other applications. Chrome-plating on instruments, common with garden implements such as potting trowels, should be avoided.

Procedure (drawn from Ford et al., 1984)

1. Clear the area to be sampled of any surface debris (twigs, rocks, litter). It may be advisable to remove the first 8 to 15 cm of surface soil for an area approximately 15 cm in radius around the drilling location to prevent near-surface soil particles from falling down the hole.
2. Carefully remove the top layer of soil to the desired sample depth with a precleaned spade.

3. Using a precleaned stainless steel scoop or trowel, remove and discard a thin layer of soil from the area which came in contact with the shovel.
4. Collect and handle sample using procedures described in A.2.1 (Soil Sample Collection Procedures for Volatiles) and A.2.2 (Soil Sample Collection and Mixing Procedures for Semivolatiles and Metals).

Appendix A.4

General Protocol for Soil Sampling with Augers and Thin-Walled Tube Samplers

Hand-held augers and thin-walled tube samplers can be used separately or in combination. Where rocky soils do not limit the use of tube samplers, a combination of augers to remove soil material to the depth of interest and tube samplers for actual sample collection allows the most precise control of sample collection. Depths to 2 meters can be readily sampled and up to 6 meters where conditions are favorable. Tables 4-1 and 4-2 provide information on the advantages and disadvantages of different types of augers and tube samplers for sampling under different soil conditions.

The recently developed in situ soil recovery auger and probe allow collection of samples in dedicated or reusable liners that reduce cross-contamination of samples and minimize contact with the atmosphere (see Table 4-1 and Appendix B).

Specific sampling tools may require slightly different handling methods. For example, if sampling devices and drill rod extensions do not have quick connect fittings, crescent or pipe wrenches may be required to change equipment configurations. The procedure described below is for hand-held equipment. Procedures for power-driven augers or tube samplers are essentially the same (drawn from Ford et al., 1984, and Brown et al., 1991).

1. Attach the auger bit to a drill rod extension and further attach the "T" handle to the drill rod.
2. Clear the area to be sampled of any surface debris (twigs, rocks, litter). It may be advisable to remove

the first 8 to 15 cm of surface soil for an area approximately 15 cm in radius around the drilling location to prevent near-surface soil particles from falling down the hole.

3. Begin drilling, periodically removing accumulated soils. This prevents accidentally brushing loose material back down the borehole when removing the auger or adding drill rods.
4. After reaching the desired depth, slowly and carefully remove auger from boring. When sampling directly from auger, collect sample after auger is removed from boring. Discard the upper portion of the sample, which may contain soil that has fallen to the bottom of the hole from the sidewalls. Proceed to sample handling and mixing procedures (see A.2.1 and A.2.2).
5. If taking a core sample, remove auger tip from drill rods and replace with a precleaned thin-walled tube sampler. Install proper cutting tip. (An optional step is to first replace the auger tip with a planer auger to clean out and flatten the bottom of the hole before using the thin-walled tube sampler.)
6. Carefully lower corer down borehole. Gradually force corer into soil. Care should be taken to avoid scraping the borehole sides. Hammering of the drill rods to facilitate coring should be avoided, as the vibrations may cause the bore walls to collapse.
7. Remove corer and unscrew drill rods.
8. Remove core from device (this may require removing cutting tip) and discard top of core (approximately 2.5 cm), to eliminate soil that may have fallen down from higher horizons.
9. Handle sample using procedures described in A.2.1 and A.2.2.

Appendix B

Manufacturers and Distributors of Soil Sampling Equipment

Table B-1. Manufacturers and Distributors of Soil Sampling Equipment (Compiled from Barrett et al., 1980; Ford et al., 1984; Rehm et al., 1985; SCS, 1983)

Supplier	Types of Samplers
Acker Drill Company P.O. Box 830 Scranton, PA 18501	Power-driven samplers
Art's Manufacturing and Supply (AMS) 105 Harrison American Falls, ID 83211 1/800/635-7330	Manual samplers In situ soil recovery auger and probe Planer auger
Boyle Brothers P.O. Box 25068 1624 Pioneer Road Salt Lake City, UT 84125	Power-driven samplers
Carl's Machine Shop and Supply Co. 1202 Main St. Woodward, OK 73801	Power-driven samplers
Mining Products Division Christensen Diamond Products Company 1937 S. 300 West Salt Lake City, UT 84115	Power-driven samplers

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Table B-1. (Continued)

Supplier	Types of Samplers
Clements Associates, Inc. RR 1 Box 186 Newton, IA 50208 515/792-8285	Manual samplers
Forestry Suppliers P.O. Box 8397 Jackson, MS 39284-8397	Manual samplers Clinometer
Gidding Machine Company 401 Pine Street P.O. Box 406 Fort Collins, CO 80521	Power-driven samplers
Hansen Machine Works 1628 North C Street Sacramento, CA 95814	Veihmeyer probe
Joy Manufacturing Company Montgomery Industrial Center Montgomeryville, PA 19936	Power-driven samplers
Longyear Company 925 Delaware Street, SE Minneapolis, MN 55414	Power-driven samplers
Mobile Drilling Company 3807 Madison Ave. Indianapolis, IN 46227	Power-driven samplers
Oakfield Apparatus Company P.O. Box 65 Oakfield, WI 53065	Manual samplers
Odgers Drilling, Inc. Ice Lake Road Iron River, MI 49935	Power-driven samplers
Penndrill Manufacturing Div. Pennsylvania Drilling Co. P.O. Box 8562 Pittsburgh, PA 15220	Power-driven samplers

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Table B-1. (Continued)

Supplier	Types of Samplers
Pitcher Drilling Company 75 Allemany Street Daly City, CA 94014	Power-driven samplers
Reed Tool Company 105 Allen Street P.O. Box 3641 San Angelo, TX 76901	Power-driven samplers
Reese Sale Company P.O. Box 645 2301 Gibson St. Bakersfield, CA 93302	Power-driven samplers
Sauze Technical Products Corp. 345 Cornelia St. Plattsburgh, NY 12901 518/561-6440	Eijkelpcamp stoney soil auger
Service Truck Body Shop 1259 Murray Alexandria, LA 71301	Manual samplers
Soilmoisture Equipment Corp. P.O. Box 30025 Santa Barbara, CA 93105 805/964-3525	Manual samplers
Soiltest, Inc. P.O. Box 931 2205 Lee Street Evanston, IL 60202 312/869-5500	Power-driven samplers Penetrometer Seives
Sprague and Henwood, Inc. 221 West Olive Street Scranton, PA 18501	Power-driven samplers
Wildco 301 Cass Street Saginaw, MI 48602 517/799-8100	Manual samplers