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Standard Guide for
Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Ground Water[1]

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INTRODUCTION

This guide covers the selection of the various ASTM Standards that are available for the investigation of soil, rock, the vadose zone, ground water, and other media where the investigations have an environmental purpose.[2] It is intended to improve consistency of practice and to encourage rational planning of a site characterization program by providing a checklist to assist in the design of an environmental reconnaissance/investigation plan. The subsurface conditions at a particular site are usually the result of a combination of natural geologic, topographic, hydrologic, and climatic factors, and of historical modifications both natural and manmade. An adequate and internally consistent site characterization program will allow evaluation of the results of these influences. Site characterization for engineering, design, and construction purposes are addressed in a separate guide, Guide D 420.

The understanding of environmental processes occurring in soil and rock systems depends on adequate characterization of physical, chemical, and biological properties of soil and rock. Processes of interest may include, but are not limited to, surface and subsurface hydrology, contaminant mobilization, distribution, fate and transport; chemical and biological degradation of wastes; and geomorphological/ecological processes. Although this guide focusses primarily on characterization of soil and rock, it is understood that climatic and biotic factors may also be important in understanding environmental processes in soil and rock systems.

1. Scope

1.1 This guide covers a general approach to planning field investigations that is useful for any type of environmental investigation with a primary focus on the subsurface and major factors affecting the surface and subsurface environment. Generally, such investigations should identify and locate, both horizontally and vertically, significant soil and rock masses and ground water conditions present within a given site area and establish the characteristics of the subsurface materials by sampling or in situ testing, or both. The extent of characterization and specific methods used will be determined by the environmental objectives and data quality requirements of the investigation. This guide focuses on field methods for determining site characteristics and collection of samples for further physical and chemical characterization. This guide does not address special considerations required for characterization of karst and fractured rock terrane. In such hydrogeologic settings refer to Quinlan and Guide D 5717, **(1)**.

1.2 This guide refers to ASTM standard methods by which soil, rock, vadose zone, and ground water conditions may be determined. Laboratory testing of soil, rock, and ground-water samples is specified by other ASTM standards which are not specifically discussed in this guide. Laboratory methods for measurement of physical properties relevant to environmental investigations are included in Appendix X1.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

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[1] This guide is under the jurisdiction of ASTM Committee D-18 on Soil and Rock and is the direct responsibility of Subcommittee D18.01 on Surface and Subsurface Characterization.

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[2] This guide is under the jurisdiction of Subcommittee D18.01 (Surface and Subsurface Characterization) of the Committee on Soil and Rock, and as such has a primary focus on subsurface characterization, including soil, rock, and fluids contained therein (including liquid and gaseous components), and subsurface biota. Surface hydrology, meteorology, air quality, geomorphic processes, biota, and waste materials (when present at a site) are to a greater or lesser extent linked to environmental processes in soil and rock systems. Consequently other ASTM methods of particular relevance to environmental site investigations are identified in this guide, but are addressed in less detail.

1.5 *This guide offers an organized collection of information or a series of options and does not recommend a specific course of action. This document cannot replace education or experience and should be used in conjunction with professional judgment. Not all aspects of this guide may be applicable in all circumstances. This ASTM standard is not intended to represent or replace the standard of care by which the adequacy of a given professional service must be judged, nor should this document be applied without consideration of a project's many unique aspects. The word "Standard" in the title of this document means only that the document has been approved through the ASTM consensus process.*

2. Referenced Documents

2.1 The pertinent ASTM guides for selection of field investigation methods are listed at appropriate points in the sections that follow, and a comprehensive list of guides, standards, methods, practices, and terminology is contained in Appendix X1. Table X1.1 and Table X1.2 provide an index of field and laboratory standards listed in Appendix X1.

2.2 *ASTM Standards:*

C 998 Practice for Sampling Surface Soil for Radionuclides[3]
D 420 Guide to Site Characterization for Engineering, Design, and Construction Purposes[4]
D 422 Test Method for Particle-Size Analysis of Soils[4]
D 653 Terminology Relating to Soil, Rock, and Contained Fluids[4]
D 1140 Test Method for Amount of Material in Soils Finer than the No. 200 (75-µm) Sieve[4]
D 1452 Practice for Soil Investigation and Sampling by Auger Borings[4]
D 1586 Test Method for Penetration Test and Split-Barrel Sampling of Soils[4]
D 1587 Practice for Thin-Walled Tube Geotechnical Sampling of Soils[4]
D 2113 Practice for Diamond Core Drilling for Site Investigation[4]
D 2434 Test Method for Permeability of Granular Soils (Constant Head)[4]
D 2487 Classification of Soils for Engineering Purposes (Unified Soil Classification System)[4]
D 2488 Practice for Description and Identification of Soils (Visual-Manual Procedure)[4]
D 2922 Test Methods for Density of Soil and Soil-Aggregate In Place by Nuclear Methods (Shallow Depth)[4]
D 3404 Guide for Measuring Matric Potential in the Vadose Zone Using Tensiometers[4]
D 3441 Test Method for Deep, Quasi-Static, Cone and Friction-Cone Penetration Tests of Soil[4]
D 3550 Practice for Ring-Lined Barrel Sampling of Soils[4]
D 3584 Practice for Indexing Papers and Reports on Soil and Rock for Engineering Purposes[4]
D 4043 Guide for Selection of Aquifer-Test Method in Determining of Hydraulic Properties by Well Techniques[4]
D 4044 Test Method (Field Procedure) for Instantaneous Change in Head (Slug Tests) for Determining Hydraulic Properties of Aquifers[4]
D 4050 Test Method (Field Procedure) for Withdrawal and Injection Well Tests for Determining Hydraulic Properties of Aquifer Systems[4]
D 4104 Test Method (Analytical Procedure) for Determining Transmissivity of Nonleaky Confined Aquifers by Overdamped Well Response to Instantaneous Change in Head (Slug Test)[4]
D 4105 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Modified Theis Nonequilibrium Method[4]
D 4106 Test Method (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of Nonleaky Confined Aquifers by the Theis Nonequilibrium Method[4]
D 4127 Terminology Used with Ion-Selective Electrodes[5]
D 4210 Practice for Interlaboratory Quality Control Procedures and a Discussion on Reporting Low Level Data[5]
D 4220 Practice for Preserving and Transporting Soil Samples[4]
D 4448 Guide for Sampling Groundwater Monitoring Wells[6]
D 4547 Practice for Sampling Waste and Soils for Volatile Organics[6]
D 4630 Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using the Constant Head Injection Test[4]
D 4631 Test Method for Determining Transmissivity and Storativity of Low Permeability Rocks by In Situ Measurements Using the Pressure Pulse Technique[4]
D 4687 Guide for General Planning of Waste Sampling[6]
D 4696 Guide for Pore-Liquid Sampling from the Vadose Zone[4]
D 4700 Guide for Soil Sampling from the Vadose Zone[4]
D 4750 Test Method for Determining Subsurface Liquid Levels in a Borehole or Monitoring Well (Observation Well)[4]
D 5079 Practices for Preserving and Transporting Rock Core Samples[7]
D 5084 Test Method of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter[7]
D 5092 Practice for Design and Installation of Ground Water Monitoring Wells in Aquifers[7]
D 5093 Test Method for Field Measurement of Infiltration Rate Using a Double-Ring Infiltrometer With a Sealed-Inner Ring[7]
D 5195 Test Method for Density of Soil and Rock In-Place at Depths Below the Surface by Nuclear Methods[7]
D 5254 Practice for Minimum Set of Data Elements to Identify a Ground-Water Site[7]
D 5269 Test Method for Determining Transmissivity of

[3] *Annual Book of ASTM Standards*, Vol 12.01.
[4] *Annual Book of ASTM Standards*, Vol 04.08.
[5] *Annual Book of ASTM Standards*, Vol 11.01.
[6] *Annual Book of ASTM Standards*, Vol 11.04.
[7] *Annual Book of ASTM Standards*, Vol 04.09.

Nonleaky Confined Aquifers by the Theis Recovery Method[7]

D 5270 Test Method for Determining Transmissivity and Storage Coefficient of Bounded, Nonleaky, Confined Aquifers[7]

D 5314 Guide for Soil Gas Monitoring in the Vadose Zone[7]

D 5408 Guide for Set of Data Elements to Describe a Ground-Water Site; Part 1—Additional Identification Descriptors[7]

D 5409 Guide for Set of Data Elements to Describe a Ground-Water Site; Part 2—Physical Descriptors[7]

D 5410 Guide for Set of Data Elements to Describe a Ground-Water Site; Part 3—Usage Descriptors[7]

D 5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem[7]

D 5451 Practice for Sampling Using a Trier Sampler[6]

D 5717 Guide for the Design of Ground-Water Monitoring Systems In Karst and Fractured-Rock Aquifers[4]

E 177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods[8]

E 380 Practice for Use of the International System of Units (SI) (The Modernized Metric System)[8]

E 1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process[6]

G 57 Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method[9]

2.3 *Non-ASTM References*—Appendix X2 identifies major non-ASTM references that focus on field methods for environmental site characterization. Other guidance documents covering procedures for environmental investigations with specific objectives or in particular geographic settings may be available from federal, state, and other agencies or organizations. The appropriate agency or organization should be contacted to determine the availability and most current edition of such documents.

3. Terminology

3.1 *Definitions:* [10]

3.1.1 *site*, *n*—a place or location designated for a specific use, function, or study.

3.1.2 *site*, *v*—to determine a place or location for a specific use, function, or study.

3.1.3 *characterization*, *n*—the delineation or representation of the essential features or qualities existing at a site.

3.1.4 *characterize*, *v*—the process of delineation or representation of the essential features or qualities existing at a site.

3.1.5 *conceptual site model*, *n*—for the purposes of this guide, a testable interpretation or working description of the relevant physical, chemical, and biological characteristics of a site.[11]

3.1.6 *environment*, *n*—the aggregate of conditions, influences, and circumstances that affect the existence or development of properties intrinsic to a site.

3.1.7 *environmental*, *adj*—having to do with the environment.

3.1.8 *environmental site characterization*, *n*—the delineation or representation of the essential features or qualities, including the conditions, influences, and circumstances, existing at a place or location designated for a specific use, function, or study.[12]

3.1.9 *environmental audit*, *n*—the investigation process to determine if the operations of an existing facility are in compliance with applicable environmental laws and regulations.

3.1.10 *environmental site assessment (ESA)*, *n*—the process by which a person or entity seeks to determine if a particular parcel of real property (including improvements) is subject to recognized environmental conditions.[13]

3.2 In addition to Terminology D 653, Appendix X3 identifies major references from a range of disciplines that can be used as sources for definitions of terms that are related to environmental site characterization.

4. Significance and Use

4.1 This guide provides a general approach to environmental site characterization. Environmental site characterization provides information for a wide variety of uses including:

4.1.1 Determination of ambient background or baseline conditions, including, but not limited to, geochemistry, hydrogeology, microbiology, mineralogy, and water quality.

4.1.2 Assessment of site suitability for a future use or a use which may be compromised by site characteristics, such as flooding, seismic activity, and landslides (mass wasting).

4.1.3 Protection of site quality from the detrimental effects of human activities and natural processes, or minimization of adverse environmental impacts. Specific examples of uses of environmental site characterization for these purposes include: (*1*) delineation of ground-water or wellhead protection areas,

[8] *Annual Book of ASTM Standards*, Vol 14.02.

[9] *Annual Book of ASTM Standards*, Vol 03.02.

[10] The first seven definitions are ordered logically to illustrate construction of the definition for *environmental site characterization* rather than in alphabetical order.

[11] The meaning of conceptual site model may have more restricted or specific meanings depending on the objective or use of the model. For example, ground water flow modeling focuses on the physical characteristics as they relate to subsurface flow (see Guide D 5447), and a conceptual site model for the purpose of risk assessment will focus on contaminant sources, pathways, and receptors to exposure.

[12] Environmental audits and environmental site assessments as defined below are examples of environmental site characterization with specific objectives.

[13] This definition is taken from Practice E 1527. Other definitions of environmental site assessment may apply in other contexts. For example, EPA's Site Assessment Branch, Hazardous Site Evaluation Division in the Office of Emergency and Remedial Response defines site assessment as the decision process for identifying the most seriously contaminated uncontrolled hazardous waste sites that will receive funding for long-term remediation. Practice E 1527 defines *recognized environmental conditions* as "the presence or likely presence of any hazardous substances or petroleum products on a property under conditions that indicate an existing release, a past release, or a material threat of a release of any hazardous substances or petroleum products into structures on the property or into the ground, ground water, or surface water of the property." In other environmental site investigations, nonhazardous substances (because of their physical condition, smell, or other aesthetic properties) or substances that have hazardous characteristics but do not meet a regulatory definition of hazardous may be the focus of concern.

(*2*) assessing the suitability of sites for disposal of industrial and residential liquid and solid wastes, (*3*) assessing soil suitability for land treatment of wastes, and (*4*) evaluating soil suitability for agricultural practices in order to minimize soil erosion and contamination from agricultural chemicals.

4.1.4 Assessment of the type, distribution, and extent of surface and subsurface contamination to determine compliance; risk to human health and the environment; and responsibility for remediation. Such assessments include: (*1*) sites involved in real estate transactions, (*2*) controlled and uncontrolled hazardous waste sites, (*3*) controlled and uncontrolled municipal solid waste, wastewater, and other nonhazardous waste disposal sites.

4.1.5 Assessment of surface and subsurface environmental processes that affect the fate, mobilization, and rate of transport of natural and anthropogenic chemicals in the subsurface.

4.1.6 Assessment of the type, distribution, and extent of natural and anthropogenic radioactive elements in the subsurface.

4.1.7 Assessment of the degree of risk that adverse subsurface site conditions not related to 4.1.4 and 4.1.5 pose to human health and safety or the natural ecosystem.

4.1.8 Selection and design of remediation systems for cleanup of subsurface contamination and of other reclamation or rehabilitation practices on disturbed land.

4.2 This guide is meant to be a flexible description of investigation requirements; methods defined by other ASTM Standards (Appendix X1) or non-ASTM techniques (Appendix X2) may be appropriate in some circumstances. The methods and amount of effort required for environmental site characterization will vary with site conditions and objectives of the investigation. This standard does not set mandatory guidelines and does not constitute a list of necessary steps or procedures for all investigations. In karst and fractured rock hydrogeologic settings, this guide should be used in conjunction with Guide D 5717.

5. Steps in Planning and Conducting Environmental Site Characterization

5.1 The following minimum elements, not necessarily in sequential order, are required for most environmental site investigations to determine project and site strategy:

5.1.1 Definition of objectives, site boundaries,[14] and other information necessary for efficient project planning.[15]

5.1.2 Collection of available existing data and information about the site, pertinent to the objectives of the investigation.[16]

5.1.3 Development of one or more conceptual site models of the site from existing information. The objectives of the investigation will affect the type and complexity of site conceptualization.

5.1.4 Performance of a reconnaissance site investigation, that may include nondestructive geophysical methods, and relatively simple field sampling and characterization methods,[17] to refine the conceptual model of the site.

5.1.5 Development of a detailed site investigation and sampling plan, that identifies methods to be used to collect and analyze required additional data, protocols for sampling and field measurements, and procedures to ensure quality assurance

[14] The boundaries of a site are defined using one or more of the following considerations: (*1*) land ownership, (*2*) current and past land use, (*3*) natural site characteristics (topography, soils, geology, hydrology, biota). Where site boundaries are initially defined by ownership, natural site characteristics should be evaluated to determine whether the scope of at least parts of the investigation should include areas that are offsite. For example, investigations of ground water contamination should include identification of any potential sources of contamination that are upgradient from a site.

[15] This should include, but not necessarily be limited to: (*1*) definition of the technical and scientific approach to be used, (*2*) organization of a data management system, including both paper and electronic records, (*3*) identification of types of personnel and technical expertise, appropriate ASTM and other methods and field equipment required to meet the defined objective, (*4*) defining how spatial data will be recorded (see Section 7.1.3), (*5*) identification of applicable primary and secondary regulatory programs, and any required coordination with government agencies and other organizations, (*6*) development of health and safety plans, where appropriate, (*7*) identification of scheduling and budgetary constraints, (*8*) definition of data quality requirements for each stage of the investigation, (*9*) identification of deliverables at intermediate stages of the investigation and upon completion, (*10*) selection of performance measures to determine whether the objective has been achieved, and (*11*) definition of project decision statements.

[16] A site visit prior to extensive collection of existing data should be made unless the limited scope of a project does not allow multiple visits. The advantage of such a visit is that it may prevent preconceived ideas derived from inaccurate existing information from influencing initial conceptual site model development.

[17] When contaminated sites are being investigated, field chemical analytical methods can be valuable for identifying areas where more detailed investigations may be required, and for designing cost-effective detailed sampling and monitoring plans. Surface geophysical methods may be especially valuable for guiding placement of exploratory drillholes and placement of vadose zone and ground water monitoring installations. Any such field methods should be documented for quality assurance and quality control.

and quality control of site characterization data. Criteria defining the quality of data that are collected is a requirement for most environmental site investigations.[18]

5.1.6 Collection of field samples and measurements in accordance with the site investigation and sampling plan.[19]

5.1.7 Analysis of field and laboratory data to further refine the conceptual model of the site and preparation of a report that fulfills the objectives of the investigation.

5.2 Environmental site characterization is an iterative process of continually refining a conceptual site model of a site as new information becomes available. The objective of the investigation and availability of funds to carry out the investigation will affect the final number of iterations that are possible. For example, a Phase I Environmental Site Assessment (Guide E 1527) for a real estate property transaction may require only a single site visit to evaluate whether any activities may have resulted in contamination of the site. Complex sites, however, may require multiple site visits to collect data in order to develop a satisfactory conceptual model of the site, especially if a human health and environmental risk assessment is required. The number of site visits may be reduced by on-site analysis of results and real-time adjustments to the site investigation plan (see Section 7).

5.2.1 Planning for environmental site investigations should recognize that regional and local differences in climate, biota, soils, geology, and hydrology will influence the selection of appropriate methods and procedures.

5.2.2 Urban settings create special challenges for planning environmental site investigations. Difficulties include busy streets, access to public and private property, especially occupied buildings and fenced areas, and determining predisturbance background environmental conditions. Consult with local agencies and private property owners for relevant information. Select methods and schedule activities accordingly.

6. Collection of Existing Data and Site Reconnaissance

6.1 Collect and review available technical data from the literature and historical records, and conduct interviews before any field program is started. These include, but are not limited to, topographic maps, aerial photography, satellite imagery, geologic maps, statewide or county soil surveys, and mineral resource surveys covering the proposed project area. Reports of subsurface investigations of nearby or adjacent projects should be studied. If feasible, all existing data should be critically evaluated and independently confirmed.

6.1.1 The Natural Resource Conservation Service (formerly U.S. Soil Conservation Service) and the Agricultural Stabilization and Conservation Service (ASCS) are the primary sources of aerial photographs at the county level. The U.S. Geological Survey is the primary source for satellite imagery, and agencies other than SCS (USGS EROS Data Center).[20] Aerial photographs also may be available from the following federal agencies where lands under their jurisdiction are involved: Bureau of Land Management, Bureau of Reclamation, U.S. Army Corps of Engineers, U.S. Environmental Protection Agency Photo-Interpretation Center (EPIC), U.S. Forest Service, and U.S. Fish and Wildlife Service. State natural resource agencies and local/regional planning agencies also may be good sources of aerial photographs.[21,22] Guide D 5518 provides additional information of how to obtain air photos.

6.1.2 The United States Geological Survey and the geological surveys of the various states are the principal sources of geologic maps, reports on mineral resources, ground water, and surface water.[23] Guidebooks prepared by professional associations, technical journals, and published conference and symposium proceedings may also be important sources of information.

6.1.3 United States Department of Agriculture Soil Conservation Service soil surveys, where available and of recent date, should enable the investigator to estimate the range in soil profile characteristics to depths of 1.5 or 2 m (5 or 6 ft) for each soil mapped.[24]

6.1.4 Preliminary information on sites where commercial and industrial activity has occurred should include site history, such as type of activity, location of existing surface and subsurface building, and chemicals, manufactured, used, or stored at the site.[25]

[18] The level of data accuracy and precision needed to meet the intended use for the data must be determined and this constitutes the "data quality requirements" referred to in this guide. The term data quality requirements is similar to the term data quality objectives (DQOs) used to describe the quality determination process in the U.S. EPA RCRA/Superfund program, but does not necessarily include statistically based confidence levels for assessing false negative or false positive designations. For chemical characterization, data quality requirements may vary depending on the phase of the investigation. For example, relatively inexpensive field instrumentation such as colorimetric test kits, or portable gas chromatographs can be used to analyze a relatively large number of samples initially to identify areas with different levels of contamination. Data requirements at this level would specify that instrumentation used be capable only of detecting the presence of a contaminant at or above the regulatory level of concern. These results in turn would guide sampling of a moderate number of samples for more accurate field analytical methods or a mobile laboratory. Finally, a relatively small number of samples might be selected for analysis that would meet the rigorous data quality requirements of EPA's contract laboratory program (CLP). This phased approach has the potential for significant cost and time savings as compared to the use of CLP laboratories for the analysis of all samples.

[19] Prior to commencement of any intrusive exploration the site should be checked for underground utilities or other buried materials. Should evidence of potentially hazardous or otherwise contaminated materials or conditions be encountered in the course of the investigation, work should be interrupted until the circumstances have been evaluated and revised instructions issued before resumption.

[20] USGS EROS Data Center, Sioux Falls, SD 57198.

[21] The following references on air-photo interpretation may be of value: Avery **(2)**,[22] Ciciarelli **(3)**, Denny et al **(4)**, Drury **(5)**, Dury **(6)**, Johnson and Gnaedigner **(7)**, Lattman and Ray **(8)**, Lueder **(9)**, Miller and Miller **(10)**, Ray **(11)**, SCS **(12)**, Strandberg **(13)**, Wright **(14)**.

[22] The boldface numbers in parentheses refer to a list of references at the end of the text.

[23] Sun and Weeks **(15)** provide a comprehensive bibliography of the U.S. Geological Survey's regional aquifer systems analysis program. Data from the RASA program are being synthesized and published in the Ground Water Atlas of the United States **(16)**.

[24] Each soil type has a distinctive soil profile due to age, parent material, relief, climatic condition, and biological activity. Consideration of these factors can assist in evaluating the potential for movement of contaminants in the vadose zone and ground water based on differing soil characteristics. Boulding **(17)** and Cameron **(18)** provide guidance on interpretation of soil properties in relation to potential for contaminant transport. Changes in soil properties in adjacent areas often indicate changes in parent material or relief.

[25] Practice E 1527 and Practice E 1528 provide guidance on the types of information that should be collected and sources from which such information can be obtained.

6.2 Study the soil and rock in the vicinity of the proposed project in areas where descriptive data are limited by insufficient or inadequate geologic or soil maps. Take advantage of all exposures of the rock and soil to obtain the best understanding of them. Obtain information on both vertical and horizontal properties of the materials and their distribution. Make appropriate notes and, where appropriate, illustrate by sketches. The notes should include data outlined in 9.3.[26]

6.3 Prepare and compile preliminary maps of the project area using aerial photography and topographic maps that show ground conditions. The scale of the map should be appropriate for the area being investigated. Aerial photographs and topographic maps at scales of 1:15 000 to 1:24 000 are available for most parts of the United States and are usually adequate as a basis for a preliminary map of sites covering tens to hundreds of acres. The distribution of the predominant soil and rock deposits likely to be observed during the investigation may be shown using data obtained from geologic maps, landform analysis, and limited ground reconnaissance. Experienced photointerpreters can deduce much subsurface data from a study of black-and-white, color, and color-infrared photographs because similar soil or rock conditions, tend to have similar patterns of appearance in regions of similar climate or vegetation.[27]

6.4 Perform site reconnaissance. This provides an opportunity to check the accuracy of information compiled from existing sources, and to make site observations to assist in refining the conceptual model of the site. Site reconnaissance should be planned to identify the site characteristics needing further investigation.[28]

7. Detailed Site Investigation

7.1 Review objectives of the investigation and develop a detailed site investigation plan. The detailed site investigation plan should clearly identify the types of data that are required to meet the objectives of the investigation.[29] A complete environmental site investigation will usually encompass the following activities:[30]

7.1.1 Review available information, both regional and local, on the geologic history (including seismic activity and other potential geologic hazards), rock, soil, ground water, surface water, and other significant environmental and anthropogenic features (for example, buried utilities) occurring at the proposed location and in the immediate vicinity of the site.

7.1.2 Interpret aerial photography and other remote sensing data.

7.1.3 Select appropriate methods for locational data collection coincident with field observations and sampling.[31] Failure to accurately locate elevation and *x-y* coordinates of observation points and samples can severely compromise the accuracy of interpretations developed from the data. Where geographic information systems (GIS) are to be used for data management, analysis and visualization, locational accuracy should at a minimum satisfy the resolution of the system to be used.

7.1.4 Perform field reconnaissance for identification of surficial geologic and hydrologic conditions, mapping of stratigraphic or lithologic exposures and outcrops, mapping of vegetation and other significant ecological conditions, and examination of anthropogenic features at the site.

7.1.5 Perform on-site investigation of the surface and subsurface materials by geophysical surveys, borings, or test pits.

7.1.6 Obtain representative samples for chemical, biological, and physical analysis of soil, rock, and ground water. When required for the objectives of the investigation, these should be supplemented by samples suitable for the determination of in situ physical and chemical properties, such as hydraulic conductivity and flow-through sorption tests (see 11.2). Measurement of in situ properties requires collection of undisturbed samples (see definitions in Terminology D 653). Where present, wastes and sediments from surface water bodies should also be sampled.

7.1.7 Perform field identification of soil, sediments, and rock with particular references to physical and chemical properties, such as, but not limited to, color, odor, texture (grain-size distribution), mineralogy, zone of increased or reduced porosity and permeability, depth of occurrence, and the types and locations of structural discontinuities.

7.1.8 Identify and measure the potentiometric surface(s) of the aquifer or aquifers. Methods for determining ground-water levels are covered in Test Method D 4750. The variability of these positions in both short (minutes to days) and long

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[26] The following major references may be useful for field geologic and hydrogeologic investigations: Bishop **(19)**, Brassington **(20)**, Bureau of Reclamation **(21, 22)**, Compton **(23, 24)**, Dutro, et al **(25)**, Erdélyi and Gálfi **(26)**, Fetter **(27)**, Lahee **(28)**, LeRoy, et al **(29)**, Low **(30)**, Rahn **(31)**, Tearpocke and Bischke **(32)**. Guides for field description of rocks include: Fry **(33)**, Thorpe and Brown **(34)**, and Tucker **(35)**.

[27] This preliminary map may be expanded into a detailed site map by locating all test holes, pits, and sampling stations and by revising boundaries as determined from the detailed subsurface survey. Geographic information systems (GIS) should be considered for visualization, map preparation, data manipulation, and analysis.

[28] Exploratory sampling of soil solids, soil gas, or ground water using temporary in situ samplers may provide useful information for design of the sampling plan in the detailed site investigation plan. Surface geophysical methods may also be useful at this stage of the investigation.

[29] Considerations for identifying data requirements include: (*1*) data required to comply with applicable federal, state, or local regulatory programs, (*2*) data required as inputs to computer models expected to be used, (*3*) data required for selection and design of implementation measures (that is, protective measures at controlled waste disposal sites, remediation options at contaminated sites).

[30] Examples of investigations that may not require all of the activities in this section include environmental site assessments for real estate property transactions that do not identify recognized environmental conditions using Practice E 1527 Phase 1 Assessment Process or Practice E 1528 Transaction Screen Process, and Environmental Audits to assess presence or degree of lead or asbestos contamination in a building.

[31] The U.S. EPA **(36)** requires latitude/longitude determination for all agency-sponsored data collection and activities that define or describe environmental characteristics about a site. The U.S. EPA **(37)** provides guidance to selecting latitude/longitude determination methods. Global positioning systems (GPS) are used for locating field observation points when accuracy on the order of tens of meters is sufficient, which is sufficient for many GIS applications (U.S. EPA, **(38)**). Other coordinate systems (such as *x-y* coordinates referenced to a known datum, State Plane, UTM) can also be used if more convenient in the field, and converted to latitude and longitude, if required.

(months to years) time frames should be considered.[32]

7.1.9 Assess vertical and horizontal variations in the pedologic, geologic, and hydrologic characteristics of the subsurface, including the vadose zone, aquifers, and confining units. When the flow direction and velocity of ground water are concerns, special emphasis should be placed on evaluating the degree of aquifer anisotropy, presence of highly permeable unconsolidated materials such as sands and gravels, extent and orientation of soil joint and rock fracture development, and extent of conduit development in karst limestone. Where unconsolidated materials consist of thick loess, alluvial, lacustrine materials, or glacial till, the spacing and depth of vertical soil jointing should be evaluated as potential zones of preferential contaminant movement **(42)**. Guide D 5717 identifies methods for characterization of karst and fractured rock aquifers.

7.1.10 Assess temporal changes in subsurface hydrologic conditions, including changes in ground-water levels using piezometers or monitoring wells, changes in soil moisture conditions using tensiometers (see Guide D 3404), neutron soil moisture probes (see Test Method D 5093) or other methods, and measurement or estimation of soil moisture flux. Changes in soil solute quality using suction lysimeters and other methods (see Guide D 4687).

7.1.11 Identify type and extent of contaminants, if present, and identify and assess the geochemical characteristics of subsurface solids and ground water that may affect the fate and transport of contaminants. Temporal changes in soil pore liquids and ground-water quality should be characterized by periodic sampling from monitoring wells installed in accordance with standard procedures (see Guide D 4696—pore liquids, and Practice D 5092—ground-water monitoring wells). Important geochemical characteristics include organic matter content, clay mineralogy, pH, Eh, specific conductance, and temperature.[33]

8. Use of Field Methods in Environmental Site Characterization

NOTE 1—All field procedures should be documented by identifying time, date, location, and personnel involved. Practice D 5254 identifies additional basic information required for documentation. Guide D 5408, Guide D 5409, and Guide D 5410 can serve as checklists to ensure that important additional information is not omitted. Paragraph 7.1.3 contains additional discussion of locational data considerations.

8.1 Equipment and procedures used in site characterization for environmental purposes can be classified in the following general categories:

8.1.1 Indirect observation of surface and subsurface conditions using remote sensing techniques and geophysical surveys (see Section 9),

8.1.2 Direct observation of subsurface conditions and field description using visual-manual procedures (see Section 10),

8.1.3 Sampling for further physical, chemical, and biological testing and analysis (see Section 11), and

8.1.4 In situ testing of soil, rock, vadose zone, and aquifer characteristics (see Section 12).

8.2 Many test methods and procedures are potentially applicable to environmental site investigations.[34] Factors to consider when selecting equipment and procedures for a site investigation include:

8.2.1 *Objectives and Data Quality Requirements of the Investigation*—For example, a Phase I Environmental Site Assessment may require only simple, hand-held equipment. On the other hand, site investigations for suitability for long-term storage of high-level radioactive wastes involve complex and sophisticated instrumentation and testing.

8.2.2 *Characteristics of the Site*—Soils and geology of the site and properties of known or suspected contaminants will influence the type of drilling methods used and selection of sampling equipment. Different aquifer test procedures and analytical methods are required based on aquifer characteristics such as degree of confinement, presence of nearby hydrologic boundaries, and how much of an aquifer is intersected by the central test well.

8.2.3 *Characteristics of the Equipment or Method*—When several alternatives are available to achieve a given objective a number of factors should be considered in selecting equipment and methods. Equipment available from commercial sources is generally preferable to homemade equipment because specifications can be readily documented and replacement parts can usually be obtained quickly and be used without affecting the comparability of results with the broken equipment. Equipment with the greatest durability and reliability is preferable. Standard ASTM test methods or standard operating procedures and protocols established by government agencies should be used whenever applicable. The timeliness of results is another important consideration when selecting equipment or methods. Methods that provide real-time data that fulfill data quality requirements are preferable to methods that require use of offsite laboratories. Special circumstances may require use of uncommon or nonstandard equipment, methods, or procedures. The use of such equipment and procedures should be justified in the detailed site investigation plan.

8.2.4 *Cost of the Equipment or Method*— All factors affecting cost should be considered before selecting equipment or methods. For example, the higher initial cost of using dedicated samplers for ground-water monitoring wells may be more cost-effective in the long run as a result of reduced sample collection costs.

8.3 Equipment and standard operating procedures (SOPs) should be identified in the detailed site investigation plan. Equipment design and specifications should be documented and standard operating procedures defined. Any departures

[32] Other methods in addition to direct water level measurements may be useful for characterizing depth to water table. For example, description of the color, depth, and patterns of mottling of soil horizons may be indicative of long-term seasonal high ground water positions. Boulding **(39)** and Vepraskas **(40)** describe methods recently adopted by the Soil Survey Staff **(41)** for description and interpretation of morphologic features indicative of soil wetness. At contaminated sites, color variations can also be chemically induced or the result of staining.

[33] Microorganisms in soil and ground water may play a significant role in the transport and fate of inorganic constituents (such as nitrate, sulfate, and redox sensitive species, such as iron, manganese, arsenic, chromium, and selenium) and organic chemicals. Table X1.2 identifies ASTM methods for characterization of microorganisms and biodegradation potential.

[34] A recent EPA report, **(43)** provides information on more than 280 methods.

from equipment and procedures defined in the site investigation plan should be documented and justified.

9. Field Methods: Remote Sensing and Geophysical Surveys

9.1 Remote sensing techniques may assist in mapping the geological formations and for evaluating variations in soil and rock properties. Satellite and airborne mapping methods, such as multispectral imagery obtained from the LANDSAT platform and SLAR (side-looking airborne radar imagery), may be used to find and map the areal extent of subsurface materials and geologic structure. Interpretation of aircraft photographs and satellite imagery may locate and identify significant geologic features that may be indicative of faults and fractures. Interpretation of aerial photography taken at different times can identify changes in land use and identify areas that have been disturbed by human activity. Some ground control is generally required to verify information derived from remote sensing data.

9.2 Surface geophysical investigations can be a useful guide in the placement of boring, test hole, vadose zone, and monitoring well locations. Surface geophysical methods are essential at most contaminated sites to avoid hazardous drilling locations. Surface geophysical methods, together with push technologies (see 10.1.5), are especially valuable for ensuring that permanent monitoring well locations intercept contaminant plumes and that background reference wells reflect uncontaminated conditions. Interpretation of surface geophysical surveys should be verified by borings or test excavations, or confirmed by different types of geophysical measurements. Surface and borehole geophysical measurements provide a useful supplement to borehole and outcrop data and assist in interpolation between holes. Seismic, ground penetrating radar, electrical resistivity and electromagnetic methods can be particularly valuable when distinct differences in the physical or electrochemical properties of contiguous subsurface materials are indicated.[35]

9.3 Major applications of surface geophysical methods for environmental site characterization include:[36]

9.3.1 Ground penetrating radar may be useful in defining soil and rock layers, water table, and man-made structures in the depth range from ⅓ to 10 m (1 to 30 ft).

9.3.2 Electromagnetic induction, electrical resistivity, and induced polarization (or complex resistivity) techniques can be used to map variations in water content, clay horizons, stratification, depth to aquifer/bedrock, and conductive contaminant plumes.[37]

9.3.3 The shallow seismic refraction method can be used to map soil horizons, stratigraphic depth profiles, and water tables. It can be especially useful in determining depth of unconsolidated material where bedrock is at a depth of 30 m or less.

9.3.4 The seismic reflection method may be useful in delineating geological units at depths below 15 to 30 m (50 to 100 ft). It is not constrained by layers of low seismic velocity and is especially useful in areas of rapid stratigraphic change.

9.3.5 Magnetic surveys may be useful for detecting the presence of subsurface ferrous materials within 1 to 3 m of the ground surface.

9.4 Borehole geophysical methods can be used to obtain information on lithology, stratigraphy and formation properties, aquifer properties, ground-water flow and direction, borehole fluid characteristics, contaminant characterization, and borehole/casing characterization. Major categories of borehole logging methods include: (*1*) electrical and electromagnetic, (*2*) nuclear, (*3*) acoustic and sonic, and (*4*) miscellaneous methods, such as caliper, temperature, and borehole flowmeters. Considerations in the selection of borehole logging methods include, but are not limited to, (*1*) diameter of the borehole, (*2*) presence or absence and type of casing, (*3*) presence or absence and type of borehole fluid; and (4) characteristics of the subsurface formations.[38]

9.5 All geophysical methods require site conditions that provide contrasts in the subsurface property being measured by the method, and, depending on the method, may be subject to interferences at a site, such as metal fences, powerlines, FM radio transmission, or ground vibrations. The depth of penetration and interference effects are highly site specific. Depth penetration and resolution vary with local conditions. Data collection and interpretation for geophysical surveys require skilled personnel familiar with the principles and limitations of the method being used.

10. Field Methods: Direct Observation of Subsurface Conditions[39]

10.1 The type of equipment required for an intrusive subsurface investigation depends upon various factors including, but not limited to, the type of subsurface material, the depth of exploration, the nature of the terrain, the intended use of the data, and prevention of cross-contamination of aquifers.[40] Identify the location of buried utility lines, pipes, and any other

[35] Major references that address use of surface geophysical methods for environmental site characterization include: Benson et al **(44)**, Boulding **(45)**, Haeni **(46)**, Ward **(47,48)**, and Zohdy et al **(49)**.

[36] Depth ranges indicated here and for other geophysical methods are typical ranges for instruments available at the time this guide was written and intended to give a general idea of the capabilities of different methods. Actual depth penetration at a particular site is dependent on site conditions, instrumentation used for field measurements, and methods used to analyze the signal data. Depth of penetration can also increase with improved instrumentation and signal analysis methods.

[37] Test Method G 57 is intended for use in the control of corrosion in buried structures. Use of the electrical resistivity method in environmental investigations involves field procedures and data interpretation that differ substantially from the procedures outlined in this guide.

[38] Major references that address use of borehole geophysical methods for environmental site characterization include: Boulding **(45)**, Keys **(50)**, Keys and MacCary **(51)**, and Respold **(52)**.

[39] Major references on borehole drilling methods for direct observation of the subsurface and for installation of ground-water monitoring wells include: Aller et al **(53)**, Eggington et al **(54)**, Clark **(55)**, Driscoll **(56)**, Harlan et al **(57)**, Lehr et al **(58)**, Roscoe Moss Company **(59)**, Ruda and Bosscher **(60)**, and Shuter and Teasdale **(61)**.

[40] Plans for a program of intrusive subsurface investigation should check whether there are requirements for licensing of installers and permits for installation and proper closure of bore holes and wells at the completion of the investigation.

subsurface anthropogenic features using maps or geophysical methods (9.2) prior to drilling.

10.1.1 Hand augers, hole diggers, shovels, and push tube samplers are suitable for exploration of surficial soils to depths of 1 to 5 m (3 to 15 ft).

10.1.2 Earth excavation equipment, such as backhoes, draglines, and drilled pier augers (screw or bucket) can allow in situ examination of soil deposits and sampling of materials containing cobbles and boulders.

10.1.3 In soil and unconsolidated material hollow-stem augers are commonly used for collection of geoenvironmental samples and installation of monitoring wells. Hollow-stem augers commonly reach depths of up to 45 m (about 150 ft) and large auger rigs can reach depths of up to 100 m (about 330 ft) under favorable conditions.[41] Greater depths are possible in unconsolidated material if casing advancement methods are used. Sections 11.2.2 and 11.2.3 identify ASTM methods for collection of unconsolidated material samples.

10.1.4 For bedrock and for deep unconsolidated material, well drilling equipment such as rotary and cable tool systems is usually required. Normally samples are collected in the form of sand sized cuttings captured from the return flow, which generally are not adequate for environmental site characterization but other methods of determining stratigraphy, such as borehole geophysical logging methods are available (see Section 9.4). Diamond rotary coring (see Practice D 2113) is the preferred method of obtaining samples for physical property testing and geologic characterization of rocks. Diamond drills are effective to depths of up to 600 m or more, even in extremely strong igneous and metamorphic rocks. As depths in unconsolidated material increase, sampling devices attached to drill rods become increasing cumbersome due to the time required to lower and retrieve the sampler. Wireline soil sampling, in which the sampler is lowered, driven, and retrieved on a wireline through the drill pipe, allows retrieval of samples at frequent intervals and provides for prompt visual identification of soil texture and subsurface features (Section 10.3). More commonly wireline systems are used for rock coring. Various factors affect the depth at which wireline sample becomes more cost effective than drill-rod attached sampling devices, including the length of the core barrel, the height of the mast on the rig being used, the number of hoist lines available for handling sampling tools and the hardness of the rock. The breakeven point for the two methods typically ranges between 15 m (50 ft) and 45 m (150 ft). As hole depths increase, cost savings using wireline sampling methods increase. Reduced physical labor for drill crews using wireline methods help to reduce worker fatigue, improving efficiency and safety.

10.1.5 Cone penetration technologies (CPT) and other drive/push technologies (DPT) are being used increasingly for environmental field investigations to depths of 100 to 300 ft (30.5 to 100 m) depending on geology and push capacity of the system. The CPT methods can be used for lithologic characterization, measurement of hydraulic conductivity of soils, sampling of solids, soil gases and ground water, and in situ chemical detection (see 11.3). Accurate lithologic characterization using CPT requires correlation of measured resistance with one or more direct subsurface observations for each site. Advantages of CPT and DPT at contaminated sites include: no cuttings, increased worker safety, and improved siting of permanent monitoring wells.

10.2 A stratigraphic profile in complex geology is often developed by correlation of lithologic character established by a significant number of borings, by continuous geophysical profiling techniques, and surface mapping. This phase of the investigation may be implemented by plotting logs of soil and rock exposures in walls of excavations or cut areas and by plotting logs of the test borings. Then one may interpolate between, and extrapolate a reasonable distance beyond, these logs. The spacing of these investigations depends on the geologic complexity of the project area and on the importance of soil and rock continuity to the project design. Exploration should be deep enough to identify all strata that might be significant in assessing environmental conditions at the site.

10.3 Field description of test pits and excavations and boring logs are an essential element of environmental site investigations. Test pits allow observation of pedogenic soil features that are larger than the diameter of borings and allow the most accurate description of subsurface features in the soil zone that may influence movement of contaminants in the vadose zone. Paragraph 6.4.3 in Guide D 5409 identifies key features that should be included in field description of samples and unconsolidated material. Additional description of samples of soil and rock may be added after samples have been transported from the field. Subsurface observation records should be kept in a systematic manner for each project. Such records should include, when applicable:

10.3.1 *Description of Each Site or Area Investigated*—Each test hole, boring, test pit, or geophysical test site should be referenced to an established coordinate system, datum, or permanent monument (see 7.1.3):

10.3.2 Subsurface investigation logs of each test hole, boring, test pit, or cut surface exposure should show the field description and location of each material, and any water encountered, either by symbol or verbal description. Guide D 5434 provides guidance for field logging of subsurface explorations for soil and rock. Reference to a Munsell Soil or Rock Color Chart designation is a substantial aid to the description of soil and rock materials.[41] Various soil classification systems are available for description of soil and other unconsolidated materials in the field. The selection of the classification system depends on the purpose and data needs of the investigation and the end users of the information. The ASTM (Classification D 2487 and Practice D 2488) version of the Unified Soil Classification System (USCS) is used by most governmental agencies and geotechnical engineering firms for the description of soil for engineering purposes both in the United States and in many other countries. The USDA textural

[41] Fluid rotary drilling can extend to greater depths in unconsolidated materials, but is generally not recommended for environmental investigations because drilling fluids can alter subsurface chemistry.

system **(41,63,64)**,[42] developed by the Soil Conservation Service for agricultural aspects of near surface soils, is especially useful for environmental investigations because it can provide hydrologic information for soils. Using the modified Wentworth grain size scale (AGI Date Sheet 29.1; **(65)**, which is widely used by geologists, in combination with the USDA textural system will provide useful additional data on soil particle-size distribution because the Wentworth system has more subdivisions in the silt and gravel particle-size classes. Field classification of samples and exposures should be confirmed with laboratory tests (Classification D 2487, Test Method D 422, and Test Method D 1140) if the information is critical to the investigation program.[43] Laboratory test results should clearly identify the textural system being used, because different systems may have slightly different grain-size cutoffs. Use of sieves that include all divisions of the USCS, USDA and modified Wentworth scales will provide the greatest amount of useful information for the coarse fraction, and measurement of all relevant cutoffs for the fine fraction in the three systems will ensure that environmental and engineering interpretations using all three systems will be possible.

10.3.3 Location and description of seepage and water-bearing zones, zones of low permeability, and records of potentiometric elevations found in each test hole, boring, piezometer, or test pit,

10.3.4 Grain size distribution of unconsolidated materials in the interval to be screened when installation of a ground-water monitoring well is planned,

10.3.5 The results and locations of in situ test results (see Section 12),

10.3.6 Percentage of core recovery and rock quality designation (RQD) in core drilling. Deere and Deere **(69)** provides guidance on RQD, and

10.3.7 Graphical presentation of field and laboratory data, such as graphic borehole logs, cross sections, potentiometric maps, and contaminant concentration isopleths, facilitates interpretation and understanding of subsurface conditions.

11. Field Methods: Sampling

11.1 The location, type of samples collected, and sampling equipment should be in accordance with the sampling plan developed in the detailed site investigation plan. A statistically valid method should be used to select sampling locations if required by the data-collection objectives. Sample equipment and procedures should be appropriate for the medium being sampled (soil, rock, soil gas, soil-pore liquids, ground water, solid/liquid waste) and be designed to minimize the introduction of error into physical and chemical test results. Barth et al **(70)** and Mason **(71)** provide guidance on development of soil sampling plans. Gilbert **(72)** provides a good general reference on statistical aspects of sampling and monitoring for environmental purposes. Geostatistical methods are especially useful for developing a sampling strategy and analysis of results when parameters are spatially correlated.[44]

11.2 *Solids Sampling*[45]—The type of solids sample will depend on the purpose of the sample.

11.2.1 Disturbed or grab samples using augers (see Practice D 1452) and trier samplers (see Practice D 5451) are used primarily for chemical analyses, but are also suitable for texture analysis.

11.2.2 Split barrel samplers (see Test Method D 1586) provide samples that allow description of lithology and other subsurface features, and laboratory measurements of soil parameters unaffected by sample disturbance (for example, water content, gradation or particle size, organic content, and nonsensitive and chemical constituents) but are not suitable for laboratory measurement of soil properties.

11.2.3 Thin-wall tube (see Practice D 1587) and ring-lined barrel samplers (see Practice D 3550) collect undisturbed samples of unconsolidated material that are suitable for laboratory testing of hydrologic properties, and diamond core drilling (see Practice D 2113) provides similar samples for consolidated rock. Undisturbed core samples can provide important information on structure, sedimentary features, secondary porosity, and color patterns that cannot be obtained from disturbed samples.

11.2.4 Guide D 4700 provides guidance on soil sampling in the vadose zone. Special considerations in sampling of soil for radionuclides and volatile organics are addressed in Practice C 998 and Practice D 4547, respectively. Practice D 4220 covers procedures for preservation and transportation of soil samples and Practices D 5079 does the same for rock core samples.

11.3 *Other Sampling*:

11.3.1 Characterization of the vadose zone may require sampling of soil gases and soil pore liquids. Guide D 5314 provides guidance on soil gas sampling for detection of volatile

[42] Color photographs of rock cores, soil samples, and exposed strata may be of considerable value. Each photograph should include an identifying number or symbol, a date, and a reference scale. Soil Conservation Service **(62)** provides standardized procedures for photographic documentation of rock cores.

[43] Both USCS and USDA classification systems can be used to estimate some hydrologic properties of soils impacting the fate and transport of contaminants. The plasticity index of the USCS is directly related to colloidal content in the soil and resulting sorptive capacity. The USCS system is more applicable to very coarse-grained alluvial deposits containing appreciable gravels. Saturated hydraulic conductivity can often be estimated within two or three orders of magnitude based on both USCS and USDA classification, and estimates can sometimes be narrowed within one order of magnitude for clean sands or in fine-grained soils where descriptions of morphology (structure, macroporosity, fissures, laminations, etc.) of undisturbed cores or exposures are possible. Numerous additional hydrologic parameters have been correlated to the USDA classification system for near-surface soils and could be useful for fine-grained unconsolidated material at greater depths. These parameters include: capillary fringe **(39)**, specific yield **(66)**, field moisture capacity **(67)**, and available water capacity **(68)**. Estimation of hydrologic parameters may be useful during the initial site characterization phases, but should not replace necessary definitive field and laboratory measurements which may be required for final site evaluations.

[44] Most soil physical and chemical properties are spatially correlated, and the location of contaminants in soil and ground water are also usually spatially correlated. Clark **(73)** is a good introductory text on geostatistics and Isaaks and Srivastava **(74)** provide advanced treatment of this subject. The ASCE Task Committee on Geostatistical Techniques in Geohydrology **(75)** contains a good review of basic concepts and applications. Several public domain geostatistical software packages are available from U.S. EPA **(76,77,78)**. Geostatistical methods may not be appropriate where soil contamination exists as localized hotspots. Zirschky and Gilbert **(79)** provide guidance on statistical sampling designs for detecting hot spots at hazardous-waste sites.

[45] The investigation may require the collection of sufficiently large soil, rock, waste, and ground water samples of such quality as to allow adequate testing to determine the soil or rock classification or mineralogic type, or both, and chemical constituents of potential interest or concern.

contaminants. Guide D 4696 addresses various methods for sampling soil pore liquids in the vadose zone.

11.3.2 *Ground Water Sampling*—Guide D 4448 covers ground-water sampling methods from permanent monitoring wells. Springs can also be used for sampling and monitoring ground water quality as covered by Guide D 5717. The CPT and other push technologies (see 10.1.5) allow collection of one-time or multiple samples for preliminary delineation of ground-water quality and installation of driven monitoring wells. Manually driven well points are generally restricted to shallow depths (<10 m) that can be sampled using suction-lift ground-water sampling devices. The CPT rigs can install small-diameter monitoring wells to depths exceeding 30 m which can be sampled with small diameter (5⁄8-in. (15.8-mm) outside diameter typical) bailers and pumps.[46]

11.3.3 Submerged sediments can be sampled with coring devices (see Guide D 4823) or with dredges, such as the Eckman, Peterson, and Ponar dredges. Guide D 4411 provides guidance on sampling of fluvial sediments in motion.[47]

11.3.4 Waste materials often require special sampling equipment and procedures. Devices for sampling single-phase and multiphase liquids include: coliwasa, dipper, drum thief, glass tube, and peristaltic pump. Mixed liquid/solid phases are usually sampled using a coliwasa, dipper, or long-handled sludge sampler. Consolidated waste solids are usually sampled using an auger, chipper, hammer and chisel, or a rotating coring device. Unconsolidated waste solids can be sampled using a trier (see Practice D 5451), grain sampler, or conventional soil sampling equipment (see 10.1.1). Lagoons may require sludge sampling tools.

11.3.5 *Biological Sampling*—Investigation of soil and ground-water geochemistry may involve sampling for aerobic and anaerobic microorganisms and other subsurface biota.[48] Special care is required when sampling for anaerobic microorganisms to ensure that the sample is not exposed to the air **(90)**. Table X1.1 identifies ASTM methods for microbiological analysis of water samples. Ecosystem characterization may require sampling of plants and animals at a site. Table X1.2 provides an index to ASTM methods for field sampling of phytoplankton, zooplankton, benthic macroinvertebrates, and fishes.

11.3.6 *Atmospheric Sampling*—Measurement of atmospheric parameters such as precipitation, humidity, temperature, and wind may be required for ground-water budget studies. Humidity, temperature, and wind should be routinely monitored during field investigations to document site conditions. Such monitoring is especially important for worker health and safety when it is very cold, or impermeable protective clothing is required when ambient temperatures are high. Air quality sampling may be required during environmental site investigations for: (*1*) identifying unsafe working conditions and monitoring worker exposure to hazardous chemicals, (*2*) evaluating air exposure pathways for environmental risk assessment, and (*3*) assessing ambient concentrations of regulated air pollutants. Table X1.1 provides an index to ASTM methods for monitoring ambient atmospheric parameters, and field sampling.

11.4 *Other Sampling Considerations*:

11.4.1 All sampling procedures for chemical analysis require cleaning and decontamination of sampling equipment to prevent cross contamination of samples. Practice D 5088 addresses decontamination of field equipment at nonradioactive waste sites.

11.4.2 Special care is required when locating permanent vadose-zone and ground-water monitoring installations for time-series sampling. Failure to site such permanent installations in locations downgradient from potential contaminant sources or to intersect zones of preferential movement of contaminants can result in wasteful expenditure of funds for chemical analysis, or even failure to detect contaminant movement. The location of permanent monitoring installations should be thoroughly justified based on the conceptual model of the site. Surface geophysical methods, multiple piezometers for measurement of ground-water flow direction, and analysis of samples taken using in situ soil gas and ground-water samplers can provide information required for rational siting of permanent monitoring installations.

12. Field Methods: In Situ Testing and Analytical Methods

12.1 In situ testing (for example, tests that measure the in-place characteristics of subsurface materials) is useful for: measuring the hydrologic properties of a larger volume of the subsurface than is possible in laboratory tests on soil and rock cores; for rapid or closely spaced measurements, or both, of earth properties without the necessity of sampling; measuring subsurface chemical parameters to minimize chemical alterations by bringing samples to the surface for analysis; and measurement of engineering properties of soil or rock in an undisturbed condition including consideration of lateral and vertical loads associated with the surrounding mass.

12.2 Field analytical methods use conventional or adapted laboratory methods for analysis of samples that have been removed from their in-place position. Mechanical sieve analysis of soil samples is commonly used to assist in field classification of soil texture. Field analytical methods such as portable gas chromatographs, X-ray fluorescence, and enzyme immunoassay kits are being increasingly used for environmental site characterization. Field instrumentation and procedures for chemical characterization are changing rapidly and the

[46] Driven wells are relatively easy and inexpensive to install in most unconsolidated materials where ground water is shallow. Deeper sampling and well installation methods using CPT and other push methods may be an alternative to conventional monitoring well installations. The decision to use these techniques for permanent monitoring well installations should be based on information indicating that sample representativeness and installation integrity (that is, avoidance of cross-contamination of aquifers) are comparable to conventional monitoring well installations with screens, filter pack, and grouting. To ensure comparability of ground-water quality results, all monitoring well installations for a particular phase of investigations at a site should be of the same type (that is, either all conventional or all drive/push installations).

[47] Good references for additional information on sampling of submerged bottom sediments include: Barth and Starks **(80)** and Palmer **(80)**. Guy and Norman **(80)** provide additional information on sampling of fluvial sediment.

[48] Chappelle **(83)** provides a useful reference for microbial sampling of ground water. Some major references on soil microbiology and ecology, geomicrobiology and microbial biogeochemistry include: Alexander **(84)**, Ehrlich **(85)**, Killham **(86)**, Kuznetsov et al **(87)**, Paul and Clark **(88)**, and Zajic **(89)**.

appropriate regulatory authority should be consulted for accepted methods and procedures when investigations are performed for regulatory purposes.

12.3 *Hydrologic Properties*:

12.3.1 Aquifer tests are used to collect data for calculating hydraulic conductivity, transmissivity, and aquifer storage properties. Tests may include, but are not limited to packer tests for low-permeability rocks (see Test Method D 4630 and Test Method D 4631), slug tests (see Test Method D 4044, Test Method D 4104, and Test Method D 4050), and aquifer tests with control wells (see Test Methods D 4105, D 4106, D 5269, and D 5270). Guide D 4043 provides guidance on selection of aquifer field test methods and analysis procedures based on aquifer characteristics. In karst and fractured rock hydrogeologic settings refer to Guide D 5717 for special approaches required for characterization of hydrologic properties. In such settings conventional aquifer test methods may not be appropriate. Similar problems may also occur in heterogeneous porous media.

12.3.2 Test Method D 5084 provides a method for measuring point hydraulic conductivity of low-permeability materials using undisturbed core materials ($<1 \times 10^{-3}$ cm/s); Test Method D 2434 provides a method for measuring hydraulic conductivity of granular materials ($>1 \times 10^{-3}$ cm/s).

12.3.3 Field measurements of vadose zone hydrologic parameters include water content, matric potential, and infiltration rate and hydraulic conductivity. Guide D 5126 provides guidance on selection of methods for measuring saturated and unsaturated hydraulic conductivity in the vadose zone. Table X1.1 identifies ASTM methods for measuring infiltration rate, matric potential, and moisture content.

12.4 *Physical Properties*—In situ measurements of vertical and horizontal variations in soil density using a standard penetration test (see Test Method D 1586), cone penetrometry (see Test Method D 3441) or a gamma-gamma nuclear probe (see Test Methods D 2922 and D 5195), can provide useful information for stratigraphic interpretation within and between boreholes. Other physical properties that affect water movement can be measured with a variety of borehole geophysical logging tools, including induction, gamma, resistivity, neutron porosity, sonic, and caliper tools. In addition, downhole video and acoustic televiewer instruments may provide information on such properties as fractures, vugs, and bedding plane orientation.

12.5 Use of ion-selective electrodes to measure chemical parameters in place in the subsurface is an established technology (see Terminology D 4127). Fiber optic chemical sensors are a relatively new technology with good possibilities for making in-situ chemical measurements for environmental site characterization.[49]

12.6 *Engineering Properties*—Engineering properties are primarily of interest for environmental site characterization if design of pollution control measures, such as impoundment liners, or remediation activities are required. Numerous ASTM field methods are available for in situ measurement of soil and rock engineering properties. These are identified in Table X1.1.

13. Analysis and Interpretation of Results

13.1 Evaluate data to determine whether data quality requirements were met (see 5.1.5). Data review and analysis should include all reliable field and laboratory data from previous investigations in the same area. Review field and laboratory QA/QC procedures and measurements to assess data validity, and determine whether data quality requirements (see 5.1.5) have been satisfied. Interpretation of field- and laboratory-measured environmental parameters should include an evaluation of possible limitations of the methods used. Basic assumptions for analytical techniques and methods should be evaluated to determine if site conditions meet assumptions. For example, the analysis of aquifer test results should identify the approximate volume of the aquifer measured by the test, and the underlying analytical or other equations used to compute aquifer parameters. If site conditions do not satisfy the assumptions of the solution method, the effect on accuracy and interpretation of results should be stated.

13.2 Develop graphical presentation of data to facilitate interpretation of spatial relationships and, when time series data are available, presence or absence of trends. Map views, cross sections, and data contouring methods are especially useful for presentation of spatial data.

13.2.1 A map of the area under investigations provides essential information about the land surface, including natural and anthropogenic features, and the locations of sampling, monitoring wells, and other observation points.

13.2.2 Cross sections should identify actual surface and subsurface observations according to elevation and location. Cross sections showing correlation of stratigraphic or lithologic units and interpretation of other conditions between direct subsurface observations should be indicated as interpretations (that is, dashed lines) and based on standard geologic procedures. When feasible, geophysical survey data, such as continuous geophysical profiles should be used to support correlations and other interpretations. The interpretive cross sections should be accompanied by notes describing anomalies or otherwise significant variations in the site conditions that might affect any interpretations.[50]

13.2.3 Contouring methods, such as structure contours of geologic strata or buried bedrock, potentiometric surfaces, and maps showing lines of equal concentration or value should be constructed using appropriate interpolation techniques.[51] The method of interpolation should be documented. When feasible, the same data should be contoured using different interpolation methods and compared.

13.3 Statistical methods used to analyze data should be appropriate for the type of data. Most conventional statistical

[49] The term in situ here is confined to methods that measure chemical parameters in place without bringing a sample to the surface. The term may also be applied to ground water sampling devices that do not require installation of a monitoring well. In situ chemical sensors can be placed in monitoring wells or by using CPT or other push technologies.

[50] Additional exploration should be considered if there is not sufficient information to develop interpretative cross sections, with realistic descriptions of anticipated variations in subsurface conditions, to meet project requirements.

[51] Most field geology texts identified in Footnote 16 discuss interpolation techniques. Davis **(91)**, Hamilton and Jones **(94)** and Jones et al. **(95)** are other good references.

methods assume a normal distribution around the mean. Typically, environmental data measurements do not exhibit normality because of spatial correlation, the presence of outliers, or other effects.[52] Geostatistical methods are best for analyzing spatially related data (see 11.1 and related references). When contaminants are present in low concentrations (at or below the detection limit), the report should indicate whether chemical data have been censored and if so, assess the possible effect of censoring (that is, values reported as not detected or below the detection limit). Practice D 4210 addresses data censoring and its possible significance.

13.4 Information on topography, geomorphology, soils, climate, vegetation, surface hydrology, and anthropogenic influences should be integrated with subsurface geologic, hydrogeologic, and geochemical/hydrochemical interpretations as required by the objectives of the investigation. At contaminated sites, identification of pathways for movement of contaminants and estimation of exposure concentrations, and determining the rate of movement may be an important result of the site characterization study.[53]

14. Report

14.1 Report the following information:

14.1.1 Pertinent ASTM Standards, (Terminology D 653, Practice D 3584, Practice E 177, and Practice E 380).

14.2 The report of an environmental site characterization study should include:

14.2.1 The location of the area investigated in terms pertinent to the project. This may include sketch maps or aerial photos on which the test pits, bore holes, and sample areas are located, as well as geomorphological data relevant to the determination of the various soil and rock types. Such data include elevation contours, stream beds, sinkholes, cliffs, and all other relevant physiographic features. All significant anthropogenic features should be located on the base map or a separate map. Where feasible, include in the report a geologic map or an agronomic soils map, or both, of the area investigated,

14.2.2 Additional basic information as required by the objectives of the investigation,

14.2.3 A description of the investigation procedures including all borings and test hole logs, graphic presentation of all lithologic and well construction logs, tabulation of all test results, and graphical interpretations of geophysical measurements, and

14.2.4 A summary of the findings obtained under Sections 6, 9, 10, 11, 12, and 13, using subhead titles for the respective sections, and appropriate recommendations and disclaimers for the use of the report.

15. Keywords

15.1 conceptual site model; environmental site characterization; exploration; feasibility studies; field investigations; geological investigations; geophysical investigations; ground water; hydrologic investigations; maps; preliminary investigations; reconnaissance surveys; sampling; site characterization; site investigations; soil surveys; subsurface investigations

[52] The EPA's GRITS/STAT software for analyzing ground-water monitoring data allows testing of the appropriateness of conventional statistical analysis of time series data, and includes a number of alternative tests if conventional tests are not appropriate **(92)**.

[53] Estimation of exposure concentrations may require use of batch sorption/leaching tests and vadose zone contaminant mobility studies. Roy et al **(93)** provides U.S. EPA guidance on batch test for estimating soil sorption of chemicals, and Table X1.2 (Laboratory Fate Testing) provides an index of ASTM sorption and leachability test methods.

APPENDIXES

(Nonmandatory Information)

X1. ASTM STANDARDS PERTINENT TO ENVIRONMENTAL SITE CHARACTERIZATION

X1.1 This appendix lists more than 400 standard test methods, practices, and guides for use in the field and laboratory that could be pertinent for site characterization for environmental purposes. Two tables provide a quick reference to two categories of standards:

X1.1.1 Table X1.1 identifies more than 320 potential field and laboratory methods for sampling and characterization of soil, ground water, and waste materials. Other ASTM methods for measuring site parameters that may need to be monitored during environmental site investigations, such as humidity and wind, are also included in Table X1.1. All standards listed in this table follow in alphanumeric sequence.

TABLE X1.1 Index to ASTM Field and Laboratory Methods Possibly Pertinent to Environmental Site Characterization[A]

Topic	ASTM Standard
General:	
Reports	Indexing papers and reports (D 3584), use of modernized metric system (E 380)
Terminology	Soil, rock and contained fluids (D 653); atmospheric sampling (D 1356); basic statistics (D 4743); waste and waste management (D 5681, D 5688 sampling and monitoring, D 5689 characterization); water (D 1189)

TABLE X1.1 *Continued*

Topic	ASTM Standard
Objective-Oriented Guides	Acquisition of file aerial photography and imagery for establishing historic site use and surficial conditions (D 5518); *Contaminated Sites:* Expedited site characterization (PS 85) developing conceptual site models for contaminated sites (E 1689); accelerated site characterization for petroleum releases (PS 3); risk-based corrective action at petroleum release sites (E 1739); short term measures or early actions for site remediation (D 5745); environmental condition of property area types (D 5746) environmental baseline surveys (D 6008); real estate property transactions (E 1527, E 1528); *Site-Characterization:* environmental (D 5730 - this guide, D 5995 cold regions; D 6067 - ECPT); engineering and construction purposes (D 420); *Septic System Characterization* (D 5879); Subsurface (D 5921): sizing (D 5925): *Environmental Management:* development and implementation of a pollution prevention program (E 1609); lifecycle costing for pollution prevention (PS 14); assessment of buried steel tanks (ES 40); environmental regulatory compliance audits (PS 11); evaluation of an organizations environmental management system (PS 12); development and implementation of a source reduction program (PS 26)
Sampling:	
General	Collection and preservation of information and physical items by a technical investigator (E 1188); probability sampling of materials (E 105)
Air	Choosing locations and sampling methods for atmospheric deposition at nonurban locations (D 5111, D5012); guide for laboratories (D 3614); flow rate calibration of personal sampling pumps (D 5337); planning ambient air sampling (D 1357); ambient air analyzer procedures (D 3249); sampling stationary source emissions (D 5835); *Airborne Microorganisms:* Sampling at municipal solid waste facilities (E 884); *Sampling Organic Vapors/Toxic Vapors:* Charcoal tube absorption (D 3686), canister (D 5466); detector tubes (D 4490); length-of-stain dosimeter (D 4599); *Particulate Matter Determination:* Filter absorbance method (D 1704, D1704M); high-volume sampler (D 4096, D 4536); dustfall (D 1739—settleable particulates); *Worker Protection:* Air monitoring at waste management facilities for worker protection (D 4844); air sampling strategies for worker and workplace protection (E 1370); collection of airborne particulate lead during abatement and construction activities (E 1553); activated charcoal samplers (D 4597), liquid sorbent difussional samplers (D 4598); pesticides and PCBs (D 4861) Sampling indoor air quality of building (D 5791)
Biological Materials	Aseptic sampling (E 1287); see also Table A.2
Soil/Rock/Sediments	Minimum set of data elements for soil sampling (D 5911); *Drilling Methods:* cable tool (D 5875); casting advancement (D 5872); diamond core drilling (D 2113); direct air-rotary (D 5782); direct fluid rotary (D 5783); direct rotary wireline (D 5876); dual-wall reverse circulation (D 5781); hollow-stem auger (D 5784); *Field Sampling and Handling Methods:* Auger sampling (D 1452); radionuclides (C 998); ring-lined barrel (D 3550); split barrel (D 1586); thin-wall tube (D 1587); volatile organics (D 4547); *Sediments:* sediments (D 4411—fluvial sediment in motion, D4823—submerged, D3213—handling, storing and preparing soft undisturbed marine soil; E1391—collection for toxicological testing)
Vadose Zone	*Field Methods:* **Pore liquids (D 4696); soil (D 4700);** soil gas (D 5314)
Water	Purgeable headspace sampling (D 3871); waterborne oils (D 4489); continual on-line monitoring (D 3864); filterable and nonfilterable matter (D 5907); on-line sampling/analysis (D 5540—flow and temperature control), water-formed deposits (D 887); *Planning:* water quality measurement program (D 5612); water monitoring programs (D 5851); *Ground Water:* **Sampling methods (D 4448);** direct push sampling (D 6001); planning a ground-water sampling event (D 5903); *Surface Water*: dipper or pond sampler (D 5358); *Closed Conduits:* equipment (D 1192); sampling (D 3370); Laboratory Practices: D3856
Waste/Contaminants	*General Guidance:* **General planning (D 4687);** representative sampling (D 6044); composite sampling and field subsampling (D 6051); Heterogeneous wastes (D 5956): *Specific Sampling Procedures:* bituminous materials (D 140); COLIWASA (D 5495); drums general (D 6063 consolidated solids—D 5679, unconsolidated solids—D 5680); single or multilayered liquids (D 5743); pipes and other point discharges (D 5013); scoop (D 5633); unconsolidated waste from truck (D 5658); UST release detection devices (E 1430, E1526); volatile organics (D 4547); waterborne oils (D 4489); oil/water mixtures for oil spill recovery equipment (F 1084) waste piles (D 6009)
Preservation/Transport	Sample chain of custody (D 4840); estimation of holding time for water samples (D 4515, D4841); *Field Methods*—Rock core samples (D 5079); sample containers for organic constituents (D 3694); soil samples (D 4220); sediments for toxicological testing (E 1391); preservation/preparation of waterborne oil samples (D 3325, D 3326); handling, storing and preparing soft undisturbed marine soil (D 3213)
Decontamination of Field Equipment	*Field Methods:* Nonradioactive waste sites (D 5088); low-level radioactive waste sites (D 5608)
Data Management/Analysis	*QA/QC:* Waste management environmental data (D 5283); waste management DQOs (D 5792); precision and bias (E 177); QC specification for organic constituents (D 5789); *Data Analysis:* Evaluation of technical data (E 678); outlying observations (E 178); reporting results of examination and analysis of water-formed deposits (D 933); *Geostatistics:* reporting geostatistical site investigations (D 5549); analysis of spatial variation (D 5922); selection of kriging methods (D 5923); selection of simulation approaches (D 5924); *Spatial Data:* digital geospatial metadata (D 5714); see also Ground Water (Data Analysis)
Soil/Rock Hydrologic Properties:	
Infiltration Rate	*Field Methods:* Double-ring infiltrometer (D 3385); sealed double-ring infiltrometer (D 5093)
Matric Potential	*Field Methods:* Tensiometers (D 3404); *Laboratory Method:* Filter paper method (D 5298)
Water Content	*Field Methods:* Calcium carbide method (D 4944); neutron probe (D 3017—shallow depth, D 5220— depth probe: D 6031 - horizontal, slanted and vertical access tubes); *Laboratory Methods:* Direct heating method (D 4959); microwave oven method (D 4643); standard oven drying method (D 2216); centrifuge moisture equivalent (D 425)
Hydraulic Conductivity	*Field Methods:* **Vadose zone (D 5126);** *Laboratory Methods:* Granular soils (D 2434—>1 $\times$ 10^{-3} cm/sec); low permeability soils (D 5084—<1 $\times$ 10^{-3} cm/sec); rigid-wall compaction-mold permeameater (D 5856); effect of freeze/thaw (D 6035); peat (D 4511)
Other Hydrologic Properties	*Laboratory Methods:* Air permeability (D 4525); Soil water retention (D 2325—medium/coarse textured, D3152—fine-textured)
Soil/Rock Physical Properties:	
Particle Size	*Soil Laboratory Methods:* Analysis (D 422); dry preparation (D 421); <200 sieve (D 1140); wet preparation (D 2217); *Sediment:* Selection of methods for fluvial sediment (D 4822)
Soil Density	*Field Methods:* Drive cylinder (D 2937); gamma-gamma (D 2922—<12″, D5195—>12″); (D 4531); penetration (D 1586); rubber-balloon method (D 2167), sand-cone method (D 1556); sand replacement method (D 4914); sellve method (D 4564) water replacement method (D 5030); nuclear method (D 6031)
Pore Volume/Specific Density	*Laboratory Methods:* pore volume (D 4404); specific gravity (D 854, D5550—gas pycnometer)

TABLE X1.1 *Continued*

Topic	ASTM Standard
Cone Penetration	*Field Methods:* In-situ cone penetration testing (D 3441, D 5778); CPT stress wave energy measurements (D 4633); liquification potential evaluation (D 6066); ECPT for environmental site characterization (D 6067)
Classification	*Field Methods:* Field logging (D 5434); noncohesive sediments (D 5387); peat (D 4544—deposit thickness, degree of humification—D 5715); sediments (D 4410); visual-manual procedure (D 2488—unified, D4083—frozen soils); rock mass classification (D 5878); rock quality designation (D 6032); *Laboratory Methods:* Dimension stone (C 199); frozen soils (D 4083); natural mineral aggregates (C 294); peat (D 2607); unified soil classification (D 2487)
Geophysical Properties	*Field Methods:* Crosshole seismic testing (D 4428/D 4428M); seismic refraction (D 5777); soil resistivity (G 57—Wenner 4-electrode method); planning and conducting borehole geophysical logging (D 5753)
Engineering Properties	*In Situ Field Methods:* Bearing capacity/ratio (D 1194, D 4429); deformability and strength of weak rock (D 4555); direct shear strength (D 4554, D 5607); erodibility (D 5852), frost heave/thaw, susceptibility (D5918); extensometers (D 4403); in situ creep (D 4553); in situ modulus of deformation (D 4394—rigid plate, D 4395—flexible plate, D 4506—radial jacking test, D 4729—flatjack method, D 4791—borehole jack); in situ stress (D 4623—borehole deformation gage, D 4645—hydraulic fracturing; D 4729—flatjack method); pressure measurement (D 4719—pressuremeter, D 5720—transducer calibration); vane shear test (D 2573); *Laboratory Methods:* California bearing ratio (D 1883); classification (D 2487); compaction (D 698, D 1557, D 5080); compressive strength (D 2166, D 2938); consolidation (D 2435); core dimensional and shape tolerances (D 4543); dispersive characteristics (D 4221—double hydrometer; D 4647—pinhole test); elastic properties (D 2845, D 3148); impact valve (D 5874); linear displacement (D 6027 - calibrating transducers); liquid limit (D 4318); moisture content-penetration resistance (D 1558); one-dimensional swell (D 4546); plastic limit/plasticity index (D 4318); point load strength (D 5731); rock hardness (D 5873) shrinkage factors (D 427; D 4943); tensile strength (D 2936; D 3967); thermal properties (D 5334, D 5335); triaxial compression (D 2850, D 2664, D 4406, D 4767, D 5311, D 5407); uniaxial compression (D 4341, D 4405); use of significant digits (D 6026); vane shear test (D 4648); *Evaluation of Laboratories:* D 3740
Miscellaneous	*Field:* Geotechnical mapping of large underground openings in rock (D 4543); *Laboratory Methods:* X-ray radiography (D 4452)
Peat/Organic Soils	*Laboratory Methods:* Bulk density (D 4531); classification (D 2607); hydraulic conductivity (D 4511); pH (D 2976); moisture/ash/organic matter (D 2974)
Frozen Soils	*Field:* Descirption (D 4083); *Laboratory:* Creep properties by uniaxial compression (D 5520)
Soil/Rock Chemistry:	
Basic Chemistry	*Field Methods:* Soil pH for corrosion testing (G 51); *Laboratory Methods:* Calcium carbonate (D 4373); pH (D 4972); soluble salt content (D 4542); diagnostic soil test for plant growth and food chain protection (D 5435); minimum requirements for laboratories engaged in chemical analysis (D 5522)
Soil Contaminants	Nitroaromatic and nitramine explosives (D 5143); screening fuels (D 5831); PCBs using room temperature phosphorescence (PS 47)
Sediments	Preparation for chemical analysis (D 3975, D3976)
Sorption/Leachability	See fate-related procedures in Table A.1
Ground Water:	
Characterization/Monitoring	Assessing aquifer sensitivity and vulnerability (D 6030); conceptualization and characterization (D 5979); existing wells (D 5980); monitoring karst and fractured rock aquifers (D 5717); statistical approaches for ground-water detection monitoring programs (PS 64)
Data Elements	*Field Methods:* Minimum set (D 5254); additional identification descriptors (D 5408); additional physical descriptors (D 5409); additional usage description (D 5410); selection of data elements (D 5474)
Data Analysis/Presentation	Presentation of water level information (D 6000); *Chemical Analysis:* Diagrams for single analyses (D 5738); trilinear diagrams (D 5754); diagrams based on data analytical calculations (D 5877); use of maps (D 6036)
Monitoring Wells	*Field Methods:* **Design/installation** (D 5092); protection (D 5787); decommissioning (D 5299); casing (D 1785, F480); grout (C 150—portland cement); water level measurement (D 4750); well development in granular aquifers (D 5521); well discharge (D 5716—circular orifice weir, D 5737—guide to methods); maintenance and rehabilitation (D 5978)
Aquifer Hydraulic Properties	*Field Methods:* Packer tests (D 4630, D 4631); aquifer tests with control wells (D 4105, D 4106, D 5269, D 5270, D 5472, D 5473); D 5920 - anistropic unconfined; D 6028; (leaky confining beds); slug tests (D 4044, D 4050, D 4104, D 5785, D 5881, D 5912); constant drawdown for flowing wells (D 5787, D 5855); constant rate pumping (D 6034); partially penetrating wells (D 5850); **test selection** (D 4043)
Modeling	Site specific application (D 5447); comparing simulation to site-specific information (D 5490); documenting model application (D 5718); defining boundary conditions (D 5609); defining initial conditions (D 5610); conducting sensitivity analysis (D 5611); simulation of subsurface air flow (D 5719); subsurface flow and transport modeling (D 5880) model calibration (D 5981); developing and evaluating codes (D 6025); describing functionality (D 6033)
Chemistry	*Field Methods:* Acidity/Alkalinity (D 1067); electrical conductivity/resistivity (D 1125); ion-selective electrodes (D 4127); low-level dissolved oxygen (D 5462); odor (D 1292); pH (D 1293, D 5464); redox potential (D 1498), test kits for inorganic constituents (D 5463); turbidity (D 1889); *Extraction Methods:* purgeable organics using headspace sampling (D 3871); micro-extraction for volatiles and semivolatiles (D 5241); *Laboratory Methods:* Organic carbon (D 2579); minimum requirements for laboratories engaged in chemical analysis (D 5522); see, generally, Vols 11.01 and 11.02
Microbiology	ATP content (D 4012); iron bacteria (D 932); sulfate-reducing bacteria (D 4412); microbial respiration (D 4478); microscopy (D 4454—total respiring bacteria, D4455—epifluorescence); plating methods (D 5465); on site screening heterotrophic bacteria (F 488)
Surface Water:	
Geometry/Flow Measurement	Depth measurement (D 5073 D 5909-horizontal positioning); measurement of morphologic characteristics of surface water bodies (D 4581); operating a gaging station (D 5674); *Discharge:* Step backwater method (D 5388); *Open Channel Flow:* Selection of weirs and flumes (D 5640); acoustic methods (D 4408); acoustic velocity method (D 5389); broad-crested weirs (D 5614); culverts (D 5243); developing a stage-discharge relation (D 5541); dye tracers (D 5613); electromagnetic current meters (D 5089); Palmer-Bowles Flume (D 5390); Parshall flume (D 1941); rotating element current meters (D 4409); slope-area method (D 5130); thin-plate weirs (D 5242); velocity-area method (D 3858); width contractions (D 5129); *Open Water Bodies:* Water level measurement (D 5413)
Other Characteristics	Suspended sediment concentration (D 3977); environmental conditions relevant to spill control systems (F 625); *Chemistry:* See ground water above
Waste/Contaminants:	

TABLE X1.1 *Continued*

Topic	ASTM Standard
Waste Properties	*Field/Screening Methods:* Compatibility (D 5059); cyanides (D 5049); flammability potential (D 4982); oxidizers (D 4981); pH (D 4980); physical description screening analysis (D 4979); radioactivity (D 5928); sulfides (D 4978); waste specific gravity/bulk density (D 5057); *Laboratory Methods:* Waste bulk density (E 1109); biological clogging of geotextiles (D 1987); coal fly ash (D 5759); solid waste freeze-thaw resistance (D 4842); stability and miscibility (D 5232); wetting and drying (D 4843); *Extraction Methods:* Single batch extraction methods (D 5233); sequential batch extraction with water (D 4793 - water, D 5284 - acidic extraction fluid); soxhlet extraction (D 5369); total solvent extractable content (D 5368); solvent extraction of total petroleum hydrocarbons (D 5765); shake extraction of solid waste and water (D 3987)
Contaminant Fate	See fate-related procedures in Table A.2
Radioactive Materials	*Monitoring:* Detector calibration (E 181); radiation measurement/dosimetry (E 170); radiation protection programs for decommissioning operations (E 1167); *Sampling/Preparation:* sampling surface soil for radionuclides (C 998); soil sample preparation for determination of radionuclides (C 999)
Asbestos	Screen analysis (D 2947)
Other Site Conditions:	
Field Atmospheric Conditions	Atmospheric pressure (D 3631); conversion unit and factors (D 1914); determining comparability of meteorological measurements (D 4430); *Humidity:* Dew-point hygrometer (D 4030); psychrometer (E 337); terminology (D 4023); *Wind:* Anemometers (D 4480, D 5096, D 5741); surface wind by acoustic means (D 5527); wind vane (D 5741, performance - D 5366) see Volume 11.03 generally
Solar insolation	Pyranometers (E 824, E 913, E 941); pyrheliometers (E 816)

[A] **Boldface**—Method selection guide.

X1.1.2 Table X1.2 identifies more than 80 standard test method, practices and guides that address field sampling for ecological characterization and laboratory methods, such as toxicity testing, relevant to human and ecological risk assessment.

X1.2 This guide does not specifically address laboratory methods, but Table X1.1 provides a convenient index to laboratory methods that might be useful for testing and analysis of soil, water, and waste samples collected during an environmental site investigation. This appendix does not contain a detailed listing of laboratory methods for measurement of specific chemicals that might be of concern in an environmental investigation. However, methods for measurement of chemical parameters that are routinely used in field investigations and laboratory methods that provide information relevant to the transport and fate of contaminants and other chemical constituents in the subsurface are included.

X1.3 The following ASTM compilations may be useful for Environmental Site Characterization:

X1.3.1 *Compilation of Scopes of ASTM Standards Relating to Environmental Monitoring*. 1993, 328 pp. [Contains 700 scope statements],

X1.3.2 *ASTM Standards on Ground Water and Vadose Zone Investigations, 2nd ed*. 1994. [46 Standards],

X1.3.3 *ASTM Standards on Environmental Site Assessments for Commercial Real Estate, 2nd ed*. 1994, 55 pp. [Includes E1527 and E1528],

X1.3.4 *ASTM Standards on Hazardous Substance and Oil Spill Response, 2nd ed*. 1994, 144 pp. [38 standards],

X1.3.5 *ASTM Standards on Lead-Based Paint Abatement in Buildings*. 1994, 174 pp. [28 standards],

X1.3.6 *ASTM Standards on Environmental Sampling*, 1995, 532 pp. [70 standards],

X1.3.7 *ASTM Standards on Analysis of Hydrologic Parameters and Ground Water Modeling*, 1996, 148 pp. [23 standards], and

X1.3.8 *ASTM Standards on Design and Planning for Ground Water and Vadose Zone Investigations*, 1996, 120 pp. [10 standards].

TABLE X1.2 Index to ASTM Field and Laboratory Methods for Ecological Characterization

Topic	ASTM Standard
General:	
Terminology	Biological effects and environmental fate (Terminology E 943)
Field Sampling:	
Phytoplankton	Classification for sampling (Classification D 4149); *Sampling Methods*—Depth-integrating samplers (Practice D 4135); Clarke-Bumpus sampler (Practice D 4134); conical tow nets (Practice D 4132); pumps (Practice D 4133); water sampling bottles (Practice D 4136); *Sample Preservation*—Practice D 4137; *Other Methods*—Measurement of chlorophyll content of algae in surface water (Practice D 3731); Sedgwick-Rafter method (Test Method D 4148)
Zooplankton	*Sampling Methods*—Clarke-Bumpus sampler (Practice E 1199); conical tow nets (Practice E 1201); pumps (Practice E 1198); *Sample Preservation*—Practice E 1200.
Benthic Macroinvertebrates	**Selection of sampling devices (Guide D 4387)**;[A] *Grab Samplers*—Ekman (Practice D 4343); Holme scoop (Practice D 4348); Okean 50 (Practice D 4346); Orange Peel (Practice D 4407); Ponar (Practice D 4342); Peterson (Practice D 4401); Shipek scoop (Practice D 4347); Smith-McIntyre (Practice D 4344); Van Veen (Practice D 4345); *Other Samplers*: Basket (Practice E 1468); drift net (Practice D 4558); multiple plate (Practice E 1469); **selecting stream net devices (Guide D 4556)**;[A] Surber and related samplers (Practice D 4557)
Fishes	Classification for sampling (Practice D 4211); sampling with rotenone (Practice D 4131)
Toxicity Testing:	
Microbial Detoxification	Chemically contaminated water and soils (D 5660)
Water	Behavioral testing in aquatic toxicology (E 1604); measurement of behavior during fish toxicity test; (E 1711); estimation of median lethal concentration for fish using octonol-water partition coefficient (Practice E 1242); ventilatory behavioral toxicology testing of freshwater fist (E 1768); *Acute Toxicity Tests*—Bivalve mollusks (Guide E 724); fishes, macroinvertebrates and amphibians (Practice E 729, Guide E 1192-aqueous effluents); mosquito *Wyoemyia smithii* (Guide E 1365); polychateous annelids (Guide E 1562); rotifer *Brachionus* (Guide E 1440), west coast Mysids (Guide E 1463); echinoid embryos (E 1563); *Life Cycle/Renewal Toxicity Tests*—*Daphnia magna* (Guide E 1193); *Ceriodaphnia dubia* (Guide E 1295); polychateous annelids (Guide E 1562); saltwater Mysids (Guide E 1191); *Static Toxicity Tests*—Bivalve mollusks (Guide E 724); *Lemna gibba* G3 (Guide E 1415); microalgae (Guide E 1218); mosquito *Wyoemyia smithii* (Guide E 1365); west coast Mysids (Guide E 1463); *Other Toxicity Tests*—Algal growth potential (Practice D 3978); chronic—polychateous annelids (Guide E 1562); early life-stage fishes (Guide E 1241); toxicity-induced enzymatic inhibition in *Daphnia magna* (Provisional Test Method P 235)
Soil	Soil toxicity test with Lumbricid earthworm *EiSenia* (E 1676)
Sediment	Collection, storage, characterization and manipulation (Guide E 1391); designing biological tests (E 1525); bioaccumulation by benthic invertebrates (E 1688); *Toxicity Tests*: marine and estuarine Amphipods (Guide E 1367); freshwater invertebrates (Guide E 1383, E 1706)
Other Tests	Sexual reproduction test with seaweeds (E 1498); *Avian Species:* Substrate dietary toxicity tests (E 857); reproductive studies (E 1062); use of lighting in laboratory testing (E 1733)
Fate-Related Procedures:	
Hazard Assessment	Assessing the hazard of a material to aquatic organisms (Guide D 1023); radioactive pathway methodology for release of site following decommissioning (Guide E 1278)
Modeling	Evaluating mathematical models for the environmental fate of chemicals (Practice E 978)
Microcosm Tests	Freshwater aquatic microcosm (Practice E 1366); terrestrial soil-core microcosm (Guide E 1197); chemical fate in site specific sediment/water microcosms (E 1624)
Laboratory-Fate Testing	Substitute wastewater specification (D 5905) *Bioconcentration*—Fishes and bivalve mollusks (Practice E 1022); *Biodegradation*—anaerobic (Test Method E 1196); shake-flask die-away method (Test Method E 1279); organic chemicals in semi-continuous activated sludge (E 1625); sealed vessel CO_2 production test (E 1720); *Fate-Related Chemical Properties*—Aqueous solubility (Test Method E 1148); hydrolysis rate constants (Practice E 895); octanol/water partition coefficient (Test Method E 1147); vapor pressure (Test Method E 1194); *Sorption/Leachability*—Contaminant sorption (Test Method D 4646); 24-h batch sorption of volatile organics (Test Method D 5285); distribution ratios (Test Method D 4319); organic carbon sorption constant (Test Method E 1195); waste leaching column test (Test Method D 4874) *Environmental Analytical Laboratories*: training programs (D 5829); see also waste extraction procedures in Table X1.1.

[A] **Boldface**—Method selection guide.

X1.4 *ASTM Standards*—Indexed in Table X1.1 (In Vols 04.08 or 04.09, unless otherwise specified).[54,55]

C 150 – 92	Specification for Portland Cement (Vol 04.01)
C 199 – 91	Terminology Relating to Dimension Stone
C 294 – 86	Descriptive Nomenclature for Constituents of Natural Mineral Aggregates (Vol 04.02)
C 998 – 90	Practice for Sampling Surface Soil for Radionuclides (Vol 12.01)
C 999 – 90	Practice for Soil Sample Preparation for Determination of Radionuclides (Vol 12.01)
D 140 – 88	Practice for Sampling Bituminous Materials
D 420 – 93	Guide to Site Characterization for Engineering, Design, and Construction Purposes
D 421 – 85	Practice for Dry Preparation of Soil Samples for Particle-Size Analysis and Determination of Soil Constants
D 422 – 63	Test Method for Particle-Size Analysis of Soils
D 425 – 88	Test Method for Centrifuge Moisture Equivalent of Soils
D 427 – 93	Test Method for Shrinkage Factors of Soils by the Mercury Method
D 653 – 90	Terminology Relating to Soil, Rock, and Contained Fluids
D 698 – 91	Test Method for Laboratory Compaction Characteristics of Soil Using Standard Effort (12 400 ft-lbf/ft^3) (600 kN-m/m^3)
D 854 – 92	Test Method for Specific Gravity of Soil
D 887 – 82	Practice for Sampling Water-Formed Deposits (Vol 11.02)
D 932 – 85	Test Method for Iron Bacteria in Water and Water-Formed Deposits (Vol 11.02)
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[54] Prior to 1994 Volume 04.08 contained all standards on soil and rock. Beginning in 1994 this volume was broken into two volumes: Volume 04.08; Soil and Rock (I): D420 to D4914, and Volume 04.09; Soil and Rock (II): D4943 to latest; Geosynthetics.

[55] The last two digits indicate the year in which the standard was adopted or the most recent year in which substantive revisions to the standard were adopted.

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D 5781 – 95 Guide for Use of Dual-Wall Reverse-Circulation Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5782 – 95 Guide for Use of Direct Air-Rotary Drilling for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5783 – 95 Guide for Use of Direct Rotary Drilling with Water-Based Drilling Fluid for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5784 – 95 Guide for Use of Hollow-Stem Augers for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5785 – 95 Test Method (Analytical Procedure) for Determining Transmissivity of Confined Nonleaky Aquifers by Under-Damped Well Response to Instantaneous Change in Head (Slug Test)
D 5786 – 95 Practice (Field Procedure) for Constant Drawdown Tests in Flowing Wells for Determining Hydraulic Properties of Aquifer Systems
D 5787 – 95 Practice for Monitoring Well Protection
D 5789 – 95 Practice for Writing Quality Control Specifications for Standard Test Methods for Organic Constituents (Vol 11.01)
D 5791 – 95 Guide for Using Probability Sampling Methods in Studies of Indoor Air Quality of Buildings (Vol 11.03)
D 5792 – 95 Practice for Generation of Environmental Data Related to Waste Management Activities: Development of Data Quality Objectives (Vol 11.04)
D 5829 – 96 Guide for Preparing a Training Program for Environmental Analytical Laboratories (Vol 11.04)
D 5831 – 95 Test Method for Screening Fuels in Soils (Vol 11.04)
D 5835 – 95 Practice for Sampling Stationary Source Emissions for the Automated Determination of Gas Concentrations (Vol 11.03)
D 5850 – 95 Test Method for (Analytical Procedure) for Determining Transmissivity, Storage Coefficient, and Anisotropy Ratio from a Network of Partially Penetrating Wells

D 5851 – 95 Guide for Planning and Implementing a Water Monitoring Program (Vol 11.02)
D 5852 – 95 Test Method for Erodibility Determination of Soil in the Field or in the Laboratory by the Jet Index Method
D 5855 – 95 Test Method for (Analytical Procedure) for Determining Transmissivity and Storage Coefficient of a Confined Non-leaky or Leaky Aquifer by the Constant Drawdown Method in a Flowing Well
D 5856 – 95 Test Method for Measurement of Hydraulic Conductivity of Porous Material Using a Rigid-Wall, Compaction-Mold Permeameter
D 5872 – 95 Guide for Use of Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5873 – 95 Test Method for Determination of Rock Hardness by the Rebound Hammer Method
D 5874 – 95 Test Method for Determination of the Impact Value (IV) of a Soil
D 5875 – 95 Guide for Use of Cable-Tool Drilling and Sampling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5876 – 95 Guide for Use of Direct Rotary Wireline Casing Advancement Drilling Methods for Geoenvironmental Exploration and Installation of Subsurface Water-Quality Monitoring Devices
D 5877 – 95 Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements—Diagrams Based on Data Analytical Calculations
D 5878 – 95 Guide for Using Rock-Mass Classification Systems for Engineering Purposes
D 5879 – 95 Practice for Surface Site Characterization for On-Site Septic Systems
D 5880 – 95 Guide for Subsurface Flow and Transport Modeling
D 5881 – 95 Test Method (Analytical Procedure) for Determining Transmissivity of Confined Nonleaky Aquifers by Critically Damped Well Response to Instantaneous Change in Head (Slug Test)
D 5903 – 95 Guide for Planning and Preparing for a Ground-Water Sampling Event
D 5905 – 95 Specification for Substitute Wastewater (Vol 11.01)
D 5907 – 95a Test Method for Filterable and Non-Filterable Matter in Water (Vol 11.01)
D 5909 – 96 Guide for Measuring Horizontal Positioning During Measurements of Surface Water Depths (Vol 11.01)
D 5911 – 95 Practice for a Minimum Set of Data Elements to Describe a Soil Sampling Site
D 5912 – 95 Test Method (Analytical Procedure) for Determining Hydraulic Conductivity of an Unconfined Aquifer by Overdamped Well Response to Instantaneous Change in Head (Slug Test)
D 5918 – 96 Test Methods for Frost Heave and Thaw Weakening Susceptibility of Soils
D 5920 – 96 Test Method (Analytical Procedure) for Tests of Anisotropic Unconfined Aquifers by the Neuman Method
D 5921 – 96 Practice for Subsurface Site Characterization of Test Pits for On-Site Septic Systems
D 5922 – 96 Guide for Analysis of Spatial Variation in Geostatistical Site Investigations
D 5923 – 96 Guide for the Selection of Kriging Methods in Geostatistical Site Investigations
D 5924 – 96 Guide for the Selection of Simulation Approaches in Geostatistical Site Investigations
D 5925 – 96 Practice for Preliminary Sizing and Delineation of Soil Absorption Field Areas for On-Site Septic Systems
D 5928 – 96 Test Method for the Screening of Waste for Radioactivity (Vol 11.04)
D 5956 – 96 Guide for Sampling Strategies for Heterogeneous Wastes (Vol 11.04)
D 5978 – 96 Guide for Maintenance and Rehabilitation of Ground Water Monitoring Wells
D 5979 – 96 Guide for Conceptualization and Characterization of Ground Water Flow Systems
D 5980 – 96 Guide for Selection and Documentation of Existing Wells for Use in Environmental Site Characterization and Monitoring
D 5981 – 96 Guide for Calibrating a Ground-Water Flow Model Application
D 5995 – 96 Guide for Environmental Site Characterization in Cold Regions
D 6000 – 96 Guide for the Presentation of Water-Level Information From Ground Water Sites
D 6001 – 96 Guide for Direct Push Water Sampling for Geoenvironmental Investigations
D 6008 – 96 Practice for Conducting Environmental Baseline Surveys (Vol 11.04)
D 6009 – 96 Guide for Sampling Waste Piles (Vol 11.04)
D 6025 – 96 Guide for Developing and Evaluating Ground-Water Modeling Codes
D 6026 – 96 Practice for Using Significant Digits in Calculating and Reporting Geotechnical Test Data
D 6027 – 96 Practice for Calibrating Linear Displacement Transducers for Geotechnical Purposes
D 6028 – 96 Test Method (Analytical Procedure) for Determining Hydraulic Properties of a Confined Aquifer Taking Into Consideration Storage of Water in Leaky Confining Beds by the Modified Hantush Method
D 6030 – 96 Guide to Selection of Methods for Assessing Ground Water or Aquifer Sensitivity and Vulnerability
D 6031 – 96 Test Method for Logging In Situ Moisture Content and Density of Soil and Rock by the Nuclear Method in Horizontal, Slanted and Vertical Tubes
D 6032 – 96 Test Method for Determining Rock Quality Designation (RDQ) of Rock Core
D 6033 – 96 Guide for Describing the Functionality of a Ground-Water Modeling Code
D 6034 – 96 Test Method (Analytical Procedure) for Determining the Efficiency of a Production Well in A Confined Aquifer From a Constant Rate Pumping Test
D 6035 – 96 Test Method for Determining the Effect of Freeze-Thaw on the Hydraulic Conductivity of Compacted or Undisturbed Soil Specimens Using a Flexible Wall Permeameter
D 6036 – 96 Guide for Displaying the Results of Chemical Analyses of Ground Water for Major Ions and Trace Elements–Use of Maps
D 6044 – 96 Guide for Representative Sampling and Management of Waste and Contaminated Media (Vol 11.04)
D 6051 – 96 Guide for Composite Sampling and Field Subsampling For Environmental Waste Management Activities (Vol 11.04)
D 6063 – 96 Guide for Sampling of Drums and Similar Containers By Field Personnel (Vol 11.04)
D 6066 – 96 Practice for Determining the Normalized Penetration Resistance of Sand for Liquefaction Potential Evaluation
D 6067 – 96 Guide for Using the Electronic Cone Penetrometer for Environmental Site Characterization
E 105 – 58 Practice for Probability Sampling of Materials (Vols 07.02 and 14.02)
E 170 – 92a Terminology Relating to Radiation Measurements and Dosimetry (Vol 12.02)
E 177 – 90a Practice for Use of the Terms Precision and Bias in ASTM Test Methods (Vol 14.02)
E 178 – 80 Practice for Dealing with Outlying Observations (Vol 14.02)
E 181 – 93 General Methods for Detector Calibration and Analysis of Radionuclides (Vol 12.02)
E 337 – 84 Test Method of Measuring Humidity with a Psychrometer (the Measurement of Wet- and Dry-Bulb Temperatures) (Vol 11.03)
E 380 – 92 Practice for Use of International System of Unit (SI) (Modernized Metric System) (Vol 14.02; excerpts included in all ASTM volumes)
E 678 – 90 Practice for Evaluation of Technical Data (Vol 14.02) [Focusses on product liability matters]
E 816 – 84 Test Method for Calibration of Secondary Reference Pyrheliometers and Pyrheliometers for Field Use (Vol 11.03)
E 824 – 81 Test Method for Transfer of Calibration from Reference to Field Pyranometers (Vol 11.03)
E 884 – 82 Practice for Sampling Airborne Microorganisms at Municipal Solid Waste Processing Facilities (Vol 11.04)
E 913 – 82 Method for Calibration of Reference Pyranometers with Axis Vertical by the Shading Method (Vol 12.02)
E 941 – 83 Test Method for Calibration of Reference Pyranometers with Axis Tilted by the Shading Method (Vol 12.02)
E 1109 – 86 Test Method for Determining the Bulk Density of Solid Waste Fractions (Vol 11.04)
E 1167 – 87 Guide for Radiation Protection Programs for Decommissioning Operations (Vol 12.02)
E 1188 – 87 Practice for Collection and Preservation of Information and Physical Items by a Technical Investigator (Vol 14.02)

E 1287 – 89	Guide for Aseptic Sampling of Biological Materials (Vol 11.04)
E 1370 – 90	Guide to Air Sampling Strategies for Worker and Workplace Protection (Vol 11.03)
E 1391 – 90	Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing (Vol 11.04)
E 1430 – 91	Guide for Using Release Detection Devices with Underground Storage Tanks (Vol 11.04)
E 1526 – 93	Practice for Evaluating the Performance of Release Detection Systems for Underground Storage Tank Systems (Vol 11.04)
E 1527 – 94	Practice for Environmental Site Assessments: Phase 1 Assessment Process (Vol 11.04)
E 1528 – 93	Practice for Environmental Site Assessment Transaction Screen Process (Vol 11.04)
E 1553 – 93	Practice for the Collection of Airborne Particulate Lead During Abatement and Construction Activities (Vol 04.07)
E 1609 – 94	Guide for Development and Implementation of a Pollution Prevention Program (Vol 11.04)
E 1689 – 95	Guide for Developing Conceptual Site Models for Contaminated Sites (Vol 11.05)
E 1739 – 95	Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites (Vol 11.04)
F 480 – 91	Specifications for Thermoplastic Water Well Casing Pipe and Couplings Made in Standard Dimension Ratios (SDR) SCH 40 and SCH 80 (Vol 08.04)
F 488 – 95	Test Method for On-Site Screening Heterotrophic Bacteria in Water (Vol 11.02)
F 625 – 79	Practice for Describing of Environmental Conditions Relevant to Spill Control Systems (Vol 11.04)
F 1084 – 90	Guide for Sampling Oil/Water Mixtures for Oil Spill Recovery Equipment (Vol 11.04)
G 51 – 92	Test Method for pH of Soil for Use in Corrosion Testing
G 57 – 78	Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method
ES 40	Practice for Procedures for the Assessment of Buried Steel Tanks Prior to the Additions of Cathodic Protection (Vol 11.04)
PS 3 – 95	Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases (Vol 11.04)
PS 11 – 95	Practice for Environmental Regulatory Compliance Audits (Vol 11.04)
PS 12 – 95	Guide for the Study and Evaluation of an Organization's Environmental Management Systems (Vol 11.04)
PS 14 – 95	Practice for Lifecycle Costing for Pollution Prevention (Vol 11.04)
PS 26 – 96	Guide for Development and Implementation of a Source Reduction Program (Vol 11.04)
PS 47 – 95	Test Method for Screening, Qualification, and Characterization of Total Polychlorinated Biphenyls by Room Temperature Phosphorescence (Vol 11.02)
PS 64 – 96	Guide for Developing Appropriate Statistical Approaches for Ground-Water Detection Monitoring Programs
PS 85 – 96	Guide for Expedited Site Characterization of Hazardous Waste Contaminated Sites

X1.5 *ASTM Standards*—Indexed in Table X1.2 (In Vol 11.05, unless otherwise specified):[56]

D 3731 – 87	Practice for Measurement of Chlorophyll Content of Algae in Surface Waters
D 3978 – 80	Practice for Algal Growth Potential Testing with *Selenastrum Capricornutum*
D 4131 – 84	Practice for Sampling Fish with Rotenone
D 4132 – 82	Practice for Sampling Phytoplankton with Conical Tow Nets
D 4133 – 82	Practice for Sampling Phytoplankton with Pumps
D 4134 – 82	Practice for Sampling Phytoplankton with a Clark-Bumpus Plankton Sampler
D 4135 – 82	Practice for Sampling Phytoplankton with Depth-Integrating Samplers
D 4136 – 82	Practice for Sampling Phytoplankton with Water-Sampling Bottles
D 4137 – 82	Practice for Preserving Phytoplankton Samples
D 4148 – 82	Test Method for Analysis of Phytoplankton in Surface Water by the Sedgwick-Rafter Method
D 4149 – 82	Classification for Sampling Phytoplankton in Surface Waters
D 4211 – 82	Classification for Fish Sampling
D 4319 – 93	Test Method for Distribution Ratios by the Short-Term Batch Method (Vol 04.08)
D 4342 – 84	Practice for Collecting Benthic Macroinvertebrates with the Ponar Grab Sampler
D 4343 – 84	Practice for Collecting Benthic Macroinvertebrates with the Ekman Grab Sampler
D 4344 – 84	Practice for Collecting Benthic Macroinvertebrates with the Smith-McIntyre Grab Sampler
D 4345 – 84	Practice for Collecting Benthic Macroinvertebrates with the Van Veen Grab Sampler
D 4346 – 84	Practice for Collecting Benthic Macroinvertebrates with the Okean 50 Grab Sampler
D 4347 – 84	Practice for Collecting Benthic Macroinvertebrates with the Shipek (Scoop) Grab Sampler
D 4348 – 84	Practice for Collecting Benthic Macroinvertebrates with the Holme (Scoop) Grab Sampler
D 4387 – 87	Guide for Selecting Sampling Devices for Collection Benthic Macroinvertebrates
D 4401 – 84	Practice for Collecting Benthic Macroinvertebrates with the Peterson Grab Sampler
D 4407 – 84	Practice for Collecting Benthic Macroinvertebrates with the Orange Peel Grab Sampler
D 4556 – 85	Guide for Selecting Stream-Net Sampling Devices for Collecting Benthic Macroinvertebrates
D 4557 – 85	Practice for Collecting Benthic Macroinvertebrates with Surber and Related Type Samplers
D 4558 – 85	Practice for Collecting Benthic Macroinvertebrates with Drift Nets
D 4646 – 87	Test Method for 24-Hour Batch Type Measurement of Contaminant Sorption by Soils and Sediments
D 4874 – 95	Test Method for Leaching Solid Material Wastes in a Column Apparatus (Vol 11.04)
D 5285 – 92	Test Method for 24-Hour Batch-Type Measurements of Volatile Organic Sorption by Soils and Sediment
D 5660 – 95	Test Method for Assessing the Microbial Detoxification of Chemically Contaminated Water and Soils Using a Toxicity Test with a Luminescent Marine Bacterium (Vol 11.04)
E 724 – 94	Guide for Conducting Static Acute Toxicity Tests Starting with Embryos of Four Species of Saltwater Bivalve Mollusks
E 729 – 88a	Guide for Conducting Acute Toxicity Tests on Test Materials with Fishes, Macroinvertebrates, and Amphibians
E 857 – 87	Practice for Conducting Substrate Dietary Toxicity Tests with Avian Species
E 895 – 89	Practice for Determination of Hydrolysis Rate Constants of Organic Chemicals in Aqueous Solutions
E 896 – 92	Test Method for Conducting Aqueous Direct Photolysis Tests
E 943 – 95	Terminology Relating to Biological Effects and Environmental Fate
E 978 – 92	Practice for Evaluating Environmental Fate Models of Chemicals
E 1022 – 94	Practice for Conducting Bioconcentration Tests with Fishes and Saltwater Bivalve Mollusks
E 1023 – 84	Guide for Assessing the Hazard of a Material to Aquatic Organisms and Their Uses
E 1062 – 86	Practice for Conducting Reproductive Studies with Avian Species
E 1147 – 92	Test Method for Partition Coefficient (*N*-Octanol/Water) Estimation by Liquid Chromatography
E 1148 – 87	Test Method for Measurements of Aqueous Solubility
E 1191 – 90	Guide for Conducting Life-Cycle Toxicity Tests with Saltwater Mysids
E 1192 – 88	Guide for Conducting Acute Toxicity Tests on Aqueous Effluents with Fishes, Macroinvertebrates, and Amphibians
E 1193 – 94	Guide for Conducting Renewal Life-Cycle Toxicity Tests with *Daphnia magna*
E 1194 – 87	Test Method for Vapor Pressure

[56] Prior to 1995 ASTM standards on biological effects and environmental fate were published in Volume 11.04. Beginning in 1995 that volume was divided into two separate volumes: (*1*) Volume 11.04 (Environmental Assessment; Hazardous Substances and Oil Spill Response; Waste Management) and (*2*) Volume 11.05 (Biological Effects and Environmental Fate; Biotechnology; Pesticides).

E 1195 – 87 Test Method for Sorption Constant (Koc) for Organic Chemicals in Soil and Sediments
E 1196 – 92 Test Method for Determining the Anaerobic Biodegradation Potential of Organic Chemicals
E 1197 – 87 Guide for Conducting a Terrestrial Soil-Core Microcosm Test
E 1198 – 87 Practice for Sampling Zooplankton with Pumps
E 1199 – 87 Practice for Sampling Zooplankton with Clarke-Pumpus Plankton Sampler
E 1200 – 87 Practice for Preserving Zooplankton Samples
E 1201 – 87 Practice for Sampling Zooplankton with Conical Tow Nets
E 1218 – 90 Guide for Conducting Static 96-h Toxicity Tests with Microalgae
E 1241 – 92 Guide to Conducting Early Life-Stage Toxicity Tests with Fishes
E 1242 – 88 Practice for Using Octanol-Water Partition Coefficient to Estimate Median Lethal Concentration for Fish Due to Narcosis
E 1278 – 88 Guide for Radioactive Pathway Methodology for Release of Site Following Decommissioning (Vol 12.02)
E 1279 – 89 Test Method for Biodegradation by a Shake-Flask Die-Away Method (Vol 11.02)
E 1295 – 89 Guide for Conducting Three-Brood Renewal Toxicity Tests with *Ceriodaphnia dubia*
E 1365 – 90 Guide for Conducting Static Acute Aquiatic Toxicity Screening Tests with the Mosquito *Wyoemyia smithii* (Coquillett) (Discontinued; 1994)
E 1366 – 91 Practice for Standardized Aquatic Microcosm: Fresh Water
E 1367 – 92 Guide for Conducting 10-Day Static Sediment Toxicity Tests with Marine and Estuarine Amphipods
E 1383 – 94a Guide for Conducting Sediment Toxicity Tests with Freshwater Invertebrates (Withdrawn 1996)
E 1391 – 94 Guide for Collection, Storage, Characterization, and Manipulation of Sediments for Toxicological Testing
E 1415 – 91 Guide for Conducting Static Toxicity Tests with *Lemna Gibba* G3
E 1440 – 91 Guide for Acute Toxicity Test with the Rotifer *Brachionus*
E 1463 – 92 Guide for Conducting Static and Flow-Through Acute Toxicity Tests with Mysids from the West Coast of the United States
E 1468 – 92 Practice for Collecting Benthic Macroinvertebrates with the Basket Sampler
E 1469 – 92 Practice for Collecting Benthic Macroinvertebrates with Multiple-Plate Samplers
E 1498 – 92 Guide for Conducting Sexual Reproduction Test with Seaweeds
E 1525 – 94a Guide for Designing Biological Tests With Sediments (Vol 11.05)
E 1562 – 94 Guide for Conducting Acute, Chronic and Lifecycle Aquatic Toxicity Tests with Polychateous Annelids (Vol 11.04)
E 1563 – 95 Guide for Conducting Static Acute Toxicity Tests with Echinoid Embroys
E 1604 – 94 Guide for Behavioral Testing in Aquatic Toxicology
E 1624 – 94 Guide for Chemical Fate in Site-Specific Sediment/Water Microcosms
E 1625 – 94 Test Method for Determining Biodegradability of Organic Chemicals in Semi-Continuous Activated Sludge (SCAS)
E 1676 – 95 Guide for Conducting a Laboratory Soil Toxicity Test with Lumbricid Earthworm *Ei Senia Foetida*
E 1688 – 95 Guide for Determination of the Bioaccumulation of Sediment-Associated Contaminants by Benthic Invertebrates
E 1706 – 95a Test Methods for Measuring the Toxicity of Sediment-Associated Contaminates with Fresh Water Invertebrates
E 1711 – 95 Guide for the Measurement of Behavior During Fish Toxicity Tests
E 1720 – 95 Test Method for Determining Ready, Ultimate Biodegradability of Organic Chemicals in a Sealed Vessel CO_2-Production Test
E 1733 – 95 Guide for the Use of Lighting in Laboratory Testing
E 1768 – 95 Guide for Ventilatory Behavioral Toxicology Testing of Freshwater Fish
P 235 – 93 Test Method for Fluorometric Determination of Toxicity-Induced Enzymatic Inhibition in *Daphnia magna*

X2. MAJOR NON-ASTM REFERENCES ON ENVIRONMENTAL SITE CHARACTERIZATION

X2.1 *General Applications:*

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