Designation: D6235 – 04 (Reapproved 2010)

Standard Practice for
Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites[1]

1. Scope

1.1 *Applicability of the ECS Process*—This practice covers a process for expedited site characterization (ESC) of hazardous waste contaminated sites[2] to identify vadose zone, groundwater and other relevant contaminant migration pathways and determine the distribution, concentration, and fate of contaminants for the purpose of providing an ESC client, regulatory authority, and stakeholders with the necessary information to choose a course of action.[3] Generally, the process is applicable to larger-scale projects, such as CERCLA (Superfund) remedial investigations and RCRA facility investigations.[4] When used as part of the Superfund response process, this Practice should be used in conjunction with U.S. EPA's guidance document titled *Using Dynamic Field Activities for On-Site Decision Making: A Guide for Project Managers* (**1**). The ESC process is also applicable to other contaminated sites where the ESC process can be reasonably expected to reduce the time and cost of site characterization compared to alternative approaches. The ESC process has been applied successfully at a variety of sites in different states and EPA regions. (See Table X1.1). It typically achieves significant cost and schedule savings compared to traditional site characterization. (See X1.2 and X1.3).[5]

1.2 *Features of the ESC Process*—The ESC process operates within the framework of existing regulatory programs. It focuses on collecting only the information required to meet characterization objectives and on ensuring that characterization ceases as soon as the objectives are met. Central to the ESC process is the use of judgement-based sampling and measurement to characterize vadose zone and groundwater contamination in a limited number of field mobilizations by an integrated multidisciplinary team, led by a technical leader and operating within the framework of a dynamic work plan that gives him or her the flexibility of responsibility to select the type and location of measurements needed to optimize data collection activities. Table 1 identifies other essential features of the ESC process, and Fig. 1 presents a flow diagram for the entire ESC process.

1.3 *Investigation Methods*—The process described in this practice is based on good scientific practice but is not tied to any particular regulatory program, site investigation method or technique, chemical analysis method, statistical analysis method, risk analysis method, or computer modeling code. Appropriate investigation techniques in an ESC project are highly site specific and are selected and modified based upon the professional judgement of the core technical team (in particular the technical team leader). Whenever feasible, noninvasive and minimally invasive methods are used, as discussed in Appendix X3. Appropriate chemical analysis methods are equally site specific. Analyses may be conducted in the field or laboratory, depending on data quality requirements, required turnaround time, and costs.

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

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[2] The term hazardous waste in the title is used descriptively. The term also has specific meanings in the context of different regulatory programs. Expedited site characterization is also appropriate for radiologically contaminated sites and some larger petroleum release sites, such as refineries. Section 4.2 further identifies types of contaminated sites where ESC may be appropriate. See Appendix X1 for additional background on the ESC process.

[3] The text of this practice emphasizes vadose zone and groundwater contamination because these contaminant migration pathways are the most difficult to characterize. An ESC project should also address all other relevant contaminant migration pathways, such as air, surface water, submerged sediments, and biota.

[4] A CERCLA preliminary assessment/site inspections (PA/SI) or a RCRA facility assessment (RFA) is generally required to provide information supporting a decision to initiate the ESC process. (See Appendix X2).

[5] This practice uses the term "traditional" site characterization to refer to the approach that has typically been used for characterizing contaminated sites at CERLA and RCRA sites during the 1980s and early 1990s.

TABLE 1 Minimum Criteria for a Project Using ASTM Expedited Site Characterization Process

NOTE 1—Other site characterization approaches may include many of the below elements, but all must be present for an investigation using the ASTM ESC process.

1. A technical team leader oversees the ESC project and leads the ESC core technical team. See Fig. 2, step 1.a in Fig. 3, 6.2 and 7.1.1.

2. Project objectives, data quality requirements, and performance criteria are defined by some process that includes ESC client, regulatory authority, and stakeholders. See Step 1b in Fig. 3 and 6.3.

3. The technical team leader and an integrated multidisciplinary core technical team with expertise in geologic, hydrologic, and chemical systems work together, as areas of expertise are needed, in the field and throughout the process. See Fig. 2, Step 2 in Fig. 3, and 7.1.

4. Intensive compilation, quality evaluation, and independent analysis and interpretation of prior data are used to develop a preliminary site model. See Step 3a in Fig. 3 and 8.1 – 8.5

5. Dynamic work plan, approved by ESC client and regulatory authority, provides framework for use of multiple complementary, site-appropriate geologic and hydrologic investigation methods, along with rapid site appropriate methods for containment analysis. See Step 4 in Fig. 3, 8.6, 9.2.4, and Appendix X3.

6. ESC project is based primarily on judgement-based sampling and measurements to test and improve the concepts and details of the evolving site model. See Steps 5 and 6 in Fig. 3, 3.1.16, 6.3.1, and X1.4.4.1.

7. Quality control procedures are applied to all aspects of ESC data collection and handling, including field work for geologic and hydrologic characterization. See Steps 5 and 6 in Fig. 3, 9.2.6, 10.1.2, and Appendix X4 and Appendix X5.

8. Field data collection is initially focused on geologic and hydrologic characterization of vadose zone, groundwater and other relevant contaminant migration pathways (and on identifying contaminants of concern, if they are not already known), followed by delineating the distribution, concentration, and fate of contaminants, based on knowledge of the relevant contaminant migration pathways. This effort typically requires no more than two field mobilizations. See Steps 5a and 6a in Fig. 3 and Sections 10 and 11.

9. Field data are integrated, analyzed, and interpreted daily to refine the evolving site model and are used to optimize the type and location of subsequent field data collection until project objectives have been met. See Steps 5b and 6b in Fig. 3 and 10.1.3.

10. Final site model provides ESC client, regulatory authority, and stakeholders with the information required to choose a course of action based on risk analysis of regulatory standards-based cleanup criteria. See Section 12.

1.4 *Sites Generally Not Appropriate for the ESC Process*—Generally, the ESC process is not applicable to: small petroleum release sites, real estate property transactions that require no more than a Phase I ESA, sites where contamination is limited to the near surface or there is no basis for suspecting that contaminant movement through the vadose zone and groundwater is a matter of concern, sites where the cost of remedial action is likely to be less than the cost of site characterization, or sites where existing statutes or regulations prohibit the use of essential features of the ESC process.[6]

1.5 *Other Potentially Applicable ASTM Standards for Site Characterization*—Guide E1912 addresses accelerated site characterization (ASC) for petroleum release sites, and Guide E1739 addresses use of the risk-based corrective action (RBCA) process at petroleum release sites. Section X1.5.1 describes the ASC process, and X1.5.2 discusses the relationship between ESC and the RBCA process. Practices E1527 and E1528 and Guide E1903 address real estate property transactions, and X1.5.3 discusses the relationship between the ESC process and investigations for real estate property transactions. Classification D5746 addresses environmental conditions of property area types for Department of Defense installations, and Practice D6008 provides guidance on conducting environmental baseline surveys to determine certain elements of the environmental condition of federal real property.

1.6 The values stated in both inch-pound and SI units are to be regarded separately as the standard. The values given in parentheses are for information only.

1.7 *This practice 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 practice 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.*

1.8 *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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[6] The ASTM knows of no federal or state statutes or regulations that would prohibit use of the ESC process. Some elements of the ESC process may not be entirely consistent with existing federal and state guidance documents, and regulatory authorities are encouraged make appropriate exceptions.

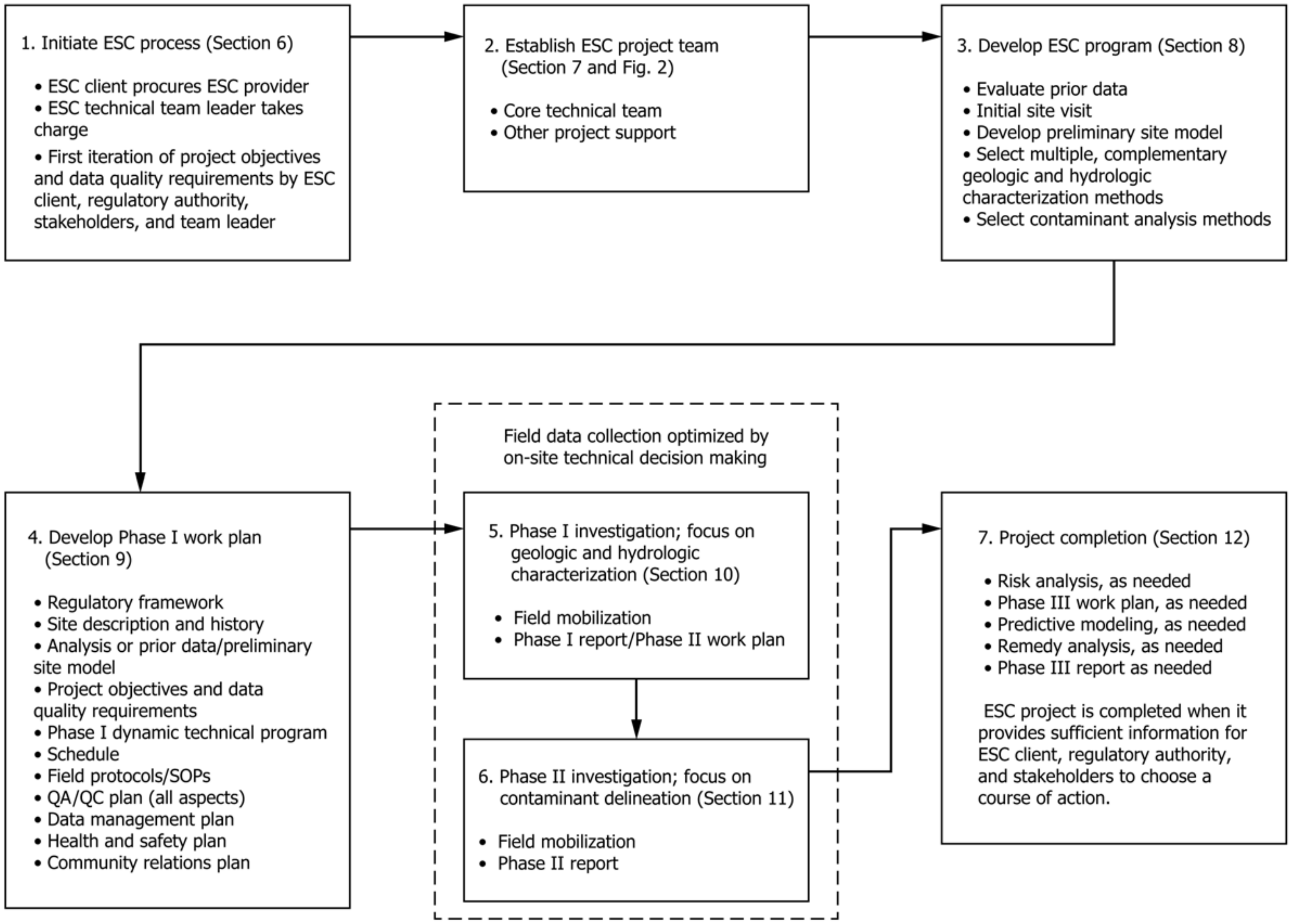

FIG. 1 Overview of the Expedited Site Characterization Process

2. Referenced Documents

2.1 *ASTM Standards:*[7]

D653 Terminology Relating to Soil, Rock, and Contained Fluids

D5717 Guide for Design of Ground-Water Monitoring Systems in Karst and Fractured-Rock Aquifers (Withdrawn 2005)[8]

D5730 Guide for Site Characterization for Environmental Purposes With Emphasis on Soil, Rock, the Vadose Zone and Groundwater (Withdrawn 2013)[8]

D5745 Guide for Developing and Implementing Short-Term Measures or Early Actions for Site Remediation

D5746 Classification of Environmental Condition of Property Area Types for Defense Base Closure and Realignment Facilities

D5792 Practice for Generation of Environmental Data Related to Waste Management Activities: Development of Data Quality Objectives

D5979 Guide for Conceptualization and Characterization of Groundwater Systems

D6008 Practice for Conducting Environmental Baseline Surveys

D6044 Guide for Representative Sampling for Management of Waste and Contaminated Media

E1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process

E1528 Practice for Limited Environmental Due Diligence: Transaction Screen Process

E1689 Guide for Developing Conceptual Site Models for Contaminated Sites

E1739 Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites

E1903 Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process

E1912 Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases (Withdrawn 2013)[8]

3. Terminology

3.1 *Definitions of Terms Specific to This Standard*—The following terms are specific to this practice, unless otherwise indicated. Because much of the terminology is specific to this practice, this section should be read carefully. Other terms are in accordance with other ASTM standards as specified.

3.1.1 *contaminants of concern (COCs)*—specific constituents that are identified for evaluation in the site characterization process.

3.1.1.1 *Discussion*—Identification of COCs from a larger list of suspected contaminants, including possible degradation products, usually takes place as a separate effort before an ESC project begins, but it can also be integrated into an ESC project. Deletions or additions to the list of COCs may occur during an ESC project, as appropriate, with approval by the ESC client and regulatory authority. This definition is the same as for chemical(s) of concern used in Guide E1912, except that "contaminants of concern" is the more common usage in hazardous waste site investigations.

3.1.2 *dynamic field activity*—a project that combines rapid on-site data generation with on-site decision making and is initiated through a process that includes systematic planning and development of a dynamic work plan (Adapted from U.S. EPA (**1**)).

3.1.2.1 *Discussion*—This practice focuses on dynamic field activities as they relate to site characterization

3.1.3 *dynamic work plan*—a site characterization work plan including a technical program that identifies the suite of field investigation methods and measurements that may be necessary to characterize a specific site, with the actual methods used and the locations of measurements and sampling points based on on-site technical decision making.

3.1.3.1 *Discussion*—The dynamic work plan, which must be approved by the ESC client and regulatory authority, provides a clearly defined framework (including geographic area, maximum depth (where appropriate), standard operating procedures for specific methods) within which the ESC technical team leader, supported by the appropriate technical core team members, has flexibility and responsibility to select the types and locations of measurements to optimize data collection activities. In contrast, a traditional site characterization work plan typically contains prescribed numbers and locations for field measurements, samples, and monitoring wells. (See Section 9).

3.1.4 *environmental receptor*—humans or other living organisms potentially exposed to and adversely affected by contaminants because they are present at the source(s) or along contaminant migration pathways. **(E1689)**

3.1.5 *environmental site assessment (ESA)*—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.

3.1.5.1 *Discussion*—This practice refers to ESC Phase I/II investigations to differentiate them from Phase I/II ESAs. The phases are not comparable. (See X1.5.3.) **(E1527)**

3.1.6 *ESC client*—the individual, agency, or organization responsible for a site or sites where ESC is being considered or has been initiated. An ESC client contracts with an ESC provider for an ESC project that characterizes a specific site.

3.1.7 *ESC core technical team*—the integrated multidisciplinary team, assembled by an ESC provider, that is responsible for an ESC project, consisting of a technical team leader and experienced individuals with expertise in geologic, hydrologic, and chemical systems; a working understanding of all elements and functions of contaminated site characterization; familiarity with risk analysis and remedial technologies; and capability to integrate and interpret all relevant data generated by the ESC project.

3.1.7.1 *Discussion*—The core technical team members are available for every stage of an ESC project and are involved in each stage as needed. The technical team leader is normally

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[7] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

[8] The last approved version of this historical standard is referenced on www.astm.org.

present in the field at all times. Other core technical team members are present during field data collection related to their area(s) of expertise. See 7.1 for further discussion of the responsibilities of the ESC core technical team.

NOTE 1—The core technical team should not be confused with the core team in the DOE SAFER process, which consists of a broader group of key decision makers for a DOE site. (See X1.4.5.) Normally, the ESC technical team leader would be a member of the SAFER core team.

3.1.8 *ESC Phase I investigation*—phase of ESC project focusing on geologic and hydrologic characterization of vadose zone and groundwater migration pathways and all other relevant contaminant migration pathways, such as air, surface water, submerged sediments, and biota as appropriate.

3.1.8.1 *Discussion*—Contaminant sources and contaminants of concern will also be identified in Phase I, if they are not already known, and sampling to establish contaminant distribution will occur to the extent that it contributes to understanding the geologic and hydrologic system and other relevant contaminant migration pathways.

3.1.9 *ESC Phase II investigation*—phase of ESC project focusing on sampling and analysis to determine the spatial distribution, concentration, and fate of contaminants, based on knowledge of the relevant contaminant migration pathways identified in Phase I. Additional geologic and hydrologic characterization is carried out as needed.

NOTE 2—This practice describes the ESC process as involving two phases with two discrete field mobilizations, because experience has shown that the amount of time required to characterize the geology and hydrology and then delineate contaminants in terms of the geologic and hydrologic system is generally too long for a single mobilization. However, when sufficient data of acceptability qualify are available, it may be possible to complete both activities in a single mobilization. In contrast, at difficult, complex sites, more than two field mobilizations might be required. A single mobilization would be designated as Phase I/II. More than one mobilization of the ESC project team (as distinct from field visits by a few project team members for collection of time-series data, such as water levels in wells) would be designated as Phase Ia, Phase Ib, and so forth.

3.1.10 *ESC Phase III study*—the final phase of an ESC project that occurs when the results of the Phase II investigation indicate that predictive modeling for risk analysis, remedy analysis and design for remedial action, or both, are required before the ESC client, regulatory authority, and stakeholders can choose a course of action. (See Section 12).

3.1.10.1 *Discussion*—At sites where remedial action is required, a Phase III study would be the equivalent to a CERCLA feasibility study and a RCRA corrective measures study. It is beyond the scope of this practice to address Phase III in detail.

3.1.11 *ESC project*—application of the ESC process by an ESC provider to a specific site to give the ESC client, regulatory authority, and stakeholders the necessary information to analyze risk or apply regulatory standards-based cleanup criteria to choose a course of action (no action, ongoing monitoring, or remedial action).

3.1.11.1 *Discussion*—This practice focuses on use of the ESC process to characterize contaminant migration pathways (and sources if they are not already known). An ESC project may also be expanded to include fate and transport modeling for risk analysis and for remedial action as additional steps after characterization of the contaminant source and migration pathways is completed. (See Section 12.)

3.1.12 *ESC project team*—the technical team leader, other members of the ESC core technical team, and all other individuals who provide technical and other support during an ESC project.

3.1.13 *ESC provider*—organization that supplies the ESC project team to an ESC client.

3.1.14 *ESC technical team leader*—an individual with training and experience in geologic and hydrologic systems (and familiarity with chemical systems and risk analysis methods) and the additional necessary skills for project management, who oversees an ESC project and leads the ESC core technical team in the field. (See also 7.1.1.)

3.1.14.1 *Discussion*—During field investigation phases, the technical team leader relies heavily on the expertise of the other core technical team members and project support personnel, but the leader retains responsibility for all decisions concerning ESC project activities, subject to quality assurance and health and safety oversight. (See 7.3.3 and 7.3.4.)

3.1.15 *expedited site characterization (ESC)*—a process for characterizing vadose zone and groundwater contaminated sites using primarily judgement-based sampling and measurements by an integrated, multidisciplinary core technical team, led by a technical team leader and operating within the framework of a dynamic work plan that gives the flexibility and responsibility to select the type and location of measurements to optimize data collection activities during a limited number of field mobilizations.

3.1.16 *judgement-based sampling and measurement*—an approach that uses expert judgement based on knowledge of the geologic, hydrologic, and chemical systems, together with analysis and interpretation of all prior measurements and sampling results, to select the type and location of subsequent measurements and samples needed to further refine the site model.

NOTE 3—In the context of the practice this type of sampling is used to determine the spatial distribution of physical and chemical properties at a site that can be used in defining the physical characteristics of the vadose zone and saturated zone. This definition differs from the definition of judgement sampling contained in Guide D6044: "taking of sample(s) based on judgement that it will more or less represent the average condition of the population." The heterogeneity of most geologic and subsurface hydrologic systems means that statistical- and geostatistical-based sampling approaches will require a much larger number of samples to delineate accurately the extent and concentration of contamination. (See X7.5.4.) Because the ESC approach depends primarily on expert judgement for characterization of vadose zone and groundwater contamination, the experience and competence of the core technical team are paramount.

3.1.17 *migration pathway*—the course through which a contaminant(s) in the environment may move away from the source(s) to potential environmental receptors.

3.1.17.1 *Discussion*—This definition is essentially the same as the term "exposure pathway" used in Guides E1912 and D5746. The ESC process focuses on vadose zone and groundwater migration pathways because they are the most difficult to characterize, but it should address all other relevant contaminant migration pathways. **(E1689)**

3.1.18 *on-site technical decision making*—the use of judgement-based sampling and measurement and statistically based approaches, as appropriate, by the core technical team, led by the technical team leader, within a framework defined by a dynamic work plan, to optimize field data collection during as ESC Phase I or Phase II field mobilization.

3.1.18.1 *Discussion*—On-site technical decision making, used by the ESC core technical team for field data collection (see 10.1.3), should not be confused with decision making by the ESC client, regulatory authority, and stakeholders to define ESC project objectives and data quality requirements and to choose a course of action when the project is completed. The use of on-site technical decision making in the context of a dynamic work plan is the approximate equivalent to the on-site iterative process described in Guide E1912.

3.1.19 *quality assurance (QA)*—measures taken to independently check and verify that the quality control procedures specified in the QA/QC plan for an ESC project are being carried out.

3.1.20 *quality control (QC)*—the process of ensuring the quality of data during their collection, measurement, integration, interpretation, and archiving, through the application of defined procedures.

3.1.21 *regulatory authority*—the federal, state, or local agency, or combination thereof, with primary responsibility for ensuring compliance with the environmental statutes and regulations that prompted initiation of ESC at a site.

3.1.22 *regulatory standards-based cleanup criteria*—contaminant cleanup criteria that do not involve a site-specific risk analysis.

3.1.23 *remedial action*—a course of action chosen by an ESC client, regulatory authority, and stakeholders which includes an engineered solution to address contamination.

3.1.23.1 *Discussion*—As discussed in 4.4.2, the ESC process avoids a presumption that remedial action is required. In this practice, no action and ongoing monitoring are considered to be alternatives to remedial action.

3.1.24 *risk analysis*—the process by which an ESC client, the regulatory authority, and stakeholders evaluate the results of an ESC project to choose a course of action based on the risk posed by contaminant sources and migration pathways to environmental receptors.

3.1.24.1 *Discussion*—This practice uses the terms "risk analysis" and "analyzing risk" to avoid the more specific connotations associated with the terms "risk assessment" and "risk evaluation." An ESC project should be designed to accommodate any method(s) of risk analysis specified by the ESC client, regulatory authority, and stakeholders.

3.1.25 *risk-based action level criteria*—contaminant concentrations above which the potential for risk to environmental receptors requires some form of risk analysis.

3.1.25.1 *Discussion*—Risk-based action level criteria would normally be defined by the ESC client, regulatory authority, and stakeholders early in the ESC process. Typically such criteria are based on non-site specific risk analysis procedures, such as those used to develop drinking water standards and maximum contaminant levels (MCLs) for specific chemicals, but may also be developed based on site-specific considerations.

3.1.26 *risk-based cleanup criteria*—target contaminant concentrations, defined by site-specific risk analysis, to be achieved by remedial action.

3.1.27 *site, n*—a place or location designated for a specific use, function, or study. **(D5730)**

3.1.28 *site characterization*—the process by which geologic, hydrologic, and chemical system information relating to contaminant migration pathways; the distribution, concentration and fate of contaminants; and environmental receptors is gathered, interpreted, and documented.

3.1.29 *site model*—a testable interpretation or working description of a site resulting from iterative characterization of the geologic, hydrologic, and chemical systems to identify relevant contaminant pathways; determine the distribution, concentration, and fate of contaminants; and where appropriate, identify environmental receptors.

3.1.29.1 *Discussion*—This practice uses the term "preliminary" site model to refer to the initial model based on regional geology and other prior data, the term "evolving" site model to refer to the site model as it develops during an ESC project, and the term "final" site model when further refinement is no longer required to satisfy the objectives of the ESC project. The initial site model may include alternative hypotheses to explain significant site features, which are tested, accepted, modified, or rejected as the evolving site model develops. Depending on the objectives of an ESC project, the final site model may or may not be comparable to the definitions of "conceptual site model" in Guides D5745 and E1689, which include sources, migration pathways, and environmental receptors. Where only regulatory standards-based cleanup criteria are to be applied, the final site model includes sources and migration pathways (12.2). Where risk analysis is the objective, environmental receptors are usually incorporated into the final site model after source and migration pathways have been fully characterized (see 12.3).

3.1.30 *source*—the location at which contamination has entered the natural environment.

3.1.30.1 *Discussion*—This definition has a more restricted meaning than the definition of source in Guide E1689 which includes primary sources, such as leaking drums, and secondary sources, such as contaminated soil. The definition in 3.1.30 refers to primary sources of contamination, which are normally delineated before an ESC project begins. **(D5745)**

3.1.31 *stakeholder*—any individual or organization other than the ESC client and regulatory authority that may be affected by the consequences of initiating ESC at a site, generally including owners, organizations, and individuals or communities that may be affected by contamination at the site. (See 5.2.1)

3.1.32 *vadose zone*—the hydrogeological region extending from the soil surface to the top of the principal water table; commonly referred to as the "unsaturated zone" or "zone of aeration." The alternate names are inadequate as they do not take into account locally saturated regions above the principle water table (for example, perched water zones). **(D653)**

3.2 *Acronyms:*

3.2.1 *ASC*—accelerated site characterization.

3.2.2 *ASTM*—American Society for Testing and Materials.

3.2.3 *BHC*—hexachlorocyclohexane (sometimes called benzene hexachloride).

3.2.4 *BLM*—Bureau of Land Management.

3.2.5 *CCC*—Commodity Credit Corporation.

3.2.6 *CERCLA*—Comprehensive Environmental Response, Compensation, and Liability Act of 1980, as amended, 42 USC 9620 et seq. (also called Superfund).

3.2.7 *CMS*—corrective measures study.

3.2.8 *COCs*—chemicals of concern.

3.2.9 *CPT*—cone penetrometer.

3.2.10 *CPT/LIF*—cone penetrometer/laser-induced fluorescence.

3.2.11 *DNAPLs*—dense nonaqueous phase liquids.

3.2.12 *DQO*—data quality objectives.

3.2.13 *DOD*—U.S. Department of Defense.

3.2.14 *DOE*—U.S. Department of Energy.

3.2.15 *EM*—electromagnetic.

3.2.16 *ECPT*—electronic cone penetrometer.

3.2.17 *EPA*—U.S. Environmental Protection Agency.

3.2.18 *ESA*—environmental site assessment.

3.2.19 *ESC*—expedited site characterization.

3.2.20 *FS*—feasibility study (Superfund).

3.2.21 *GPR*—ground penetrating radar.

3.2.22 *IA*—Iowa.

3.2.23 *ICP/AES*—inductively coupled plasma/atomic emission spectrometer.

3.2.24 *ICP/MS*—inductively coupled plasma/mass spectrometer.

3.2.25 *IMA*—immunoassay.

3.2.26 *KS*—Kansas.

3.2.27 *MO*—Missouri.

3.2.28 *NE*—Nebraska.

3.2.29 *NM*—New Mexico.

3.2.30 *MCL*—maximum contaminant level.

3.2.31 *MDL*—minimum detection limit.

3.2.32 *MSL*—mean sea level.

3.2.33 *NPL*—National Priority List (Superfund).

3.2.34 *OSB*—oil seepage basin.

3.2.35 *PA*—preliminary assessment (Superfund).

3.2.36 *PA/SI*—preliminary assessment/site inspection (Superfund).

3.2.37 *PAHs*—polyaromatic hydrocarbons.

3.2.38 *PCE*—perchlorethylene (tetrachloroethylene).

3.2.39 *QA*—quality assurance.

3.2.40 *QA/QC*—quality assurance/quality control.

3.2.41 *QC*—quality control.

3.2.42 *RBCA*—risk-based corrective action.

3.2.43 *RCRA*—Resource Conservation and Recovery Act, as amended, 42 USC 6901 et seq.

3.2.44 *RI*—remedial investigation/feasibility study (Superfund).

3.2.45 *RI/FS*—remedial investigation/feasibility study (Superfund).

3.2.46 *RFA*—RCRA facility assessment.

3.2.47 *RFI*—RCRA facility investigation.

3.2.48 *RFI/CMS*—RCRA facility investigation/corrective measures study.

3.2.49 *RFP*—request for proposal.

3.2.50 *SACM*—superfund accelerated cleanup model (U.S. EPA).

3.2.51 *SAFER*—streamlined approach for environmental restoration (DOE).

3.2.52 *SC*—South Carolina.

3.2.53 *SI*—site inspection (Superfund)

3.2.54 *SOPs*—standard operating procedures.

3.2.55 *SDHEC*—South Carolina Department of Health and Environmental Control.

3.2.56 *SDWA*—Safe Drinking Water Act.

3.2.57 *SRS*—Savannah River Site.

3.2.58 *SVOCs*—semivolatile organic compounds.

3.2.59 *TCE*—trichloroethylene.

3.2.60 *TDEM*—time domain electromagnetic.

3.2.61 *TX*—Texas.

3.2.62 *UMTRA*—Uranium Mill Tailing Remediation Act.

3.2.63 *USDA*—U.S. Department of Agriculture.

3.2.64 *USDI*—U.S. Department of the Interior.

3.2.65 *VOCs*—volatile organic compounds.

4. Significance and Use

4.1 *The ESC Process*—This practice describes a process for characterizing groundwater contamination at sites, that provides cost-effective, timely, high-quality information derived primarily from judgement-based sampling and measurements by an integrated, multidisciplinary project team during a limited number of field mobilizations. (See Appendix X1 for additional background on the ESC process, its distinction from traditional site characterization, and its relationship to other approaches to site characterization and Appendix X6 and X7 for illustrative examples of the ESC process.)

4.2 *Determining Appropriateness of ESC*—The ESC process should be initiated when an ESC client, regulatory authority, and stakeholders determine that contaminants at a site present a potential threat to human health or the environment and the ESC process will identify vadose zone, groundwater, and other contaminant migration pathways in a timely and cost-effective manner, especially when decisions concerning remedial or other action must be made as rapidly as possible. Situations where the process may be applicable are as follows:

4.2.1 *CERCLA*—CERCLA remedial investigation/feasibility studies (RI/FS). (See Appendix X2.) This practice should be used in conjunction with U.S. EPA (**1**).

4.2.2 *RCRA*—RCRA facility investigation/corrective measures studies (RFI/CMS). (See Appendix X2.)

NOTE 4—The ESC process can be continued to include CERCLA feasibility studies and RCRA corrective measures studies (see Section 12), but this practice focuses on its use for site characterization. Section X1.4.5 describes the relationship of the ESC process to the DOE SAFER and EPA SACM programs for accelerating the cleanup of contaminated sites.

4.2.3 *ESA*—Sites where environmental site assessments (ESAs) conducted by using Practice E1527, Practice E1528, and Guide E1903 identify levels of contamination requiring further, more intensive characterization of the geologic and hydrologic system of contaminant migration pathways. Section X1.5.3 discusses the relationship between ESAs and the ESC process.

4.2.4 *Petroleum Release Sites*—Large petroleum release sites, such as refineries. The user should review both this practice and Guide E1912 to evaluate whether the ESC or ASC process is more appropriate for such sites.

4.2.5 *Subsurface Radioactivity*—Sites or facilities with subsurface contamination by radioactivity not regulated by RCRA or CERCLA.

4.2.6 *Defense Department Base Closure Actions*—where vadose zone and groundwater contamination are present.

4.2.7 *Other Subsurface Contamination* —Other sites or facilities where contaminant migration in the vadose zone and groundwater is a matter of concern and heterogeneity of the vadose zone and groundwater system or potential complex behavior of contaminants requires use of the ESC process.

4.3 *Defining Objectives and Data Quality Requirements*—The ESC process requires project objectives and data quality requirements that will provide the ESC client, regulatory authority, and stakeholders with the necessary information to analyze risk or apply regulatory standards-based cleanup in order to choose a course of action. Once these have been defined, the ESC process relies on the expert judgement of the core technical team, operating within the framework of an approved dynamic work plan, as the primary means for selecting the type and location of measurements and samples throughout the ESC process. An ESC project focuses on collecting only the information required to meet the project objectives and ceases characterization as soon as the objectives are met.

NOTE 5—This practice uses the term "data quality requirements" to refer to the level of data accuracy and precision needed to meet the intended use for the data. The U.S. EPA Data Quality Objectives (DQO) process is one way to accomplish this. The ESC process applies the concept of quality control and data quality requirements to geologic and hydrologic data as well as chemical data, but within a general framework of judgement-based rather than statistical sampling methods. Section X1.4.4 discusses the DQO process in more detail along with the role of judgement-based and statistically based sampling methods in the ESC process. Practice D5792 provides guidance on development of DQOs for generation of environmental data related to waste management.

4.4 *Use of ESC Process for Risk Analysis and Remedial Action:*

4.4.1 *Characterizing Contaminant Migration Pathways*—Normally an ESC project will characterize the contaminant migration pathways (and sources if not already known) before any detailed risk analysis involving exposure to environmental receptors is performed, because environmental receptors are not known until the migration pathways are known. Risk analysis expertise will normally be required as an input into defining project objectives and data quality requirements (see 4.3); such expertise is involved as appropriate during field data collection phases of an ESC project. Identification of contaminant sources and environmental receptors for risk analysis is straightforward at most sites and does not, per se, require the ESC process. The ESC process focuses on characterizing vadose zone and groundwater contaminant migration pathways and determining the distribution, concentration, and fate of contaminants along these migration pathways, because these factors are more difficult to identify than sources and environmental receptors.

4.4.2 *Considering Remedial Action and Alternatives*—The ESC process is designed to avoid a presumption that remedial action is required (that is, an engineered solution rather than no further action or ongoing monitoring). In any ESC project, remediation engineering expertise is incorporated into the process at the earliest point at which a need for remedial action is identified. (See 13.3.) Guide D5745 provides guidance for developing and implementing short-term measures or early actions for site remediation.

4.5 *Flexibility Within ESC*—Modification of procedures described in this practice may be appropriate if required to satisfy project objectives or regulatory requirements, or for other reasons. The ESC process is flexible enough to accommodate a variety of different technical approaches to obtaining environmental data. However, for an investigation to qualify as an ESC project, as formalized by ASTM, modifications should not eliminate any of the essential features of the ESC process listed in Table 1. Alternative site characterization approaches that use some, but not all, of the essential elements described in Table 1 may be appropriate for a site, but these approaches would not qualify as an ESC project as defined in this practice. ASTM expects that as the ESC process becomes more widely used, modifications, enhancements, and refinements of the process will become evident and will be incorporated into future versions of this practice. ASTM requests that suggestions for revisions to the guide based on field application of the process be addressed to: Committee D18 Staff Manager at ASTM International.

NOTE 6—Users may prefer to use or develop alternative terminology for different aspects of the ESC process, depending on the regulatory context in which it is applied. However, precise or approximate equivalencies to steps or functions in the ESC process should be clearly identified. See, for example, RCRA and CERCLA equivalencies in Appendix X2.

4.6 *Use of ESC in Conjunction with Other Methods*—This practice can be used in conjunction with Guide D5730 for identification of potentially applicable ASTM standards and major non-ASTM guidance. In karst and fractured rock hydrogeologic settings, this practice can be used in conjunction with Guide D5717.

5. Summary of ESC Process

5.1 *Advantages of ESC*—The ESC process, when properly implemented, should provide higher quality information for decision making in a shorter period of time and a lower cost than traditional site characterization where contaminant migration in the vadose zone and groundwater are a matter of concern. Appendix X1 discusses the features of ESC that make this possible. Many current problems with remedial action at contaminated sites can be attributed to inadequate understanding of the geologic and hydrologic system of contaminant migration pathways, which results in failure to delineate the full extent of contamination and the controls on contaminant migration and suboptimal design of remedial measures. The multidisciplinary and focused nature of the ESC process results in a final model of a site that minimizes uncertainty concerning the geologic and hydrologic conditions and the spatial distribution and concentration of contaminants, providing a sound basis for choosing the appropriate course of action.

5.2 *Organization of an ESC Project*—The ESC client is primarily responsible for deciding that the ESC process is the best way to obtain the information needed to choose a course of action to address contamination at a site (see 6.1). Fig. 2 illustrates key relationships in an ESC project.

5.2.1 *ESC Client, Regulatory Authority, and Stakeholders*—The ESC client, regulatory authority, and stakeholders provide the overall framework for an ESC project by defining project objectives and data quality requirements. The technical team leader along with other project team members as appropriate, also participate in this process to ensure that the objectives and data quality requirements are reasonable and technically feasible.

NOTE 7—The ESC client is responsible for defining the level of involvement of the regulatory authority and stakeholders in an ESC project and for setting protocols for their interactions with the ESC project team. The credibility of ESC project results will be seriously compromised if the ESC client does not provide for meaningful participation of stakeholders throughout the ESC process. The ESC client is encouraged to facilitate responsible stakeholder involvement in the ESC process. This practice normally refers to the ESC client, regulatory authority, and stakeholders as a group, but the extent of stakeholder involvement, in particular, will be determined by the willingness of the ESC client to allow participation and the extent to which stakeholders insist that they be involved in the process.

5.2.2 *Core Technical Team*—The core technical team, headed by a technical team leader and typically consisting of three or four individuals with expertise in geologic, hydrologic, and chemical systems appropriate to the site, provides a continuous, integrated, multidisciplinary presence throughout the process (see 7.1). The technical team leader operates in close communications with the ESC client, and with the regulatory authority and stakeholders, subject to protocols established by the ESC client. (See Note 7.) The core technical team members are involved, as needed, in all steps of the ESC process; they are present in the field during data collection involving their areas of expertise and participate in the data collection, processing, and interpretation. The optimization of field investigation activities and the quality of the final site model depend on the interaction of the different perspectives of the core technical team members.

5.2.3 *Project Support*—The ESC core technical team operates with the support of a larger project team that includes technical personnel and equipment operators involved in data collection and sampling, as well as personnel providing other support functions such as logistics, data management, QA/QC, health and safety, and community relations (see 7.3). Some areas of project support expertise, such as statistics/geostatistics, fate and transport analysis (including digital modeling), risk analysis, and remediation engineering, may have a special role early in a project in defining the type of data required for the project and data quality requirements and are involved throughout the project as needed.

5.2.4 *Individuals with Multiple Responsibilities*—Qualified individuals within the core technical and support team carry out several functions to decrease costs and increase integration of the team. The number of individuals required to provide project support for an ESC project is site specific. Although the number of project support functions shown in Fig. 2 is large, the total amount of time spent for each function varies considerably. For example, during field operations, project support personnel involved in data management and health and safety are present at all times, whereas personnel providing most other project support functions are present only as needed.

5.2.5 *ESC Work Plans*—Each phase of an ESC investigation take place within the framework of a dynamic work plan that is reviewed and approved by the ESC client, regulatory, authority, and stakeholders. The Phase I work plan provides the overall framework for an ESC investigation (Section 9). The word "dynamic" refers to the section of the work plan that identifies the suite of field investigation methods and measurements that may be necessary to characterize a site, and the field approach where the actual methods used and the location of measurements and sampling points is based on on-site technical decision making. Work plans for subsequent phases are generally incorporated into the report for the previous investigation phase and only include information about the next phase of investigation that is not already included in the Phase I work plan.

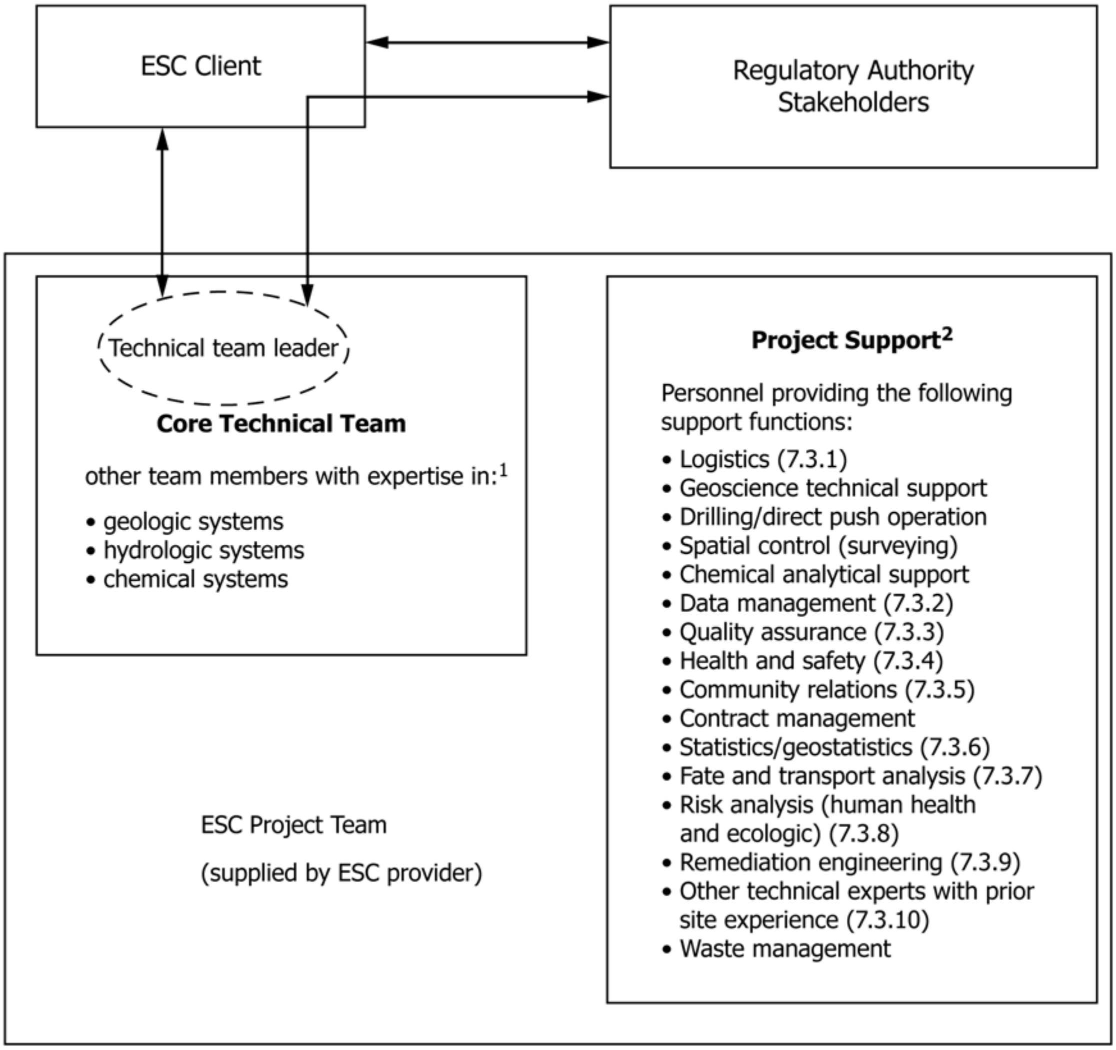
5.3 *Overview of ESC Process*—Figs. 3-5 present expanded flow diagrams illustrating important features and decision points in the ESC process. The steps outlined in this figure generally need to be followed in sequence. However, some steps are not strictly sequential. For example, Step 3b is the first iteration of the evolving site model that continues to be refined throughout the process. Major steps are as follows:

5.3.1 Initiate the ESC process and define project objectives and data quality requirements (see Section 6).

5.3.2 Establish ESC project team (see Section 7).

5.3.3 Develop ESC project (see Section 8), including review and interpretation of prior data, initial site visit, development of preliminary site model, and selection of multiple complementary investigation methods.

5.3.4 Develop Phase I dynamic work plan (See Section 9).



[1] Other areas of expertise may be included in the core technical team, as appropriate. The main criterion for determining whether a person with an area of expertise should be included in the core technical team is whether the type of expertise is required both for the process from beginning to end of an ESC project and for on-site technical decision making to optimize field investigations.

[2] Involved as needed throughout the process.

FIG. 2 ESC Project Team Relationships

5.3.5 ESC Phase I investigation, focusing on geologic and hydrologic characterization (see Section 10).

5.3.6 ESC Phase II investigation, focusing on the distribution, concentration, and fate of contaminants (see Section 11).

5.3.7 Project completion (see Fig. 4 and Fig. 5, and Section 12).

5.4 *Implementation of ESC*—Section 13 discusses considerations in the implementation of ESC as follows:

5.4.1 Relationship to regulatory process (see 13.1 and Appendix X2).

5.4.2 Role of risk analysis in ESC process (see 13.2).

5.4.3 Relationship of remediation engineering design and implementation to ESC (see 13.3).

5.4.4 Role of modeling in ESC process (see 13.4).

5.4.5 Procurement and contracting procedures for ESC (see 13.5).

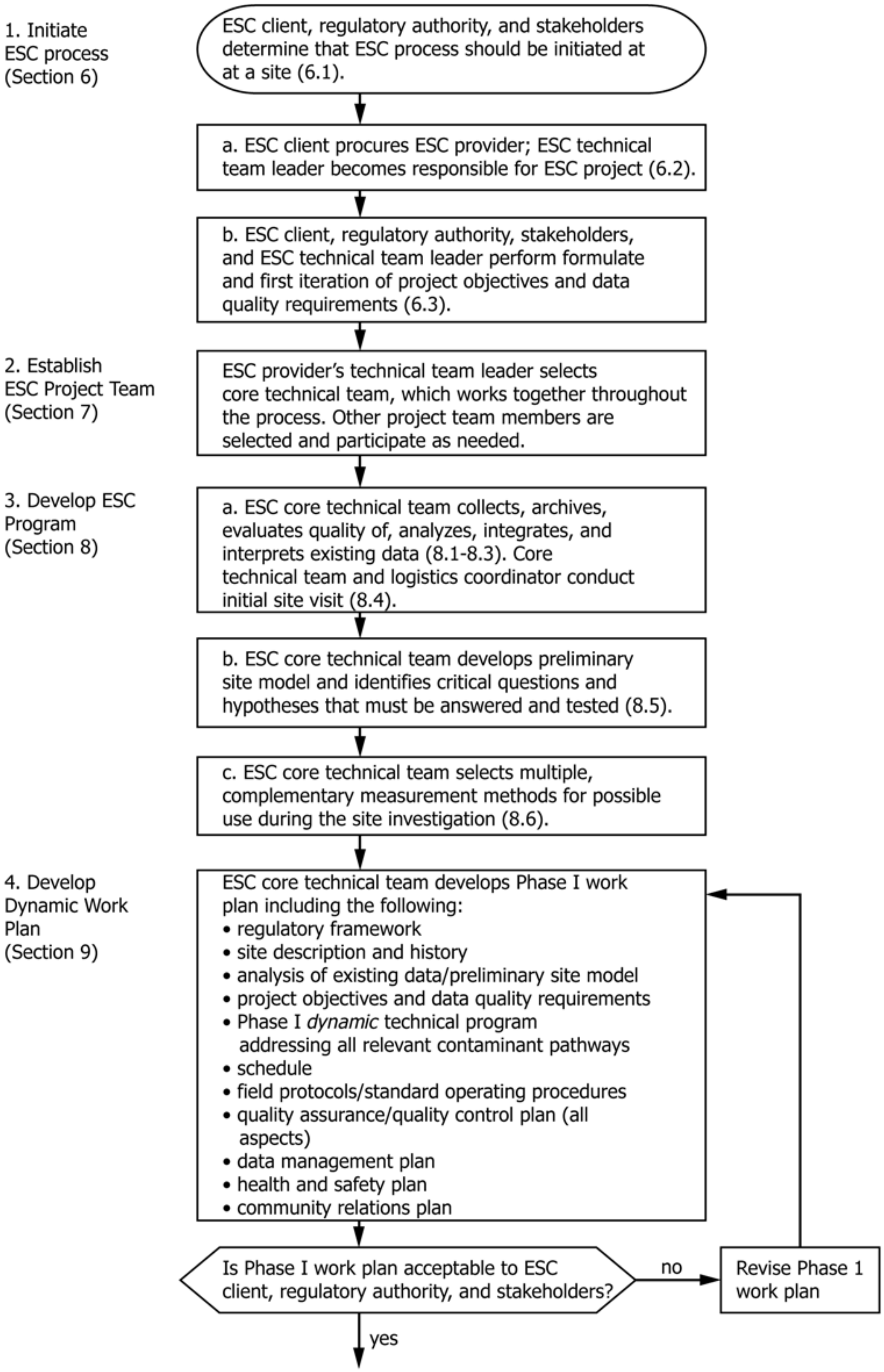


FIG. 3 Expedited Site Characterization Flow

5.4.6 Performance indicators for evaluating the success of ESC (see 13.6).

5.4.7 Factors that may affect performance indicators (see 13.7).

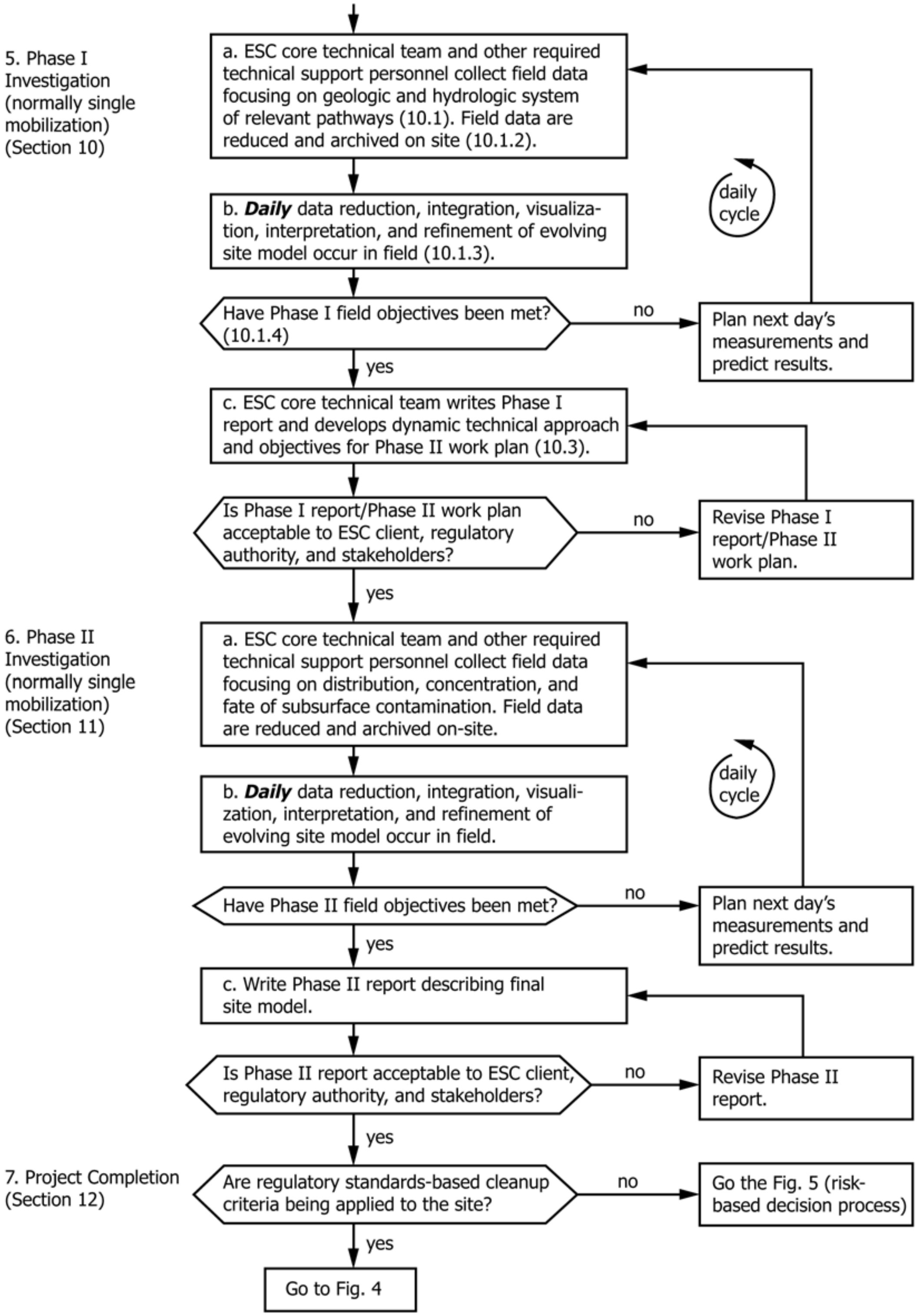


FIG. 3 Expedited Site Characterization Flow *(continued)*

6. Initiating the ESC Process and Defining Objectives and Data Quality Requirements

6.1 *Decision to Initiate ESC*—The ESC process is initiated when an ESC client, regulatory authority, and stakeholders determine that contaminants at a site present a potential threat to human health or the environment, and the ESC process will identify vadose zone, groundwater, and other relevant contaminant migration pathways in a timely and cost-effective manner, especially when decisions concerning remedial or other action must be expedited as rapidly as possible. The decision to initiate the ESC process is based on chemical sample and other data from preliminary site characterization. This practice does

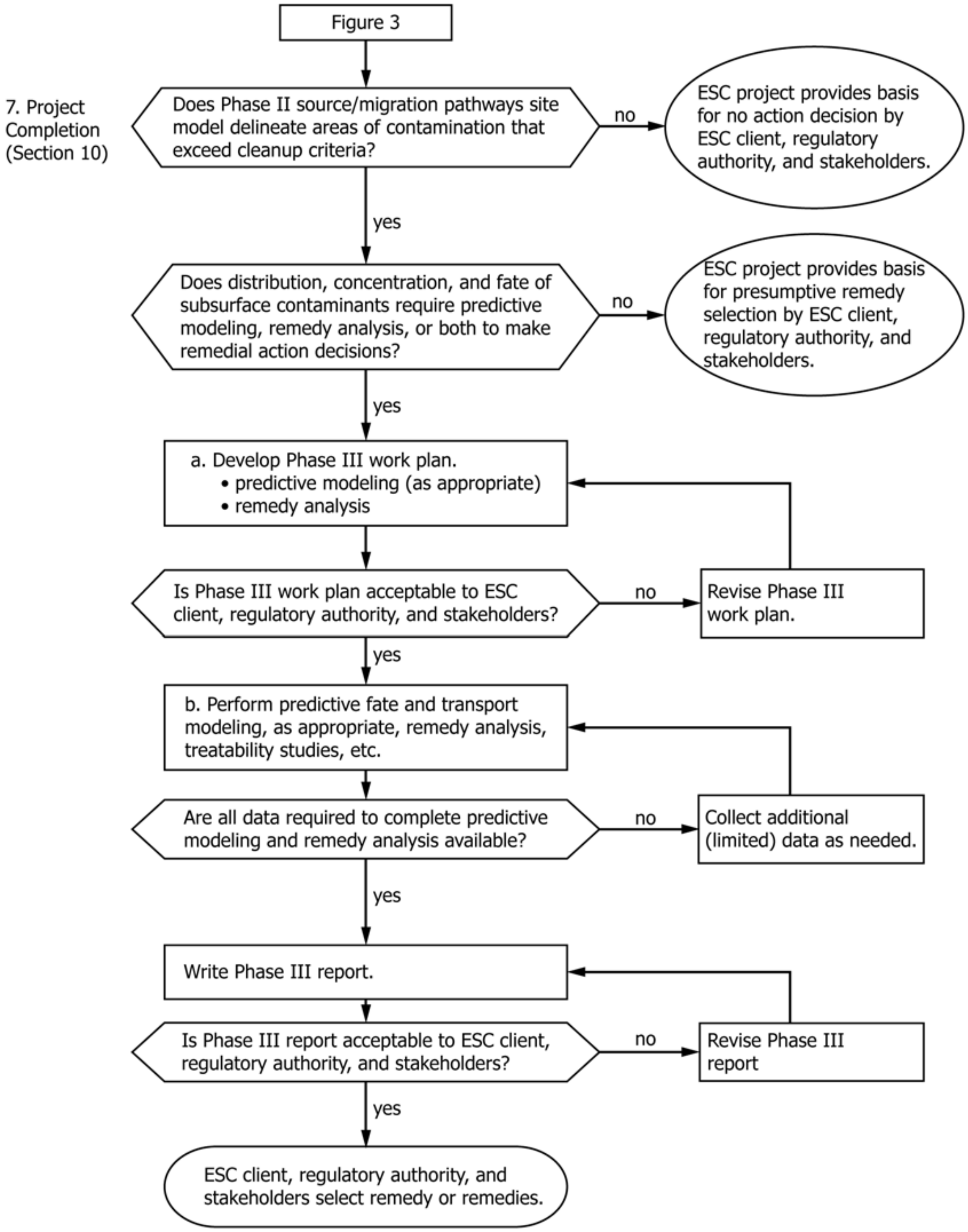


FIG. 4 ESC Project Completion Flow Diagram (Regulatory Standards-Based Cleanup Criteria)

not address specific procedures for such preliminary site characterization, but it assumes that the ESC client and regulatory authority have sufficient information to decide that the ESC process should be initiated. Acquiring this information generally requires a RCRA facility assessment (RFA) at RCRA sites or a preliminary assessment/site inspection (PA/SI) at CERCLA sites; see Appendix X2. At petroleum release sites, Guide E1739 may provide the basis for deciding whether the ASC or ESC processes should be initiated at a site (see X1.5.1 and X1.5.2). Some form of initial assessment would also be required at other types of contaminated sites to provide the basis for a decision to initiate the ESC process. Fig. 6 presents a flow diagram that can help determine whether the ESC process of other site characterization approaches may be appropriate for a site.

6.2 *Procuring an ESC Provider*—The ESC client is responsible for procuring an ESC provider. The ESC provider identifies the technical team leader at the outset, who then

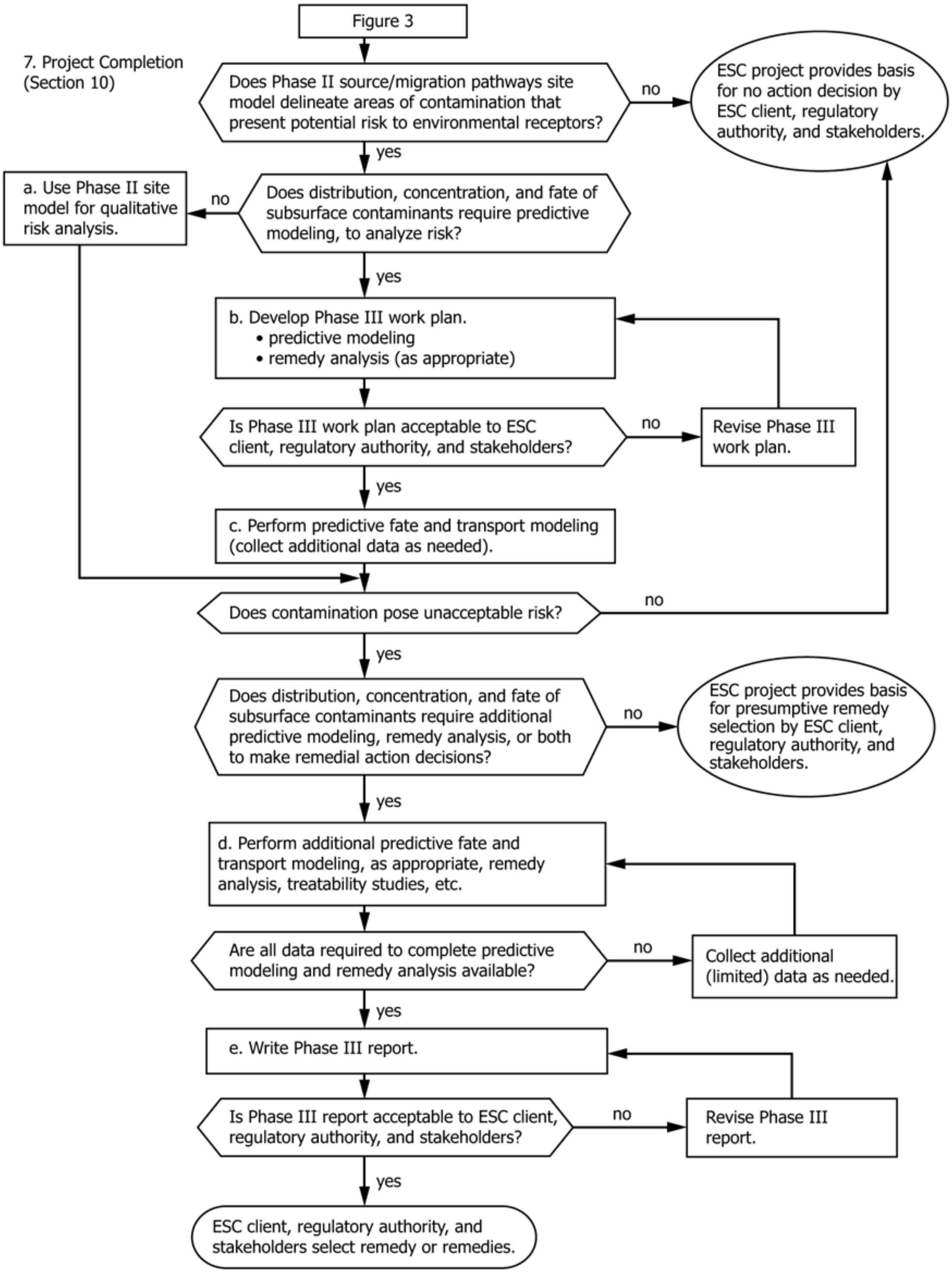
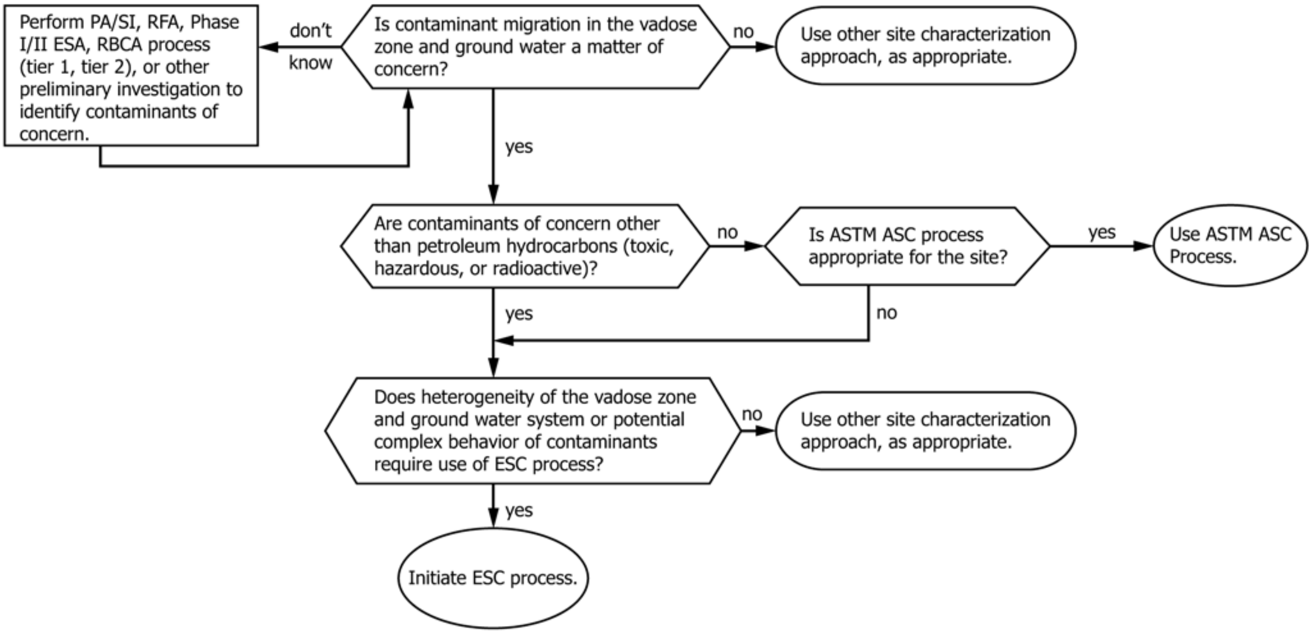


FIG. 5 ESC Project Completion Flow Diagram (Risk-Based Decision Process)

becomes responsible for the ESC project. Section 13.5 discusses some considerations in procuring an ESC provider. Section 7.4 describes criteria for evaluating qualifications of the ESC core technical team and other project support personnel.

6.3 *Defining Objectives and Data Quality Requirements*—Project objectives, data quality requirements, and criteria to evaluate when objectives have been met should be defined by some process that includes the ESC client, the regulatory



ASC = Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases (ASTM Guide PS 03).
ESA = Environmental Site Assessment (ASTM Practices E1527/E1528).
PA/SI = CERCLA Preliminary Assessment/Site Inspection.
RBCA = Risk-Based Corrective Active (ASTM Guide E1739 for Petroleum Release Sites).
RFA = RCRA Facility Assessment.

FIG. 6 Flow Diagram for Initiation of Expedited Site Characterization Process

authority, stakeholders, and the technical team leader, supported by other core technical team members.

6.3.1 *Data Quality Requirements*—The use of a primarily judgement-based sampling approach in the ESC process for delineation of the distribution and concentration of contaminants means that chemical analysis methods that provide definitive data for contaminants of concern are used from the beginning of an ESC project. This allows maximum acceptance of the analytical results by the ESC client, regulatory authority, and stakeholders and allows the data to be used for risk analysis without resampling. Screening-type chemical analysis methods for indicator geochemical and contaminant parameters, may be used as a complementary method for developing an understanding of the geologic and hydrologic system. Also, once the extent of contamination is known, additional sampling using less expensive analytical methods may be used to map contaminant concentrations in more detail.

NOTE 8—Chemical data quality classifications schemes vary somewhat between regulatory programs. The previous paragraph uses the term "definitive data" in the sense defined in U.S. EPA's *Data Quality Objectives Process for Superfund, Interim Final Guidance* (EPA/540/G-93/071). This would generally require methods meeting Data Quality Level 3 that is described in Appendix X2 in Guide E1912, which in turn is adapted from the data quality hierarchy used by the New Jersey Department of Environmental Protection.

6.3.2 *Modifications*—Definition of project objectives and data quality requirements is an iterative process that may require some modification as an ESC project proceeds. Where an ESC project is to be used for risk-based decision making, the risk analysis method to be used will affect data quality requirements. If contaminant sources and contaminants of concern are not known, their definition can occur by additional sampling and analysis as a separate activity before an ESC project begins, or this activity can be incorporated as an objective of the ESC project.

7. Establishing the ESC Project Team

7.1 *ESC Core Technical Team*—The ESC process will not work without an effective, integrated technical team consisting of experienced individuals with expertise in geologic, hydrologic, and chemical systems. The ESC provider is responsible for establishing the ESC core technical team, which will typically consist of two or three members in addition to the technical team leader. The core technical team members are hands-on professionals who supervise all field operations in their area of expertise and are personally involved with much of the data acquisition. The technical team leader, with the support of other core technical team members, is responsible for all data and for ensuring proper data management, interpretation, and integration of data into a site model and reports. The technical team leader and other core technical team members are supported by appropriate personnel and on-site and off-site contracted personnel as needed (see 7.2 and 7.3). The members of the ESC core technical team must be qualified to perform the following functions:

NOTE 9—EPA guidance (1) recommends a project organization that includes a planning team and a field team. In this practice and in the EPA guidance, the team leaders are functionally and practically equivalent. Both this practice and the EPA guidance strongly emphasize the importance of the active involvement of highly experienced personnel in the areas of geologic, hydrologic, and chemical systems in planning and field activities. In practice, core technical team members would be on both the planning team and the field team (as needed) and other project personnel would be on either the planning team, the field team, or both.

7.1.1 *Technical Team Leader*—The technical team leader is ultimately responsible for all decision related to the design and implementation of an ESC project, within the framework provided by the approved dynamic work plan. This authority should not be confused with the authority to make decisions concerning a course of action based on the results of an ESC project, which is the responsibility of the ESC client, regulatory authority, and stakeholders. The technical team leader is a fully technically qualified and functioning member of the core technical team, who leads the project, works with the other technical core team members in interpreting data and integrating results, and determines when project objectives have been met (see 10.1.4). The technical team leader is expected to exhibit a high level of professional judgement and personal initiative in carrying out an ESC project. The technical team leader is the primary point of contact for the ESC client and, if authorized by the ESC client, the regulatory authority. The technical team leader works with project team members to ensure that regulatory requirements specific to filling permits, securing access agreements, meeting local codes, and so forth are met, although the actual tasks may be assigned to other project personnel. She or he is responsible for ensuring that the ESC client and regulatory authority are fully informed about the progress of an ESC project. The technical team leader is in the field during the entire field investigation and works with the core technical team in interpretation of data as it is collected, modifying the evolving site model in collaboration with other technical members of the team and making decisions concerning subsequent data collection efforts. The technical, management, and leadership responsibilities of the technical team leader require an individual with extensive training and experience in geologic and hydrologic systems (and a familiarity with chemical systems, risk analysis methods, and remedial technologies) and a working understanding of other aspects of project management for contaminated site characterization.

7.1.2 *Core Technical Team Expertise*—The core technical team, which includes the technical team leader, requires a high level of expertise and experience in geologic, hydrologic, and chemical systems. Individuals on the core technical team need to be integrators as well as specialists, with in-depth expertise in some areas and the ability to communicate well with other team members having complementary areas of in-depth expertise. Section 7.4 discusses criteria for evaluating qualifications of core technical team members and other project personnel. The relative importance of specific areas of geologic and hydrologic expertise will vary somewhat from site to site, but most sites will require individuals on the core technical team with expertise in soil science, geology (with emphasis on stratigraphy, petrology, and structural geology), geophysics (where geophysical methods are appropriate for the site), hydrogeology, and geochemistry (broadly defined to include chemistry of solid, gaseous, and aqueous phases). Desirable areas of secondary expertise (or primary expertise where air and surface water are significant contaminant pathways) may include geomorphology, surface water hydrology and sedimentology, and climatology/meteorology. Areas of secondary expertise may also be provided by other project support personnel. Chemistry expertise on the core technical team needs to cover both analytical chemistry (organic/or inorganic chemistry, or both, as appropriate) and knowledge of contaminant characteristics for evaluating their fate and transport. To this end, desirable areas of secondary expertise may include soil and water microbiology and ecotoxicology. Areas of secondary expertise may also be provided by other project support personnel. The core technical teams includes such other technical or functional expertise as may be needed to address the specific site being characterized.

7.1.3 *Core Technical Team Field Operations*—The ESC process differs from traditional site characterization by the involvement of multiple experienced technical personnel throughout the process, including field operations (see Appendix X1). All members of the core technical team are directly involved with supervising field operations in their area(s) of expertise and are personally involved with much of the data acquisition. The technical team leader, supported by other core technical team members, is responsible for ensuring data quality and effective data management and also interprets data and integrates the results into the evolving site model and reports. The technical team leader has the final authority on-site technical decision making concerning field operations. If unavoidable circumstances require the technical team leader to be absent during field operations, another member of the core technical team should be designated as the acting technical team leader, who, in telephone consultation with the technical team leader, makes decisions concerning the next day's activities. Other core technical team members are in the field for data collection involving their primary area(s) of expertise and are available for telephone consultation when they are not present in the field.

7.1.4 *The Importance of Continuity* —The individuals on the core technical team who begin an ESC project should stay with the team to completion. The success of the ESC process depends on a high level of integration and continuity within the ESC core technical team. Individuals capable of performing the various functions of the ESC core technical team should be identified and regularly briefed on the progress of work as a contingency if unforeseen events require a change in the team.

7.1.5 *The Importance of a Multidisciplinary Perspective*—The ESC process differs from traditional site characterization and other accelerated site characterization approaches by its emphasis on placing a group of experienced personnel (the core technical team) in the field (see Appendix X1). The cost of fielding highly experienced personnel can generally be expected to be offset by the expert judgement that typically reduces time and total cost to obtain an accurate final site model (see Table X1.3). This expert judgement is required, because the heterogeneity of vadose zone and groundwater flow systems has historically resulted to two common outcomes from site characterization efforts: a site model with so much uncertainty that it does not provide a useful basis for making decisions (when decisions are made, often resulting in bad decisions) or very high costs because the variability of geologic and hydrologic systems requires a large number of samples to reduce uncertainty with statistically based sampling approaches. The multidisciplinary perspective of the core technical team functions as an on-site peer review of the evolving site model and will reveal inconsistencies that might be missed by a single experienced individual.

7.1.6 *Core Technical Team Data Management and QA/QC Responsibilities*—Although data management (7.3.2) and QA/QA (7.3.3) are specific ESC project support functions, the technical team leader, supported by the other core technical team members, is responsible for ensuring that data collection is relevant to the objectives of the project (that is, necessary to satisfy data quality requirements), QA/QC procedures for data collection and processing for respective areas of expertise are strictly followed, and field data reduction and processing do not introduce errors into the data and evolving site model. It is especially important that core technical team members be familiar with the limitations of any software used to analyze data, such as truncation of numeric data and the interpolation/extrapolation errors associated with gridding, contouring, and visualization programs.

7.2 *ESC Project Team*—Fig. 2 identifies the major functional areas required to support an ESC core technical team, and 7.3 discusses major project support functions further. Individuals providing some types of project support expertise, such as statistics/geostatistics, fate and transport analysis (including computer modeling), risk analysis, and remediation engineering, may have a special role early in a project in defining the type of data required for the project and data quality requirements and are involved throughout the project as needed. Depending on training and experience, technical support personnel may cover more than one area of expertise. The ESC project team roster should clearly identify the expertise of each member. As with the ESC core technical team, continuity is important. If a discipline is required for more than one mobilization, the same individual should be involved, if possible, in all phases of the investigation, including review, planning field data interpretation and report writing. The logistics coordinator plays an essential role in facilitating field operations (see 7.3.1). The data manager is responsible for identifying other personnel needs for data management, such as needs for computer data entry and quality control (see 7.3.2). The QA officer (see 7.3.3) and health and safety officer (see 7.3.4) are the only personnel who are not ultimately answerable to the technical team leader. They are independently responsible for assuring that the investigation complies with appropriate regulations and practice in their areas of expertise. Two basic approaches are available for assembling an ESC field team. Whichever approach is used, the core technical team should function as a single, unified team during the entire ESC project.

NOTE 10—U.S. EPA ((**1**), Chapter III, Section 3, and Appendix B) provides additional guidance on personnel responsibilities and qualifications.

7.2.1 *In-House Project Team*—Where an ESC provider has enough qualified staff, it may be possible to establish a field team entirely or mostly from within the organization. The close, ongoing relationship between team members allows integration during all phases of the ESC project for a site. A single team is typically engaged in multiple projects. In-house expertise may be supplemented in certain areas, such as by subcontracting for chemical analysis, drilling, and geophysical surveys.

7.2.2 *Project Team with Consultants and Subcontractors*—The ESC provider may develop an ESC core technical team that consists largely of individual consultants and subcontractors. The involvement of different organizations provides different perspectives with the effect of fostering peer review. Integration and coordination of the field team may be more difficult than with a single organization, and scheduling conflicts for subcontractors with small staff may occur if the ESC project extends longer than expected. It is essential that the core technical team and subcontractors have a good working relationship when this approach is used. The ESC case study in X7 illustrates an ESC project team that used primarily consultants and contractors.

NOTE 11—In the context of this practice the ESC provider is the prime contractor, and ESC subcontractors would be companies that have entered into a contract with the ESC provider to provide equipment or expertise required for the project team

7.3 *Other Project Support Functions:*

7.3.1 *Logistics Coordination*—The logistics coordinator is responsible for ensuring that all aspects of a field mobilization run smoothly. Activities performed by the logistics coordinator include all mobilization and demobilization coordination, making site security arrangements, and anticipating needs/organizing supplies and equipment for technical team members. Technical training and experience are not required for a logistics coordinator, but good organizational skills are essential.

7.3.2 *Project Data Management*—The project data manager is responsible for assembling, organizing, and archiving project data (see Appendix X5) and is in the field for the duration of any field work when the full ESC team is mobilized. This function is essential for allowing the technical team leader and other technical members of the field team to interpret the field data for on-site technical decision making. Ideally, the individual performing field data management is fully qualified, with experience in geologic and hydrologic systems, and has training and experience with computer hardware and software used by the team (that is, databases and database management, geographic information systems, computer-assisted drawing programs, contouring/cross section programs, and other visualization software). A critical capability of the data manager is the ability to convert a wide variety of data from various software programs expediently for use by the project team members. Field spatial control should be under the direction of a licensed land surveyor or other qualified staff where appropriate. Spatial data should be managed and referenced to a single site coordinate system, and maps and cross sections should be developed by an individual familiar with cartography and appropriate computer graphics software.

7.3.3 *Quality Assurance/Quality Control*—The QA manager is independently responsible for monitoring field activities and conducting audits, as appropriate, to ensure that procedures in the QA/QC plan are being followed. The personnel responsible for QA should have broad familiarity with field and analytical methodologies. As noted in 7.1.6, the technical team leader, supported by the appropriate core technical team members, has primary responsibility for data adequacy. Quality control of data begins with the individuals who are directly involved with data acquisition, initial data processing, and interpretation. Initial data processing is commonly done by the individuals making the measurements (that is, geologic boring logs, slug tests, geophysical measurements, and so forth.) and is often done on a separate computer with specific software. Once the data are in the hands of the data manager, data quality control becomes his or her responsibility (see Appendix X5), except that the person who originally acquired the data has a continuing responsibility to check the integrity of the data.

7.3.4 *Health and Safety*—The health and safety officer is independently responsible for monitoring field activities and to ensure that operations are in conformance with the health and safety plan.

7.3.5 *Stakeholder Liaison and Community Relations*—Smooth functioning and acceptance of ESC team activities requires participation by and good communication with stakeholders who are concerned with the outcome of an ESC project. The liaison function is proactive, having the objective of positive and early engagement with all stakeholders in the ESC project and the future of the site and continues until the ESC project is completed. The technical team leader supports the ESC client in stakeholder liaison and, if authorized, may serve as the primary point of contact for an ESC project. Other project personnel may provide support for community relations, such as publicity and organization of public meeting. See also 7.4 and 9.2.9.

7.3.6 *Statistics/Geostatistics*—As noted in 7.1.5, the ESC process uses primarily judgement-based sampling and measurements to characterize the geologic and hydrologic system and contaminant distribution along vadose zone and groundwater migration pathways. Statistical sampling approaches may also be used, as appropriate.

7.3.7 *Fate and Transport Analysis*—As discussed in 13.4, if it occurs as part of an ESC project, full-scale fate and transport analysis takes place after the ESC Phase I and Phase II investigations are completed. The person primarily responsible for this function should provide input into the work plan to ensure that data necessary for fate and transport analysis are collected. Individual(s) in this functional area may also be involved in field data collection as a technical support function.

7.3.8 *Risk Analysis*—As discussed in 13.2, and ESC project should ensure that data collected during ESC Phase I and Phase II provides information required for risk analysis where such analysis provides the basis for decision making (see Section 12). Risk analysis needs will usually be defined as part of the process for developing project objectives and data quality requirements (see 6.3) in order to ensure that the necessary data are being collected by the ESC project. Where project objectives require quantitative risk analysis, this function requires knowledge of regulatory-approved risk analysis procedures and familiarity with EPA and state contaminant screening levels and health-based cleanup criteria.

7.3.9 *Remediation Engineering*—As discussed in 4.4.2 and 13.3, remediation engineering expertise is incorporated into the ESC process at the earliest point when a need for remedial action is identified.

7.3.10 *Technical Experts with Prior Site Experience*—The ESC client or client's subcontractor often has years of experience with the site where an ESC project is being initiated. At a minimum, this experience should be leveraged by using such knowledgeable individuals in an advisory capacity. Such individuals would also be potential candidates for membership in the core technical team or for project support if they satisfy the criteria for evaluating ESC project team technical qualifications (see 7.4).

7.4 *Criteria for Evaluating ESC Project Team Qualifications*—Technical qualifications of personnel for ESC projects should be evaluated on the basis of four major factors: education, experience, professional registration or certification, and publications. Some project functions, such as logistics coordination and stakeholder liaison, require good organizational and communication skills rather than technical qualifications.

7.4.1 *Education*—Educational qualifications include academic degrees (B.S., M.S., Ph.D.), course work, and continued education in the fields of geoscience and contaminate chemistry for the core technical team and in relevant additional fields for other project support personnel.

7.4.2 *Experience*—Experience and area of specialization are the most important factors in assessing an individual's capacity to do ESC work. For core technical team members, such experience must be documentable and verifiable and must include direct participation by the individual at a high professional level. The individual's experience must have been in a hands-on role, carrying the project from beginning to end. Experience should be weighed heavily in evaluating an individual's ability to carry out quality ESC work.

7.4.3 *Registration or Certification* —Professional registration at the state level or certification by a recognized professional organization in the appropriate area of expertise is an additional means of assessing education and experience.

7.4.4 *Publications*—Publications directly associated with work carried out in the field of site characterization provide another useful means of assessing education and experience.

7.4.5 *Documentation of Technical Team Member Qualifications*—Documenting the qualifications and experience of ESC core technical team members and other field team members provides one means for an ESC client to compare the qualifications of several potential ESC providers. The ESC provider should maintain a file of full resumes for each core technical team member and one- to two-page vita for each field team member, including ESC subcontractors. The file should include the following information for each individual: name; functions and disciplinary expertise (for technical field team members) performed as part of ESC team; education, including years and types of degrees received, major and minor subjects, and post-acedemic technical and professional training courses; field project experience, including year(s), location, client, purpose of project, responsibilities, weeks/months in the field, and activities performed; professional memberships, registrations, certifications; major publications other than project reports; and optional references (names, addresses, and telephone numbers of professionals familiar with the individual's work). The purpose of this file is to provide a succinct summary of the most relevant information concerning an individual's competence for performing the designated functions as part of an ESC team. Any other information normally included in a vita should be eliminated. The ESC provider should maintain a file with full vitae for all technical ESC project team members.

7.4.6 *Documentation of Core Technical Team Qualifications*—In addition to documenting the qualifications of individual ESC core technical team members, the overall team qualifications can be evaluated by documenting prior experience working as a team on ESC or other projects, examples of integrated reports prepared by the team for ESC or other projects, and references from ESC clients or regulators who have participated in ESC projects.

NOTE 12—The number of experienced ESC core technical teams is presently limited. Consequently, the collective qualifications of individual core technical team members would be the primary basis for evaluating core technical team qualifications in the absence of prior ESC experience.

8. Developing the ESC Project

8.1 *Use of Prior Data*—Traditional site characterization practice, using multiple contractors and mobilizations, has often resulted in underutilization of available prior data for developing the preliminary site model and for guiding collection of new data. The ESC process breaks this cycle by emphasizing the importance of compiling original source materials and critically evaluating, integrating, interpreting all available data for a site as part of developing the preliminary site model. When possible, integration and review of prior data is a core technical team activity.

8.2 *Archiving Prior Data*—The ESC provider collects and develops an archive of all prior site data.

8.2.1 *Archive Contents*—Materials in an archive should include available historical information about contaminant use and locations, including the results of interviews with individuals familiar with the history of the site (such as current and former employees with knowledge of the waste stream generation and management that created the problem); available aerial photography and relevant remote sensing imagery of the site; published and unpublished topographic, vegetation, soils, geologic, hydrologic, and other maps, including relevant site maps and drawings; originals or copies of well, other borehole, and geophysical logs; copies of published soil survey, geologic, hydrologic, and engineering reports containing information about the site and surrounding area; any reports, such as CERCLA PA/SI reports, RFA reports, and site investigation reports prepared by consultants or regulators and where available and appropriate, similar reports from nearby investigations; soil and groundwater sample analytical results; any geophysical survey results, including copies of electronically stored data when available; original or copies of data from aquifer tests; available stream flow, fluvial sediment, and climatic data, as appropriate; and any other information, as appropriate.

8.2.2 *Inventorying the Archive*—Each item should be given a locatable archive number, and a master list with the full title of each item and a topical index (well logs, geology, soil sample data, and so forth.) should be prepared and updated as new information becomes available.

8.3 *Evaluating Archived Data*—The ESC core technical team (7.1) reviews the archive data emphasizing compilation of original source materials, such as well and borehole logs, water level measurements, and soil and water sample analyses. All such original data should be evaluated and given a data quality classification (such as low, medium, and high [or acceptable, acceptable with some questions, and unacceptable],[9] copied, clearly identified as to source, and placed in notebooks for the field archive. If sample analytical data are too voluminous as a result of time series sampling, simple statistical summaries of key parameter values should be compiled (mean, coefficient of variation, and so forth.) and evaluated for possible trends or discontinuities. Reprocessing of data may be performed if there is a reasonable expectation that the benefits of the information obtained will exceed the cost of reprocessing. Essential interpreted maps and cross sections from existing sources, such as soils, geology, potentiometric surfaces, and so forth, should also be copied, clearly identified as to source, and placed in notebooks for the field archive.

8.4 *Initial Site Visit*—The ESC core technical team and other project team members, such as the logistics coordinator and health and safety officer, visit the site as a unit, along with the ESC client, the regulatory authority and stakeholders. The purpose of the site visit is threefold: visually inspect the site to identify significant site features as part of developing the preliminary site model; evaluate logistic concerns that may affect timing and efficiency of field mobilizations, including utility clearance or location and marking or all subsurface utilities for safety and planning of sampling locations; and identify site conditions that may affect the suitability of field investigation methods. Viewing the site from the air may also be beneficial.

8.4.1 The technical core team members give particular attention of evaluating site conditions that may adversely affect use of specific field techniques used for their area of expertise. The initial site visit also provides the first opportunity for the core technical team to explain the ESC process and to hear the concerns of site personnel, the regulators, and other stakeholders.

8.4.2 An accurate digital site map with site survey grid serves as a framework for all collected data and should be developed if it is not already available. Key features of the site and any survey grids should be surveyed, and elevations should be obtained as needed.

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[9] In compiling interpretative maps and cross sections from existing data, data quality classification, or some other means of identifying the quality of a source of data, can be useful for identifying areas of greater and lesser uncertainty for focusing field investigations. Criteria for making such ratings would be developed by the core technical team. For example, poorly documented chemical sampling data would be classified as acceptable with some questions or unacceptable, whereas well-documented chemical sampling data would be classified as acceptable.

8.5 *Developing a Preliminary Site Model*—The ESC technical team leader, with support from other appropriate core technical team members, develops the preliminary site model, focusing on features of the geologic and hydrologic system that exert controls on contaminant movement. Documentation of the preliminary site model should note consistency with prior data or note where prior data are contradictory or at variance. Knowledge of the direction of groundwater flow and the potential preferential pathways for contaminant transport allows targeted sampling for three dimensional mapping of contamination. Guide D5979 provides a comprehensive framework for developing the preliminary site model as it relates to groundwater systems. Guide E1689 provides additional guidance on developing conceptual site models at contaminated sites. Section 13.4 discusses the possible role of computer modeling in developing the preliminary site model.

8.5.1 *Developing Preliminary Maps and Cross Sections*—Develop a preliminary site model that includes one or more interpreted plan maps with key site features (roads, buildings, surface water features, depth to bedrock, direction of groundwater flow, and so forth.) and cross sections that clearly identify water levels, zones of high and low permeability, other aquifer boundaries, and vertical variations in geochemical parameters (if available). The maps and cross sections should be based on original rather than interpreted sources (in this context, driller's well logs are considered original sources, although they represent interpretations of the driller) and should clearly identify the data quality classification of individual sources[9]. Serious data gaps should be left as blank spaces on the maps and cross sections, and uncertain features should be identified with question marks or dashed lines. All spatial data should be referenced to a single site coordinate system compatible with needs of the ESC client and regulatory authority.

8.5.2 *Devising Tests for the Preliminary Site Model*—The ESC core technical team identifies essential features and alternative interpretations of the interpreted plan maps and cross sections as they relate to the system's migration pathways for contaminant movement in the subsurface. These essential features of the preliminary site model are formulated as critical questions and hypotheses that must be answered and tested. For example, specific questions could be formulated, such as: Is the continuity of low-permeability strata sufficient to create two separate aquifers? Are there stratigraphic controls that could cause DNAPLs to migrate in a direction different from the direction of groundwater flow? Are there preferential flow paths that could cause groundwater to flow in directions different from that indicated by the potentiometric surface? Alternatively, testing of the preliminary site model could be formulated as specific objectives, such as define the number of aquifers and degree of connection between them and determine the direction of groundwater flow and identify potential migration pathways for preferential flow. In the DQO process, questions are formulated in the form of decision rules in which the answer to the question determines the next course of action (see X1.4.4).

8.5.3 *Revising the Site Model*—Refinement of the preliminary site model is documented primarily in the form of revisions to maps and cross sections representing the site surface and subsurface, as well as to the text, where appropriate, that identifies measurements that may not fit the model and require explanation. Section X5.4 addresses documentation procedures for revisions to maps and cross sections.

8.6 *Selecting Multiple, Complementary Investigation Methods:*

8.6.1 *Identifying the Types of Measurements Required for the ESC Project*—The core technical team is responsible for identifying the types of observations and measurements that are required to answer critical questions and test hypotheses in order to refine the site model. Other needs might include collection of data to rule out alternative site models, to support the preliminary site model, and to resolve observations that are inconsistent with the preliminary model. Although the emphasis on the first phase of the ESC project is on geologic and hydrologic characterization, this step also requires identification of chemical and fate-related parameters needed during the contaminant characterization in ESC Phase II. In addition, data-required for computer modeling of vadose zone and groundwater flow and transport and for risk analysis should be identified. For chemical analysis of samples, it is important to specify appropriate sensitivity and detection limits (such as practical quantitation limits and sample quantitation limits) that will provide useful data for comparison with background, risk-based, or other thresholds.

8.6.2 *Identifying All Appropriate Measurement Techniques*—A key element of the ESC process is use of multiple, complementary measurement and sampling methods to characterize geology and hydrology at a site. For chemical characterization, the most appropriate analytical methods that satisfy the data quality requirements of the project are selected. One of the first steps in optimizing the dynamic field characterization and sampling plan is to identify all appropriate measurement and sampling techniques for a particular site. This step includes selection of the appropriate EPA or other analytical methods and protocols, as specified by the appropriate regulatory authority, to be used during the investigation. Refer to Guide D5730 for a discussion of major types of field investigation methods, an index of more than 400 ASTM standards that may be useful for environmental site characterization, and major reference sources that provide information on the characteristics of site characterization methods. Section X3.3 identifies selected major ASTM guides and practices pertinent to selection of field investigation methods.

8.6.3 *Selecting Multiple Measurement Techniques*—The core technical team leader, with support from the appropriate core technical team members, selects a suite of site investigation methods that are suitable for conditions at the site and that will allow independent testing of essential features of the preliminary site model by use of multiple methods to characterize a given site feature. Appendix X3 discusses further criteria for selection of measurement techniques and their use in the ESC process.

9. Developing a Phase I Dynamic Work Plan

9.1 *Designing a Dynamic Technical Program*—The core technical team, with appropriate support from other project team members, prepares the work plan, which includes all information required to conduct the ESC project and addresses project objectives and data quality requirements defined by the ESC client, the regulatory authority, and stakeholders (see 6.3). The element of the work plan that makes it dynamic is the technical approach, which identifies the suite of field investigation methods and measurements that may be necessary to characterize a specific site but does not specify the number and location of observations or measurements. The dynamic work plan may identify the maximum potential number of samples, provided that there is a clear understanding that the actual number and location of samples will be determined by on-site technical decision making. The technical team leader, with support from the other appropriate core technical team members, adjusts the location and type of field data collection efforts in response to previous observations and data in order to optimize the site characterization effort. The dynamic technical program operates within constraints defined in the work plan, including the geographic area within which the investigation will take place, maximum depth of penetration (where appropriate), and standard operating procedures for methods that are to be used. The dynamic technical program and all other aspects of the work plan create a well-defined framework from which departures are not allowed without the review and approval of the ESC client and regulatory authority.

NOTE 13—U.S. EPA (**1**) provides additional guidance on developing a work plan (Chapter III, Section 1) and for preparing and overseeing field work (Chapter III, Section 4). The EPA guidance for using dynamic field activities does not explicitly define a Phase I focusing on geologic and hydrologic characterization and extent of soil contamination, and a Phase II focusing on contaminant distribution in groundwater. As indicated in Note 2, separate phases may not be necessary, but it is essential that the delineation of the extent of groundwater contamination be based on an understanding of the geologic and hydrologic system at the site.

9.2 *Work Plan Contents*—A typical dynamic work plan should include the elements described below. The organization and contents of the work plan may be modified, as appropriate, for specific regulatory programs or projects.

9.2.1 *Regulatory Framework*—The regulatory framework identifies all federal, state, and local laws, executive orders, regulations, and site-specific regulatory agreements that may be a source of environmental protection controls or performance standards for the ESC project. In this section or in the section describing the dynamic technical program (see 9.2.4) the extent of involvement of regulatory personnel during field activities should be defined and, if a continuous presence during field activities is not feasible, identify critical checkpoints where the regulatory authority should be consulted or be present.

9.2.2 *Site Description and History of Contaminant Use and Discovery*—This section of the work plan includes information such as site structures and use, topography and surface drainage, regional and local geology, climate, demographics and land use (including potential environmental receptors), history of contaminant use and discovery, environmental concerns, and previous environmental activities. Information on natural background levels and contamination from chemical discharges is ordinarily included in this section. If such information is not available but is required for the investigation, obtaining it would be incorporated as an objective of the dynamic technical program (see 9.2.4).

9.2.3 *Analysis of Prior Data and Preliminary Site Model*—This section of the work plan presents an overview of regional and local geology, hydrogeology, and geochemistry, including appropriate maps and cross sections. The emphasis in this section should be on the independent synthesis and interpretation of available information as it relates to identification of potential contaminant migration pathways. The conclusion of the section should identify critical questions to be answered and hypotheses to be tested when field activities commence.

9.2.4 *ESC Phase I Dynamic Technical Program*—This section of the work plan identifies the multiple investigation methods discussed in 8.6 and the area(s) where they may be applied. Although such plans are at the core of the ESC process, this section of the work plan does not need to be very long. It may include a table, listing all features of the site to be characterized in one column and methods or measurements that may be used during the field mobilization (see, for example, Table X7.1). This section will include clear criteria, in the form of a list of essential questions to be answered or specific objectives (see example in 8.5.2), for determining when project objectives have been met. This section and the subsequent section on field protocols and standard operating procedures (SOPs) are the functional equivalent of the field sampling and analysis plan in traditional site characterization.

9.2.5 *Field Protocols and SOPs*—This section of the work plan contains descriptions or copies of all field protocols and SOPs including sample collection and analytical methods, direct push methods, geophysical methods, drilling and monitoring well installation methods, and aquifer test methods. This portion of the work plan may consist of field protocols and SOPs developed by the ESC team and approved by the appropriate regulatory authority, published protocols developed by regulatory agencies, and ASTM protocols or other consensus or peer-reviewed standard methods. All field protocols and SOPs must satisfy existing regulatory requirements. If it is very large, this section may be attached to the work plan as a separate document.

9.2.6 *Quality Assurance/Quality Control Plan*—The QA/QC plan clearly defines responsibilities of different members of the ESC team for ensuring that protocols and SOPs are followed. In addition to regulatory program-specific sampling and analysis procedures, the QA/QC plan should define QA/QC procedures for other field activities, including geologic characterization, hydrologic characterization, geophysical surveys, spatial control procedures (x,y,z accuracy of point measurements), and computer records keeping. The QA/QC plan describes procedures to be used to monitor conformance with, or documentation and justification of departures from, the field protocols and SOPs, along with procedures in the data management plan. Appendix X4 provides illustrative examples of QC procedures for geologic characterization.

9.2.7 *Data Management Plan*—The on-site technical decision making that guides the dynamic field characterization and sampling activities requires a level of data management in the field that is not normally a part of traditional field investigations. The data management plan identifies staff and infield computer equipment to be used, software for field operations, and software to be used for post-field-investigation analysis and interpretation. The plan also includes procedures for QA of ESC project data. Measurement data are formally archived once in the field. Appendix X5 presents suggested procedures for quality control of computer records.

9.2.8 *Health and Safety Plan*—Although a health and safety plan is necessary, no special features of the health and safety plan in an ESC project distinguish it from the plan for any other type of environmental investigation.

9.2.9 *Community Relations Plan*—A community relations plan is desirable to facilitate stakeholder involvement in the ESC project (7.3.5 and 13.1.5.) A typical community relations plan should include site description, community background, community relations objectives, timing of community relations activities (including a schedule of follow-up meetings, briefings, and input solicitation, if the stakeholders feel it is necessary), and a contact list of key officials and other major stakeholders. The stakeholder liaison member of the ESC project team is responsible for implementation of the community relations plan. A formal community relations plan may not be required for all ESC projects, but it is strongly recommended that the ESC client provide for meaningful stakeholder participation throughout the process. (See 5.2.1 and Note 7.)

9.3 *Work Plan Approval*—The ESC Phase I work plan is developed as a stand-alone document, and the ESC Phase II work plan is usually incorporated into the ESC Phase I report (see 10.3). The draft work plans are reviewed by the ESC client, the regulatory authority, and stakeholders and are revised by the ESC core technical team until the plan is acceptable. The ESC client, regulatory authority, or stakeholders may also chose to have the draft plans reviewed by peer technical reviewers.

10. ESC Phase I Investigation (Focus on Geologic and Hydrologic Characterization)

10.1 *Field Mobilization*—The ESC Phase I investigation is normally completed with a single field mobilization of two to four weeks. Four weeks approximates about the maximum time that an ESC project team can operate effectively in the field. If site size or other conditions preclude completing a Phase I investigation in a single mobilization, two options are possible: divide the site into smaller units and plan separate but coordinated ESC projects for each unit or plan a second (Phase Ib) mobilization. More than two mobilizations would be the exception rather than the rule. Acquisition of seasonally varying data, such as groundwater levels, may require additional site visits involving only a few personnel.

10.1.1 *Daily Field Data Collection Activities*—The core technical team oversees and participates in field collection activities. Each core technical team member directs field collection activities in his or her respective area of expertise (see 7.1.2). The focus of the ESC Phase I investigation is on characterizing vadose zone and groundwater migration pathways. Contaminant sources and contaminants of concern are also identified, if they are not already known, and subsurface contaminant distribution sampling occurs to the extent that it contributes to understanding the vadose zone and groundwater migration pathways. Other potential contaminant migration pathways (air, surface water, submerged sediments, biota) are also characterized, as appropriate. Characterization of near-surface contamination may incorporate the adaptive sampling and analysis approach described in X1.4.3.

10.1.2 *On-Site Data Management*—The ESC data manager and supporting staff are responsible for monitoring the coordination of site activities to ensure that all data incorporated into the computerized site database and made available to the core technical team as rapidly as possible. For technical or other reasons, it may not be possible to reduce and archive all field data daily, but, at a minimum, enough field data must be reduced each day to provide a basis for planning the next day's field data collection activities (see 10.1.3). Integration of ESC data sets with prior site data sets should be accommodated without restricting the ESC provider from using state-of-the-practice hardware and software tools. Section X5.4.1 describes in more detail how data can be processed to allow on-site technical decision making.

10.1.3 *On-Site Technical Decision Making*—The core of the ESC process is the use of multidisciplinary integration and interpretation of field measurements and sample analyses to select the type and location of subsequent field measurements and sampling points. During an ESC Phase I field mobilization, the technical team leader and other core technical team members, with input from other technical field team members, meet on a daily basis to plan the next day's measurements. The regulatory authority, ESC client and designated stakeholder representative are encouraged to participate in any or all of the meetings at which the next day's activities are planned. They are always kept informed through brief notes and telephone calls, if not in attendance, and should be alerted when critical points in the investigation have been reached. The daily cycle of data collection, processing, and evaluation continues until the technical team leader, in consultation with other core technical team members, the ESC client, and the regulatory authority, determines that the objectives of the ESC Phase I investigation have been met. A useful procedure during field activities is to record in field notebooks, before an observation is made or a measurement is taken, the reason for the activity and the expected result. This discipline helps focus data collection activities on the objectives of the investigation and provides immediate feedback concerning the accuracy of the evolving site model when the measurement result is available.

10.1.4 *Determining When ESC Phase I Field Objectives Have Been Met*—The overall objective of the ESC Phase I investigation, defined in the work plan as essential questions to be answered and hypotheses to be tested or as a list of specific objectives or decision rules (see 8.5.2), is to characterize the geologic and hydrologic system with sufficient accuracy to allow targeted sampling to delineate the concentration and distribution of contaminants in ESC Phase II. This goal is achieved when the field data fit into a consistent site model of the geologic and hydrologic systems that has no major unexplained anomalous observations. The technical team leader, in consultation with other core technical team members, the ESC client, and the regulatory authority, is responsible for deciding when the objectives of the ESC Phase I investigation have been met. Information used to make this decision may include an assessment of data accuracy and adequacy. Data accuracy involves defining acceptable levels of data quality and identifying and correcting errors in the data. Data adequacy may be assessed in a variety of ways, including considerations of spatial density, temporal density, location significance, and resolution.

10.2 *Post-Field-Investigation Analysis and Interpretation*—Upon return from the field, additional processing and interpretation of data are performed, if required. The results of this analysis may identify aspects of the evolving site model that require further refinement during the ESC Phase II investigation. This analysis also forms the basis for developing the ESC Phase II work plan for detailed contaminant characterization, and includes identification of contaminants of concern, if not already identified.

10.3 *ESC Phase I Report and Phase II Work Plan*—The Phase I report presents the site model and supporting data. Usually the Phase II work plan is incorporated into the Phase I report in order to speed the review and approval process. the Phase II work plan cites the Phase I work plan as a reference and includes only information that is pertinent to the Phase II investigation. The Phase II work plan must include the final list of contaminants of concern that has been approved by the ESC client, regulatory authority, and stakeholders.

11. ESC Phase II Investigation (Focus on Contaminant Distribution)

11.1 *Field Mobilization*—The ESC Phase II field mobilization focuses on determining the spatial distribution, concentration, and the fate of contaminants, on the basis of knowledge of the relevant contaminant migration pathways identified in Phase I. Aquifer characterization, geochemical analyses, and geophysical surveys continue, as necessary, to guide sampling decisions. On-site technical decision making functions as in the Phase I investigation (see 10.1.3). When the results are an ESC project are used to analyze risk, Phase II field objectives have been met when the distribution and concentration of contaminants have been mapped with sufficient spatial and temporal accuracy to evaluate exposure of possible environmental receptors. When regulatory standards-based cleanup criteria are used, the Phase II objectives have been met when areas of contamination that exceed cleanup criteria have been fully delineated.

11.2 *Post-Field-Investigation-Analysis and Interpretation*—Upon return from the field, additional processing and interpretation of data are performed, if required. Because most of the data being analyzed are chemical data, the focus is on understanding how contaminants are interacting with the physical and biological system as they move and are transformed in the subsurface.

11.3 *ESC Phase II Report*—The Phase II report, reviewed and approved by the ESC client, regulatory authority, and stakeholders, presents contaminant distribution and concentrations as two-dimensional maps or maps and cross sections showing the distribution of contaminants in the vadose zone and groundwater, together with supporting data. Three-dimensional images may be used to illustrate the spatial distribution of contaminants, but these images should be based on actual data points. The Phase II report also presents any refinements of the site model relating to the source and migration pathways that may be pertinent to fate and transport analysis for risk analysis.

12. Project Completion

12.1 *Steps to Project Completion*—An ESC project is completed when the ESC client, regulatory authority, and stakeholders choose a course of action based on results of the project. Depending on the results of the ESC Phase II investigation, this may occur without significant additional involvement of the ESC project team or it may involve a level of effort comparable to a Phase I or Phase II investigation if predictive modeling for risk analysis or remedy analysis and design for remedial action, or both, are required. The steps to project completion differ somewhat depending on whether regulatory standards-based cleanup criteria (see Fig. 4) or a risk-based decision process (see Fig. 5) is used.

12.2 *Regulatory Standards-Based Cleanup Criteria*—Where regulatory standards-based cleanup criteria form the basis for choosing a course of action, the final model of source and migration pathways at the site presented in the ESC Phase II report will delineate any areas where contaminant concentrations exceed cleanup criteria. Fig. 4 shows various paths to project completion resulting in the following possible decisions: no action, presumptive remedy selection, and remedy selection, based on results of a Phase III study. When a Phase III study is required (CERCLA FS, RCRA CMS, or applicable regulatory program equivalent), it is logical for the ESC project team to conduct the study because of its detailed knowledge of the site gained during the Phase I and Phase II investigations. However, a Phase III study would not differ significantly from one following traditional or other site characterization approaches and the ESC client has the option of giving the task for remedy selection and engineering design to an organization different from the ESC team. The process of remediation selection, design, and implementation, if it has not already begun, can focus exclusively on areas where contaminants exceed cleanup criteria. Further field investigations may be required, but collection of data can be targeted to the specific needs of design engineers (see 13.3).

12.3 *Risk-Based Action Criteria*—Where risk-based action criteria form the basis for choosing a course of action, the model of source and migration pathways at the site presented in the ESC Phase II report will delineate any areas where contaminant concentrations exceed the criteria. If contaminant sources have been removed or are contained and there are no areas where contaminants exceed risk-based action levels, then the ESC project provides a sound basis for the ESC client, the regulatory authority, and stakeholders to chose no action or ongoing monitoring. Fig. 5 shows that ESC project completion may follow a number of paths if risk-based action level criteria are exceeded at the site. If more than qualitative risk analysis of the Phase II investigation results is required, a Phase III work plan will normally be developed by the ESC project team that includes, at a minimum, procedures for quantitative risk analysis and, as appropriate, remedy selection and design.

12.3.1 *Quantitative Risk Analysis*—If required, the ESC core technical team, with the assistance of project team members with modeling and risk evaluation expertise, performs fate and transport analysis for quantitative risk analysis. Additional data acquisition, such as water level monitoring and aquifer tests for calibration of fate and transport models, may be required. This work would involve a limited number of team members, targeted at collecting the needed data. The ESC project team uses methods for evaluating the risk of contamination that are approved by the ESC client, the regulatory authority, and stakeholders.

12.3.2 *Using Risk Analysis Results*—Where risk analysis is performed, the final site model, which includes sources, migration pathways, and environmental receptors, provides the basis for establishing risk-based cleanup criteria for remedial action. When no action other than monitoring is required, the final site model provides a good basis for optimal location of permanent monitoring wells. If remedial action is required, the final ESC site model provides the starting point for remediation selection, design, and implementation. Further field investigations may be required, but collection of data can be targeted to the specific needs of the design engineers (see 13.3).

12.4 *ESC Phase III Work Plan*—If predictive computer modeling is required to analyze risk or remedy selection and engineering is required for remedial action, the ESC project team will normally prepare a Phase III work plan. Although it is not shown specifically on the flow diagram in Fig. 1, this can be incorporated into the ESC Phase II report in the same way that the Phase II work plan is incorporated into the Phase I report. The Phase III work plan would describe any limited additional field work, such as aquifer tests, to provide additional data for predictive computer modeling and will typically not require the entire core technical team in the field.

13. Considerations in Implementation of ESC

13.1 *Relationship of ESC to the Regulatory Process*—The ESC process operates within the framework defined by the agencies or organizations responsible for ensuring compliance with the environmental statutes, regulations, and management practices that affect the site being investigated. The increased flexibility inherent in on-site technical decision making requires increased accountability. It is the responsibility of the ESC provider to take seriously the elements of the ESC process that increase accountability. Elements of the ESC process that are intended to increase accountability and the quality of information provided by the process are as follows:

13.1.1 *ESC Team Qualifications*—Experienced personnel are required on the ESC field team. Although it is difficult to quantify professional competence, the recommended documentation of qualifications and field experience of ESC team members (see 7.4) provides some accountability.

13.1.2 *Work Plan*—In an ESC work plan the QA/QC plan, which covers all aspects of the field investigation (not just chemical sampling and analysis (see 9.2.6, Appendix X4)), and the data management plan (see 9.2.7, Appendix X5) increase the accuracy of nonchemical data obtained, and the practice of reducing data into a form suitable for archiving while still in the field ensures that useful information is not lost in the transition from the field to the office.

13.1.3 *Use of Multiple Complementary Geologic and Hydrologic Investigation Methods*—See Appendix X3.

13.1.4 *Field Investigations*—During each field investigation phase, regulatory personnel have access to the same information as the ESC team and can observe and, to the extent appropriate, participate in the on-site technical decision making that guides the investigation (see 10.1.3). The involvement of regulatory staff in on-site technical decision making increases the likelihood and speed of obtaining regulatory approval for the Phase I report, the Phase II work plan and report, and the final decision. Such involvement may also result in more efficient use of regulatory staff resources, because familiarity with the site may reduce the amount of time required to critically review draft ESC project reports.

13.1.5 *Involvements of Stakeholders*—The community relations plan (see 9.2.9) improves accountability by providing a mechanism for the ESC project team to learn about principal concerns of those who may be adversely affected by contamination at a site. This knowledge may help the ESC project team collect the type of data that is responsive to stakeholder concerns and present the information in a responsive way. Furthermore, when other stakeholders understand the ESC process and are kept informed about how the investigation is proceeding, the credibility of the results increases.

13.2 *Role of Risk Analysis in ESC*—The primary objective of the ESC process is to provide scientifically and technically sound information for decision making, for which assessment of risk is a major consideration. Risk analysis is incorporated into the process in the following ways:

13.2.1 *Risk Analysis Initiating the ESC Process*—The decision to initiate the ESC process will usually be based on a risk-based judgement that contaminants at a site present a potential threat to human health or the environment (see 6.1). Where the decision for a course of action is to be based on considerations of risk, it is important that potential environmental receptors be identified in consultation with stakeholders at the outset of the ESC project.

13.2.2 *Planning ESC Phase I and Phase II Field Mobilizations*—Risk analysis methodology and any associated transport and fate computer models should be identified early in the process to ensure that field data collection provides information required for the risk analysis that concludes the ESC process.

13.2.3 *Concluding Risk Analysis*—The ESC process follows accepted regulatory protocols for risk analysis (see 12.3.1).

13.3 *Relationship of Remediation Engineering Design and Implementation to ESC*—As discussed in 4.4, the ESC process normally avoids a presumption that remedial action will be required because no action and ongoing monitoring are possible outcomes, in addition to remedial action requiring an engineering solution. Where the ESC process provides information for risk-based decisions, costs during site characterization activities to collect data required only for remediation design may be wasted if the ESC project results in a decision for no action or ongoing monitoring. Where remedial action is required, an advantage of the ESC process is that the reduced time for site characterization allows timely initiation of CERCLA feasibility studies or RCRA corrective measures studies. Section 12 describes briefly how such studies can be integrated into the ESC process as a Phase III study. Furthermore, the thorough understanding of the geologic, hydrologic, and chemical system at a site reduces the uncertainties that remediation engineering design must address. However, remediation engineering expertise is incorporated into the ESC process at the earliest point at which a need for remedial action is identified. The time required for ESC Phase I and Phase II investigations is normally short enough to confine interim corrective actions to noninvasive measures, such as access restriction, with more invasive measures optimized by using information obtained by the ESC project. Remediation engineering expertise should be involved at the outset of an ESC project where application of regulatory standards-based cleanup criteria is expected to require remedial action. ESC projects at sites where presumptive remedies have been identified, but the decision for further action is risk-based, should involve remediation engineering expertise from the outset, but the cost of collecting data required only for remediation engineering design should be weighed against the possibility that it becomes an unnecessary expense if the ESC project supports a decision for no action or ongoing monitoring. Guide D5745 provides guidance for developing and implementing short-term measures or early actions for site remediation.

13.4 *Role of Computer Modeling in ESC*—The ESC process relies heavily on computers in the field for compilation and management of field data and may benefit from the use of visualization software and geographic information systems for two-dimensional and three-dimensional presentation of spatial data to refine the evolving site model. Interpretative computer groundwater modeling or water budget analysis based on relatively simple arithmetic or analytical models may be useful when developing the preliminary site model and to identify geologic and hydrologic system parameters that need better resolution by additional sampling or testing. Formal numerical computer modeling of vadose zone/groundwater flow and contaminant fate and transport, if used, occurs only after the ESC Phase I and Phase II investigations are completed. The final site model, based on multiple complementary investigation methods, should drive the modeling process, not vice versa. However, the person on the ESC project team responsible for the final vadose zone and groundwater contaminant fate and transport analysis should be involved in work plan development and field operations, as appropriate, to ensure that critical data necessary for definition and calibration of the methods to be used are collected. The person responsible for fate and transport analysis should document all model assumptions, computer codes employed, and model input values, so that an independent party can reproduce the results and, if necessary, modify the model in response to additional data.

13.5 *Procurement and Contracting for ESC*—The flexibility in the ESC process, which allows time and cost reductions compared to traditional site characterization, also requires use of procurement and contracting procedures that address the distinctive characteristics of the process. Specifically, although the daily costs of an ESC project will tend to be high because of the use of multiple, highly qualified personnel in the field, significant total cost savings can be expected, as discussed in X1.3. The cost of field activities contains an element of uncertainty, but upper bounds can be placed. This is because it is not possible to predict beforehand the precise combination of multiple, complementary investigation methods that will ultimately be used during an ESC project, or how extensively a particular method will be used. Appendix X8 discusses some ways to address these issue.

13.6 *Performance Indicators for Evaluating ESC*—Quantitative performance indicators may be useful for both ESC clients and ESC providers for the following purposes: comparing the ESC process to traditional site characterization at a site, comparing performance of ESC teams (taking into consideration any differences in objectives), and evaluating the effect of site characteristics on the ESC process. The key performance indicator is the ability of the final site model to predict contaminant fate and transport and to support realistic risk calculations for correct resolution of remedial issues or preventative measures, or both, including no action. Ongoing groundwater monitoring provides an additional means for verifying the final site model.

13.6.1 *Comparative Indicators*—The following indicators can sometimes be quantified: length of each mobilization (days), number of mobilizations, cost of each phase of the investigation (dollars), total time for each phase, and fraction of chemical measurements in which no contaminants are detected. Care should be taken when using comparative indicators between sites to consider the effect of site conditions on each performance indictor used (see 13.7).

13.7 *Factors that May Affect Performance Indicators*—The ESC process at a typical site requires single mobilizations of two to four weeks for Phase I and a mobilization of similar length for Phase II. (See further discussion in 10.1). Various site-specific factors may affect the actual time and cost of an investigation. Planning the schedule for an ESC site investigation should take these factors into account. The following factors may contribute to either lengthening the time required, or increasing the cost of an investigation:

13.7.1 *Stakeholder Relationships*—Polarization and antagonism between stakeholders creates an environment in which it is more difficult for the ESC process to function smoothly. Conflict between stakeholders will not necessarily affect the field investigation time, but it may affect the scheduling of field mobilizations and lengthen the total time for a project. The individual executing the community relations plan and the ESC team member responsible for other stakeholder liaison have the responsibility for facilitating interactions between stakeholders in a way that reduces polarization and antagonism.

13.7.2 *Site Area and Access*—All other things being equal, time and cost may increase as the size of the site increases. If performance indicators for sites of greatly different areas are compared, the indicators should be in the form of unit area comparisons (that is, penetrations, days, dollar per unit area). Site access limitations may also increase characterization costs.

13.7.3 *Site Geology and Hydrogeology*—In general, as site complexity increases, performance indicators may appear less favorable as a result of increased time requirements and costs to satisfy regulatory requirements. However, for any given site, the ESC process can be expected to take less time and to cost less than traditional site characterization for a given level of data and accuracy. Factors that may increase time and costs include significant seasonal effects on the hydrologic system (requiring more time to characterize seasonal variations, but not necessarily increasing time or cost required for field mobilization), multiple or very deep aquifers, structurally complex bedrock sedimentary aquifers (folding and faulting), and fractured-rock and karst aquifers.

13.7.4 *Contaminant Characteristics*—Optimal selection of chemical analytical methods should result in use of a technique or techniques having the lowest cost and analysis time and providing the level of desired data quality for the regulatory framework of the project. For most contaminants, analytical methods are available that yield results in minutes to days and do not significantly affect the time required for field mobilization, all other things being equal. Contaminants that tend to increase times and cost include: dense nonaqueous phase liquids (DNAPLs), which tend to sink to the base of an aquifer, requiring deeper sampling, dioxins and furans, which have special health and safety requirements, and radioactive contaminants, which may need lengthy counts and slow sample collection and analysis because of health and safety considerations. Robbat (**2**) and U.S. EPA ((**1**), Chapter IV and Appendix C) provide detailed guidance for selection and data quality of field-based analytical methods.

14. Keywords

14.1 environmental site characterization; exploration; feasibility studies; field investigations; geological investigations; geophysical investigations; groundwater; hydrologic investigations; maps; preliminary investigations; reconnaissance surveys; sampling; site characterization; site investigations; subsurface investigations

APPENDIXES

(Nonmandatory Information)

X1. BACKGROUND ON EXPEDITED SITE CHARACTERIZATION

X1.1 *History of the ESC Process:*

X1.1.1 *Origins*—The process described in this practice originated in 1989 in the work of Dr. Jacqueline Burton's multidisciplinary team at the U.S. Department of Energy's (DOE) Argonne National Laboratory, Argonne, Illinois. The process was first developed for the U.S. Department of the Interior, Bureau of Land Management, for use at several landfills in New Mexico. Use of multiple surface geophysical techniques (magnetic, electromagnetic [two types], and seismic surveys), combined with targeted subsurface drilling and sampling at the Flora Vista landfill, led to a determination that contaminants present at the landfill were not migrating deeper than the upper few metres and that the landfill could be closed without continuing groundwater monitoring. (See Appendix X6). The process was formalized by the Argonne team and has resulted in significant cost and time savings for the following federal agencies: U.S. Department of Agriculture Commodity Credit Corporation, at numerous grain elevator storage sites in Nebraska and Kansas known to be contaminated by carbon tetrachloride (Burton et al. (**3**),[10] (**4**)); the U.S. Department of Energy at the Pantex Plant in Texas (Burton et al. (**4**)); and the Department of Defense at several Air Force and Navy installations. Table X1.1 provides summary information on ESC investigations at these sites.

X1.1.2 *Further Testing and Demonstration*—Dr. Al Bevolo, with a core technical team (including some consultants) at the DOE's Ames Laboratory, Ames, Iowa, and a project using contract consultants has tested and demonstrated the ESC process at a manufactured gas site in Marshalltown, Iowa (Bevolo et al. (**9**)); at a DOE site near the St. Louis airport with low-level radioactive contamination in 1994; at an oil seepage basin at DOE's Savannah River Site, South Carolina, in 1995 (**10**) (see X7); and at an active oil refinery in the Katowice region of Poland (**12**). Table X1.1 summarizes information on these ESC investigations.

X1.1.3 *U.S. EPA's On-Site Decision Making Guidance*—In 2003 U.S. EPA published a document that provides guidance on integrating on-site decision making into field work at hazardous waste sites. The guidance addresses uses of on-site decision making for dynamic field activities involving characterization, cleanup, and monitoring. Chapter V provides summary case study information on soil and groundwater characterization at the Marine Corps Air Station, Tustin, Califronia (Section 1), soil and sediment cleanup at Loring Air Force Base, Maine (Section 2). groundwater treatment system optimization at Utmatilla Chemical Depot, Oregon (Section 3), and three examples of innovative dynamic strategies during initial site screening (Section 4). The chapter also provides summary information on case studies involving eight dry cleaning sites in Florida described by Applegate and Filton (**13**); soil and groundwater contamination at Hanscom Air

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

TABLE X1.1 Examples of the ESC Process

Client	Site Type/ Size/Depth	Location/ EPA Region	Contaminants of Concern	Regulatory Setting	Problem or Objectives	Results of ESC Investigation	Selected References
USDI/BLM	3 landfills 650 by 800 ft to 1000 by 2000 ft	NM/ Region VI	Metals, VOCs, SVOCs, petroleum products	CERCLA RI/FS	PA/SI results indicated likely migration to ground or surface water.	All three landfills closed with no remediation; cost $300,000 less than projected. See case study, Appendix X6.	Burton (5), Burton et al. (3)
USDA/CCC	20 former grain storage facilities 800 by 1000 to 23 mi^2	NE, KS/ Region VII	Carbon tetrachloride (CCl_4), chloroform	CERCLA RI/FS (2 NPL sites), SDWA	CCl_4 contamination of groundwater drinking water supplies potentially linked to CCC's former operations.	Streamlined RI/FS process and generated technically defensible data for rapid remedial action decision making for 1/5 to 1/10 cost and 1/30 time of traditional methods.	Aggarwal et al. (6), Burton (7), Burton et al. (3), Hastings et al. (8)
DOE	Zone 12 Pantex weapons facilitiy, 1 mi^2	Amarillo TX/ Region VI	Explosives, metals, fuels, chlorinated hydrocarbons	CERCLA RI and RCRA RFI	Previous RI had not generated technically acceptable explanation for contaminant distribution, migration pathways, and potential for cross aquifer contamination.	Reevaluation, interpretation, and integration of existing (pre-ESC) database allowed for a streamlined field investigation that generated technically defensible explanation of all issues. ESC saved a minimum of $4 million and 4 years from original project estimates.	Burton et al. (4)
DOD/Navy	Closing Marine air station, 3 mi^2	Western US/ Region IX	Fuels, sovlents, oils, paints, pesticides	CERCLA RI/FS	Previous RI had not defined aquifer systems (flow, number of aquifers, and so forth.), migration pathways, sources, or contaminant distribution.	Phase I investigation delineated hydrologic systems, including flow, number of aquifers, isolation of aquifers, and migration pathways. Phase II presently being conducted by private-sector firm.	Burton et al., in progress
DOD/Air Force	Air Force base, 1300 by 2600 ft	South-west/ Region VI	TCE, 1,2 dichloroethene, carbon tetrachloride	CERCLA RI, RCRA RFI	Rapid transfer of ESC technology to agency and contractor for interium corrective action measures selection.	ESC investigation ongoing.	Burton et al., in progress
IA Department of Natural Resources	Former gas manufacturing plant, 3 acres, 50'	Marshall-town, IA/ Region VII	16 polyaromatic hydrocarbons (PAHs)	State regulatory program	DOE technology demonstration: IMAs, geophysics, five PAH soil extraction methods, percussive conductivity logging.	Technology evaluations	Bevolo et al. (9)
DOE	St. Louis Airport site (SLAP), 52 acres, 65'	St. Louis, MO/ Region VII	Uranium, thorium, radium, radon isotopes	UMTRA	Delineate extent of radioactive soil contaminants (ICP/MS and ICP/AES in mobile labs); evaluate connection to karst aquifer.	Microgravity surveys and geochemical dating of karst aquifer completed.	Ames Laboratory, in progress
DOE	Savannah River Site, 10 acres, 65'	SC/ Region IV	TCE, PCE, vinyl chloride, alpha-BHC pesticide, SB, Be, Mn, and As metals	CERCLA RI, RCRA RFI	Determine contaminants of concern; delineate extent of groundwater contamination; assess risk of soil/groundwater contamination.	Contaminant plume would have been missed by originally proposed monitoring well locations; discovered two shallow controlling aquitards.	Savannah River Site (10), Technos (11)
Polish government/ DOE	Oil refinery, 15 acres, 60'	Czecho-wice, Poland	VOCs, 5 PAHs, RCRA metals	Polish action levels	Demonstration of Eastern and Western European site characterization technologies.	CPT/LIF, CPT/Hg lamp, IMA comparison; percussive conductivity logging, horizontal drilling and sampling.	Ames Laboratory (12)

Force Base in Massachusetts described by Robbat (**14**), and pesticide contaminated soil at Wenatchee, Washington described in U.S. EPA (**15**). Other parts of the EPA document that provide useful information in relation to this ASTM Practice are cited elsewhere.

X1.2 *Comparison of Traditional and Expedited Site Characterization* —Traditional site characterization has benefited from, and uses to a varying extent, the advances in technology described in Appendix X3 that allow the ESC process to compress site characterization into a limited number of field mobilizations. Perhaps the defining difference between ESC and traditional site characterization is that the ESC process is structured to produce a final site model developed by an experienced multidisciplinary team, in which high confidence can be placed as a basis for deciding an appropriate course of action. In contrast, traditional site characterization is structured to produce mainly specified numbers of boreholes, monitoring wells, and chemical sample analyses, which may or may not result in an accurate final site model. Table X1.2 summarizes the differences between traditional site characterization and ESC for eight site characterization process components. The limited number of mobilizations in ESC results in significant time savings compared to the multiple mobilizations required by traditional site characterization. Use in ESC of multiple measurement and sampling technologies with on-site technical decision making by a technically skilled team results in a more accurate characterization of essential features of the geologic and hydrologic system as they affect contaminant movement. Fewer invasive penetrations mean increased safety for field personnel and reduced risk of inadvertently creating paths for contaminant transport.

X1.3 *Cost Savings of ESC*—The ESC process can be expected to yield significant cost savings compared to traditional site characterization, both in terms of total life cycle cost of a project and in terms of the cost required to obtain information of comparable quality. Typically, initial costs in ESC for analysis of prior data and planning for a mobilization and daily costs during mobilization will be higher than in traditional site characterization. The cost savings come primarily from the shorter period of time required to complete the investigation and the reduction in permanent monitoring well installations (which have high ongoing costs for sample analysis). The improved quality of information for decision making may also result in reduced costs for interim corrective actions and remediation. Table X1.3 summarizes the relative costs of various aspects of traditional site characterization and ESC. Burton et al. (**3**) calculated that at two ESC investigations in Nebraska where direct-push groundwater sampling was used to delineate contaminant plumes, the cost was 10 to 20 % the cost of obtaining equivalent data by using monitoring wells. Burton (**7**) presented data indicating that the staffing costs for the ESC process are about 87 % those for the traditional approach in a typical remedial investigation, in spite of the higher daily cost of mobilizing highly experienced personnel. Starke et al. (**16**) estimated that total costs for an ESC investigation at the Pantex Plant, near Amarillo, Texas, were 30 % the cost to execute the original traditional work plan. U.S. EPA (**1**) summarized time and cost savings for various projects where dynamic field activities were used for on-site decision making. The range in cost savings for six case studies rang from 15 to 57 percent and the range of time savings was from 33 to 60 percent.

TABLE X1.2 Process Comparison of Traditional and Expedited Site Characterization

Process Component	Traditional[A]	Expedited
1. Project Duration	Longer because of muliple mobilizations and intervals between where data are compiled and analyzed.	Shorter because of fewer, coordinated field mobilizations, analysis and archiving of most data in the field, and improved regulatory and community acceptance.
2. Project Leadership	Project leader typically in office; junior staff in field.	Project leader in field with experienced, multidisciplinary team.
3. Use of Prior Data	Reviewed, but often not carefully evaluated or interpreted.	Carefully compiled, evaluated for quality, analyzed, and interpreted as part of developing preliminary site model.
4. Technical Approach	Different disciplines tend to work independently at different times for field data collection and interpretation.	All phases of field investigations–data collection, compilation, analysis, and interpreation–integrated in the field.
5. Field Investigation Methods	Measurements usually not corroborated by complementary methods. Emphasis on installation of monitoring wells.	Use of multiple, complementary methods. Emphasis on noninvasive and minimally invasive investigation methods.
6. Work Plan	Field characterization and sampling plan defined before full mobilization and generally not modified during the course of a mobilization (may be modified if DQO process used).	Dynamic field technical program uses data as they come in to guide type and location of field measurements and samples for analysis.
	QA/QC plan for chemical sampling and analysis but usually not for other characterization activities.	QA/QC plan for all aspects of field data collection and handling; strong emphasis on indivdual team members' responsibility for QA/QC.
		Data management plan formal part of work plan.
		Community relations plan considered important part of work plan.
7. Number of Mobilizations	Multiple mobilizations, often carried out by different groups with little communication, interspersed with office analysis of data for a given investigation phase.	Normally one full mobilization for each investigation phase (two total), carried out under direct control and participation of a single core technical team.
8. Data Results and Analysis	Data analysis and interpretation usually accomplished in office weeks to months after field work. Computers not normallys used in field for data management and analysis.	Data obtained, interpreted, and archived in the field (within hours to days) as part of dynamic technical program. Computers used in field for data management as as aid in analyzing data.

[A] Certain elements included in the "expedited" column may be incorporated into a given "traditional" site investigation, but the characteristics described in this column can be considered typical of most site characterization activities at CERCLA and RCRA sites during the 1980s and early 1990s.

TABLE X1.3 Cost Comparison of Traditional and Expedited Site Characterization

Cost Factor/ Component	Traditional	Expedited
Initial cost	Lower because multiple mobilizations have lower separate costs, and junior staff are used in the field.	Higher because multiple senior technical personnel and supporting junior staff are in 2-phased, coordinated multidisciplinary field investigation.
Field Characterization	Higher because field characterization activities tend to be proposed in terms of a fixed number of borings/wells and samples.	Lower because on-site technical decision making allows efficient use of field methods to target collection to meet project objectives.
Monitoring	Higher because monitoring wells tend to be installed before the geologic and hydrologic system is well understood, resulting in a larger number of monitoring wells (higher well installation costs) and consequent high ongoing costs for sampling and analysis.	Lower because installation of permanent monitoring wells may be avoided, or is limited to a few locations where wells are needed.
Interim Corrective Action	Higher because less coordinated nature of field data collection may prevent optimal decisions for interium corrective action.	Lower because on-site technical decision making can target data collection to minimize interim corrective action costs.
Remediation	Higher to the extent that suboptimal remedial action decisions are made compared to the ESC process.	Lower as a result of one of more effects: (1) an improved conceptual site model and risk evaluation may allow a decision of no action or ongoing monitoring instead of remedial action; (2) where remedial action is required, reduced design and implementation costs as a result of an improved site model.
Total Cost	Higher,[A]	Lower.

[A] Not all factors will necessarily be higher than for ESC but all cost factors combined can be expected to be higher for a comparable level of data quality for decision making.

X1.4 *Other Related Approaches*:

X1.4.1 *Multiple Working Hypotheses*—The method of multiple working hypotheses, first described by Chamberlain (**17**) in a paper read before the Society of Western Naturalists in 1889 and later revised to focus on applications for geologic study (Chamberlain (**18**)), is well suited for initial stages of environmental site characterization of geologic and hydrologic systems, because the relative difficulty in making direct observations means that conceptualization of potential migration pathways for contaminants in the vadose zone and groundwater system is based on a relatively limited number of observations for which more than one explanation is possible.

X1.4.2 *Observational Method*—The observational method, used by Dr. K. Terghazi for applied soil mechanics investigations from the 1920s to the 1950s and documented by Bjerrum (**19**) and Peak (**20**), is an investigation process for geotechnical characterization of soils and geotechnical engineering design, in which characterization, design, and construction proceed hand in hand. Observed change and response of the soil system as construction proceeds are used to modify the design, as required. A critical element of the method is an early assessment of the most probable conditions and the most unfavorable conceivable deviations from these conditions. Approaches to the U.S. EPA Superfund RI/FS process (see Appendix X2) using the observational method have been described by Mark et al. (**21**), Brown et al. (**22, 23**), and Holm (**24**) and applied at DOE's Hanford site (**25**). In this approach, the emphasis in the RI stage is to gather information to establish general site conditions and identify most probable conditions and reasonable deviations as the basis for a flexible approach to remedial design.

X1.4.3 *Adaptive Sampling and Analysis*—Adaptive sampling and analysis is an approach that has been used successfully at a number of Department of Defense facilities to characterize near-surface contamination of soils (Robbat and Johnson (**26**); U.S. EPA (**27**); Robbat (**14**). The approach uses field chemical analytical methods and on-site technical decision making with geostatisically based models to guide sampling to determine the nature, extent, and level of contamination present at a site. The approach requires field analytical techniques applicable to the contaminants and action levels of concern for the site and a means for rapidly making decisions in the field regarding the course of the sampling program, which is accomplished by on-site computer processing using geostatistical, visualization, and other data analysis software. The adaptive sampling approach generally focuses on characterization of near-surface soil contamination.

X1.4.4 *Data Quality Objectives (DQO) Process*—The DQO process is a quality management tool developed by the U.S. EPA (**28**) to facilitate the planning of environmental data collection activities. The DQO process involves seven major steps: (*1*) state the problem, (*2*) identify the decision(s), (*3*) identify inputs, (*4*) define boundaries, (*5*) develop a decision rule, (*6*) specify acceptable decision errors, and (*7*) optimize data design. The process brings together the right players (stakeholders and technical staff) at the right time to gain consensus and commitment about the scope of the project. This interaction results in a clear understanding of the problem, the actions needed to address that problem, and the level of uncertainty that is acceptable for making decisions. Through this process, data collection and analysis are optimized so only those data needed to address the appropriate questions are collected. The benefit of applying DQO is that it improves planning efficiency, promotes defensibility of data, saves resources, is able to manage uncertainty, ensures consistency in decision analysis and reporting, and provides clear decision rules to identify the point at which further collection of data is no longer needed.

X1.4.4.1 *Comparison of the DQO and ESC Processes*—The ESC and DQO processes share common elements, and both are flexible enough to be used together, but differences between ESC and the DQO process as it is commonly practiced should be recognized. Both the ESC and DQO processes start with identifying all parties responsible for data use and decision making. They develop strategies, goals, and actions designed to address the problem. Both methodologies are driven by the scientific method. The DQO process is designed to ensure that each measurement is of known quality and consistent with available budgetary resources. It also usually assumes an optimal but fixed number of measurements. Information from the first measurement of the batch is usually not used to refine the next set of measurements. A completely efficient data acquisition system would incorporate all previous measurements to decide the nature and location of the next measurement, as is done in ESC. The DQO process typically uses a statistical approach, which is predicted on a random, independent set of measurements, in contrast to the ESC's focus on judgmental sampling. Finally, the DQO process often focuses only on chemical measurement of the contaminants of concern; in contrast, in ESC an integrated understanding of the geologic, hydrologic, and chemical system is required.

X1.4.5 *SACM and SAFER Processes*—The U.S. EPA's Superfund Accelerated Cleanup Model (SACM) and the U.S. DOE's Streamlined Approach for Environmental Restoration (SAFER) are complementary approaches for speeding up the CERCLA RI/FS process (U.S. EPA (**29, 30**); DOE (**31**)). Both SACM and SAFER were developed primarily because site characterization efforts at CERLA and RCRA sites were taking too long and did not always provide the information required for effective remedial action. SAFER integrates the DQO process (X1.4.4) with the observational method (see X1.4.2). SAFER involves regulators, stakeholders, and project managers in an integrated process that includes all activities associated with site characterization and remediation. The SAFER approach is designed to be aggressive and flexible in making decisions based on current information, as well as compatible and compliant with existing environmental regulations. ESC, SACM, and SAFER all emphasize the importance of including all stakeholders in the planning process. The ESC process can be readily incorporated into the site characterization component of the SAFER process. Because ESC reduces the time needed to obtain an accurate understanding of the geologic, hydrologic, and chemical system at a site, it allows less reliance on the observational approach, which focuses on identifying most probable conditions and contingency planning for reasonable deviations during remedial action. Because uncertainties concerning optimal design and operation of remedial measures are reduced by the accurate site model, contingency planning would be a less significant element when ESC is used in the framework of SACM or SAFER.

X1.4.6 *Triad Campaign*—The triad campaign led by the U.S. EPA's Technology Innovation Offices focuses on managing uncertainty in environmental decisions by promoting the use of systematic planning, dynamic work plans, and quick turnaround measurement technologies (Crumbling, et al. (**32**)). The campaign addresses all aspects contaminated, site assessment, and cleanup. The campaign has supported development of a number of guidance documents related to investigation and cleanup of brownfields (U.S. EPA (**33, 34**)).

X1.4.7 *Other Rapid Assessment Approaches*—Other approaches that use on-site decision making have been developed that share common elements with ESC. These include the Rapid Site Assessment Process used in the state of Florida (Applegate and Fitton (**13**); Rodriguez, et al. (**35**), STERDI (Simultaneous testing, Exploration, Remedial Design, and Installation) described by Waslenchuk and Man (**36**), and the Expedited Site Assessment Process promoted by EPA's Office of Underground Storage Tanks (U.S. EPA (**37**)). Although not specifically focused on contaminated sites, the approach described by LeGrand and Rosen (**38**) emphasizing the use of existing hydrogeological information to develop a prior conceptual model explanation (PCME) is an important element of the ESC process.

X1.5 *Relationship of ESC to Other ASTM Standards*:

X1.5.1 *Guide E1912*—The ASTM's Committee E50 has developed an accelerated site characterization (ASC) process for use at petroleum release sites. Basic principles of the ACS and ESC processes that are similar include the use of highly experienced personnel in the field to lead the investigation and an on-site iterative process to guide data collection and limit the number of field mobilizations. The ASC process is distinguished by its orientation toward petroleum releases sites, leadership by a single on-site field manager, and completion in a single mobilization. The ESC process may be appropriate for large petroleum release sites, such as refineries. At such sites both this practice and Guide E1912 should be reviewed in order to evaluate whether the ESC or ASC process is more appropriate.

X1.5.2 *Guide E1739*—The ASTM's Committee E50, with funding support from U.S. EPA, has developed a tiered approach to assessing risk for making decisions concerning remedial action at petroleum release sites. Depending on the geographic extent and amount of contamination, the expanded site assessment involved in Tier 3 of the risk-based correction action (RBCA) process might justify initiation of the ESC process.

X1.5.3 *Guide E1903*—The ASTM's Committee E50 has developed guidance for conducting a Phase II environmental site assessment (ESA) for real estate property transactions, where a Phase I ESA has identified environmental conditions that might result in liability under CERCLA or other statutes. The general focus of the E50 guide is on chemical characterization, and Phase II ESAs can normally be expected to provide the kind of information required in Step 1a (see Fig. 3) of the ESC process. If a Phase I ESA identifies the likelihood of significant soil and groundwater contamination, it may be more cost effective to initiate the ESC process designated to meet the special needs of a real estate property transaction rather than to conduct a Phase II ESA. In this event, care should be taken to incorporate into the ESC process the specific needs of investigation for a real estate property transaction as identified in Guide E1903.

X1.5.4 *Development of This Practice*—In April 1996, DOE provided funding to the ASTM to facilitate development of a guide that would formalize the ESC process, which was approved as PS 85 in December 1996 with the title Provisional Guide for Expedited Site Characterization of Hazardous Waste Contaminated Sites. The provisional guide was the result of an intensive effort by a ten-member core task group. In addition to the normal ASTM balloting process for a provisional standard, pre-ballot drafts of the guide received review by selected groups of geophysicists, practitioners of direct-push technology, chemists, and individuals representing the perspectives of state regulatory agencies, including a nine-state review panel convened by the Interstate Technology and Regulatory Cooperation Group (ITRC), the U.S. EPA, the U.S. Department of Defense (Air Force, Army, and Navy), DOE, and the U.S. Department of Agriculture. The provisional guide was reviewed by all 22 states in the ITRC. This full-consensus practice includes revisions in response to that review. The change in title from guide to practice occurred when the Task Group reviewed the ASTM definitions of guide and practice, and found that the latter term was more appropriate. In 2003 this practice was revised to facilitate its use in conjunction with the U.S. EPA guidance *Using Dynamic Field Activities for On-Site Decision Making* (**1**). See also X1.1.3.

X2. RELATIONSHIP OF ESC PROCESS TO RCRA AND CERCLA

X2.1 The Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also called Superfund) are the two main federal statutes and regulatory programs that require investigations to determine the extent and seriousness of subsurface contamination and to identify and implement appropriate remedial measures. Most ESC projects will take place in the context of RCRA or CERCLA, or both.

X2.2 *Terminology*—The RCRA and CERCLA programs have developed the different terminologies summarized below for similar phases of facility and site investigations. (Refer to DOE (21-22) for additional information and for relevant statutory and Code of Federal Regulation citations.)

X2.2.1 *RCRA Facility Assessment (RFA)*—Initial site investigation at a proposed RCRA facility at an existing facility with a solid waste management unit with a known or potential release, or upon the discovery of a solid waste management unit that was not examined during a previous RFA. The U.S. EPA (**39**) provides guidance on RFAs.

X2.2.2 *RCRA Facility Investigation (RFI)*—Detailed site investigation initiated when an RFA determines that hazardous waste constituents have been or are likely to be released from a solid waste management unit. The U.S. EPA (**40**) provides guidance on RFIs.

X2.2.3 *Corrective Measures Study (CMS)*—Study to evaluate corrective measures and select an alternative at a RCRA facility where an RFI indicates that concentrations of one or more hazardous constituents exceed action levels or may pose a threat to human health or the environment.

X2.2.4 *Preliminary Assessment/Site Inspection (PA/SI)*—Phase of an initial site investigation for a potential Superfund (CERCLA) site, generally involving review of readily available prior information (preliminary assessment) and a site visit to obtain samples for chemical analysis (site inspection). The U.S. EPA provides guidance on PAs (**41, 42**), The Hazard Ranking System (**43**), and on SIs (**44**). Refer to U.S. EPA (**45, 46, 47, 48**) for more recent guidelines on site assessments.

X2.2.5 *Remedial Investigation/Feasibility Study (RI/FS)*—Detailed site investigation at a Superfund site to obtain data for developing and evaluating effective remedial alternatives (RI) and selecting an alternative (FS). The U.S. EPA (**49, 50**) provides guidance on RI/FS.

X2.3 *Relationship to ESC Process*—The various phases of RCRA and CERCLA investigations relate to the ESC process as indicated below.

X2.3.1 *Support for Initiation of ESC*—Completion of a RCRA RFA or CERCLA PA/SI is necessary to make a determination that contamination is serious enough to initiate the ESC process (Step 1a in Fig. 3).

X2.3.2 *ESC Phase I and Phase II*—ESC Phase I and II investigations are roughly equivalent to a RCRA RFI and the RI phase of a CERCLA RI/FS.

X2.3.3 *ESC Phase III*—The ESC process can be extended into the CERCLA FS or RCRA CMS phases, but this practice does not address this phase in detail. (See Section 12 and Fig. 4 and Fig. 5.)

X3. SELECTION AND USE OF MULTIPLE, COMPLEMENTARY INVESTIGATION METHODS

X3.1 *Site Characterization Technologies Used in ESC*—The ESC process represents a significant shift from the approach to environmental site characterization that has evolved since the 1970s as a result of interaction between the regulatory, scientific, and applied environmental consulting communities. Individual elements of the process are currently used in traditional site characterization. The ESC process differs from traditional site characterization in formally combining relatively recent technological developments.

X3.1.1 *Advances in Noninvasive and Minimally Invasive Technologies*—Improvements in instrumental and signal processing have reduced the cost and turnaround time for data interpretation for a variety of surface and borehole geophysical techniques. Similar advances have occurred for direct-push soil and groundwater sampling equipment, and by adaptation and enhancements of standard geotechnical cone penetration technology, for subsurface physical and chemical characterization. The various noninvasive and minimally invasive techniques that are available allow use of multiple, complementary measurement and sampling methods for three-dimensional characterization of the subsurface to an extent that would be prohibitively expensive with conventional drilling and monitoring well installation.

X3.1.2 *Advances in Chemical Field and Laboratory Analytical Technologies*—Improvements and miniaturization of standard laboratory chemical analytical instruments, including automation of sample analyses and improvement in software for analyzing instrument signals, together with the development of a wide variety of field chemical test kits for environmental contaminants, makes "real time" (minutes to days) sample data results available during a single mobilization for three-dimensional mapping of subsurface contamination. Mobile laboratories or the use of overnight delivery to fixed laboratories means that there are essentially no limits on the quality of chemical data that can be used for on-site technical decision making during the ESC process.

X3.1.3 *Advances in Data Analysis and Management Technologies*—Miniaturization and increased computing power, along with the availability of a wide range of software for environmental data management, visualization, and analysis, make field data compilation, reduction, and interpretation possible.

X3.2 *Use of Complementary Methods for a Site*—The ESC process is not technology specific but is designed to optimize selection and use of the most appropriate technologies for a particular site. The process has a bias toward noninvasive and minimally invasive methods, but the use of any method that is not producing good results should be discontinued during a field mobilization. The principle of using multiple, complementary measurements can be applied in two different ways: use of multiple methods to measure the parameter or site quality of interest and use of the same method by more than one individual.

X3.2.1 *Multiple Methods for Geologic and Hydrologic Characterization*—Agreement between different methods or approaches used to obtain the same information increases confidence that the measurements accurately represent what is actually in the subsurface. Disagreement among measurements is an indication that additional investigation is required to explain the differences. Examples of complementary methods include the use of multiple geophysical surveys (such as ground-penetrating radar, electromagnetic induction, and magnetic surveys) to detect areas of buried waste, collection of continuous soil cores adjacent to an electronic cone penetration boring to correlate the electronic cone penetrometer (ECPT) log with actual lithology, the acquisition of multiple borehole geophysical logs (resistivity, induction, gamma) in a single borehole, analysis for multiple geochemical constituents and isotopes to differentiate aquifers, and the analysis of a single soil or groundwater sample with different analytical methods. Multiple methods are not necessarily required at all sampling points. For example, if soil cores adjacent to two or three ECPT logs show good correlation between logs and major lithologic units, complementary boring may be discontinued. Conversely, if ECPT logs show poor correlation with visually logged lithologic units, more careful evaluation of the ECPT sensor outputs (tip, sleeve, and pore pressure) may be required, or the lithologic log descriptions may need to be evaluated to see whether inaccurate description or poor recovery is causing the poor correlation. The same would be true for any innovative technology that could potentially provide information with greater ease or at a lower cost. Complementary methods must be used along with the innovative technology enough times to demonstrate that the latter can continue as a stand-alone method at the site. Caution should be used in applying innovative technology to assure that it is based on sound principles and carried out by reputable professionals.

X3.2.2 *Multiple Individuals Using the Same Method*—The principle stated in X3.2.1 also applies when different individuals use the same method: agreement increases confidence in the measurement or observation, and disagreement requires further investigation to resolve differences. Examples of this complementary use of a single method include the following: two geophysical surveys, such as gravity, designed by two individuals or groups using the same or different instruments; preparation of two separate lithologic logs of the same soil or rock cores by two individuals; and analysis of the same soil or groundwater sample by the same method in a field laboratory and an EPA-approved Contract Laboratory Program (CLP) laboratory.

X3.3 *ASTM Guidance on Field Investigation Methods*—Guide D5730 includes an index of more than 400 ASTM guides, practices, and test methods that may be useful for environmental site characterization. Table X3.1 identifies major ASTM guides and practices that may be of value in selecting field characterization methods and conducting field investigations.

TABLE X3.1 Major ASTM Guides and Practices Potentially Useful for Environmental Site Characterization[A]

D420 Guide to Site Characterization for Engineering Design and Construction Purposes (Vol 04.08)
D2488 Practice for Description and Indentification of Soils (Visual-Manual Procedures) (Vol 04.08)
D4043 Guide for Selection of Aquifer-Test Field and Analytical Procedures in Determination of Hydraulic Properties by Well Techniques (Vol 04.08)
D4448 Guide for Sampling Groundwater Monitoring Wells (Vol 11.04)
D4687 Guide for General Planning of Waste Sampling (Vol 11.04)
D4696 Guide for Pore-Liquid Sampling From the Vadose Zone (Vol 04.08)
D4700 Guide for Soil Sampling from the Vadose Zone (Vol 04.08)
D5088 Practice for Decontamination of Field Equipment Used at Nonradioactive Waste Sites
D5092 Recommended Practice for Design and Installation of Groundwater Monitoring Wells in Aquifers
D5126 Guide for Comparison of Field Methods for Determining Hydraulic Conductivity in the Vadose Zone
D5254 Practice for the Minimum Set of Data Elements to Identify a Groundwater Site
D5314 Guide for Soil Gas Monitoring in the Vadose Zone
D5408 Guide for the Set of Data Elements to Describe a Groundwater Site, Part 1–Additional Identification Descriptors
D5409 Guide for the Set of Data Elements to Describe a Groundwater Site, Part 2–Physical Descriptors
D5410 Guide for the Set of Data Elements to Describe a Groundwater Site, Part 3–Usage Descriptors
D5434 Guide for Field Logging of Subsurface Explorations of Soil and Rock
D5474 Guide for Selection of Data Elements for Groundwater Investigations
D5518 Guide for Acquisition of File Aerial Photography and Imagery for Establishing Historic Site-Use and Surficial Conditions
D5521 Guide for Development of Groundwater Monitoring Wells in Granular Aquifers
D5753 Guide for Planning and Conducting Borehole Geophysical Logging
D5777 Guide for Using the Seismic Refraction Method for Subsurface Investigations
D5792 Practice for Generation of Environmental Data Related to Waste Management Activities: Development of Data Quality Objectives (Vol 11.04)
D5903 Guide for Planning and Preparing for a Groundwater Sampling Event
D5980 Guide for Selection and Documentation of Existing Wells for Use in Environmental Site Chracterization and Monitoring
D5911 Practice for a Minimum Set of Data Elements to Describe a Soil Sampling Site
D6001 Guide for Direct Push Groundwater Sampling for Geoenvironmental Investigations
D6067 Guide for Using the Electronic Cone Penetrometer for Environmental Site Characterization
D6169 Guide for Selection of Soil and Rock Sampling Devices Used with Drill Rigs for Environmental Investigations
PS 78 Guide for Selection of Surface Geophysical Methods
D6282 Guide for Direct Push Soil Sampling for Environmental Site Characterization
D6286 Guide for Selection of Drilling Methods for Environmental Site Characterization and Monitoring
D6429 guide for Selecting Surface Geophysical Methods
D6634 Guide for Selection of Purging and Sampling Devices for Groundwater Monitoring Wells
D6724 Guide for Installation of Direct Push Groundwater Monitoring Wells
D6725 Practice for Direct Push Installation of Prepacked Screen Monitoring Wells in Unconsolidated Aquifers

[A] In *Annual Book of ASTM Standards*, Vol 04.09, unless otherwise indicated.

X3.4 *Field Sampling and Analysis*—The importance of rapid turnaround of chemical sample analyses for on-site technical decision making in the ESC process requires special attention to chemical QA/QC issues. The optimization of sampling locations allowed by the ESC process is generally accompanied by selection of analytical methods that provide high levels of data quality. Appendix X2 in Guide E1912 discusses data quality levels for field chemical characterization in more detail. It is the responsibility of the ESC provider to address and resolve issues of field quality with the appropriate regulatory authority in the Phase I and Phase II work plans. Examples of such issues are as follows:

X3.4.1 *Comparability of Direct-Push and Conventional Monitoring Well Groundwater Samples*—Direct-push groundwater samples may be more turbid than samples from properly developed monitoring wells, so issues of filtration, including sizes of filters, need to be addressed in the ESC work plan protocols. Direct push wells may also be useful as an alternative to conventional monitoring well installations for time-series groundwater monitoring.

X3.4.2 *Comparability and Quality of Field, Mobile Laboratory, and CLP Laboratory Analytical Results*—Where volatile contaminants are involved, field analytical methods may well provide more accurate measurements than a fixed laboratory. This may or may not be the case for other constituents. In addition, some state regulatory authorities require the use of certified laboratories for chemical analyses. The field sampling and analysis protocols in the ESC work plan may need to address these issues specifically.

X4. QUALITY CONTROL FOR GEOLOGIC AND HYDROLOGIC CHARACTERIZATION

X4.1 *Strategies for Quality Control in Geologic Characterization*—An important feature of an ESC dynamic work plan is incorporation of quality control (QC) procedures for geologic and hydrologic characterization activities into the QA/QC plan, in addition to the more established QA/QC procedures for collection, handling, and analysis of samples for chemical analysis. The variability of geologic and hydrologic systems means that it is difficult to assign statistically based confidence levels to measurements. Consequently, QC focuses on the use of multiple complementary methods or the use of a single method by multiple individuals, as described in X3.2. In addition to the usual QA/QC procedures for chemical sampling and analysis, an ESC QA/QC plan should include sections on QA/QC for other field activities, including data management (Appendix X5) and geologic, hydrologic, geophysical, and spatial control procedures (that is, the accuracy of horizontal and vertical location of measurement and sampling points). Each procedure should be formulated in a way that allows the project team member responsible for QA to determine whether procedures were followed. In the illustrative examples for geologic characterization that follow, the QC procedure is described first, followed by the QA check in the form of one or more questions that can be answered yes or no. QC procedures and QA checks can be developed similarly for hydrologic and geophysical characterization and for spatial control. Once an ESC provider has developed QC procedures in these areas, the appropriate ones can generally be incorporated into the QA/QC plan for a particular site with little or no modification.

X4.2 *Illustrative Examples of Quality Control in Geologic Characterization*:[11]

X4.2.1 *Preparing Geologic Cross Sections*—Identification of marker stratigraphic units and drawing of geologic cross sections based on original interpretation, by core technical team members with expertise in geology and hydrology, of all aerial photographs, geologic surface outcrops, wells, borings, and test holes within the immediate area of the site (within at least two- or three-mile radius). *QA check*: Have original cross sections been prepared, and how many people were involved in preparing them? (Increasing QC as number of individuals increases).

X4.2.2 *Identifying Stratigraphy and Water-Bearing Units*—Initial use of continuous coring (including appropriate measures to prevent possible cross-contamination), with selected cores logged separately in detail by at least two qualified project team members and differences reconciled, to confirm or modify hypotheses for the stratigraphic sequence and to identify water-bearing units. *QA check*: Are there two separate core logs and a reconciled one if they differ significantly?

X4.2.3 *Recording Borehole Logs*—Identification of the minimum information that will be recorded on standard borehole log forms. *QA check*: Does a random check of one or more log forms indicate that all minimum information has been recorded?

X4.2.4 *Use of Particle Size Analysis to Correct Borehole Logs*—Initial field or laboratory particle size analysis of selected logged units performed to check accuracy of field soil textural descriptions (USDA, unified soil classification (See Practice D2488, see Table X3.1 for full citation, Wentworth) in field logs, until there is a good match between manual textural classification and particle size analyses; borehole log descriptions revised when field textural classification is in error. *QA check*: Have initial field logs been corroborated and corrected by particle size analysis?

X4.2.5 *Calibration of Electronic Logs Against Cored Logs*—Use of continuous geologic logs as initial controls for multiple geophysical borehole logs and electronic cone penetrometer (ECPT) logs. *QA check*: Are geophysical logs available for at least one continuous geologic log, and is there an adjacent ECPT log?

X4.2.6 *Use of Surface Geophysical Measurements*—Use of surface geophysical measurements, if technically appropriate, to identify continuities and discontinuities of major stratigraphic boundaries or units. *QA check*: Have surface geophysical measurements been used to identify continuities and discontinuities of major stratigraphic boundaries or units? If not, have surface geophysical measurements been determined to be technically inappropriate?

X4.2.7 *Use of Subsurface Geophysical Measurements*—Use of continuous coring or direct-push geophysical measurements to confirm possible stratigraphic discontinuities identified by surface geophysical measurements. *QA check*: Have any surface geophysical surveys identified possible stratigraphic discontinuities? If so, have the survey results been checked by coring or borehole geophysical observations?

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[11] Adapted from *Master Work Plan: Expedited Site Characterizations at CCC/USDA Sites in Nebraska,* Applied Geosciences and Environmental Management Section, Environmental Research Division, Argonne National Laboratory, Argonne, Illinois, January 1994.

X5. QUALITY CONTROL FOR FIELD DATA AND COMPUTER RECORDS

X5.1 *Quality Objectives*—Computer records are files that contain either prior data, data acquired in the course of ESC field work, or the results of processing and interpreting these data. The primary quality objective with regard to computer records is to maintain the security and integrity of characterization data, from initial acquisition through final archival, and provide characterization team members with ready access to information contained in computer records.[12]

X5.2 *Quality Assurance Responsibility*—The data manager is responsible for verifying that computer records of field data are assembled and maintained according to the QA standards defined in this appendix. Each team member involved in acquiring computer-recorded field data is responsible for recording the original computer records according to procedures defined in X5.3 and for making these records available to the data manager in the prescribed formats. After field data have been verified by the data manager, assuring the continued quality of computer records is the responsibility of the computer group.

X5.3 *Field Data*—The following are requirements for field records that are generated, stored, or transferred in the form of computer files. These include data recorded directly by means of computer systems, such as geophysical well logs, seismic recordings, and electromagnetic soundings, and data that are transferred to computer systems for analysis, storage, or both, such as survey information, geologic well logs, processed geophysical data, and transcribed chemical analysis data.

X5.3.1 *Original Records*—The primary QA concern with regard to original field data is that accurate and secure copies of all data are preserved and that no data are lost or altered because of transcription, mishandling, transfer of computer files, or computer system failure. Any original records that are entered directly onto a computer hard disk or memory are transcribed in a timely fashion after collection onto a removable storage medium, such as floppy disks or tapes, and these copies are handled as original or master data files. If the original recording is made on a removable medium, these originals are considered to be original data master files, and all further processing of the data is done with working copies made from these master files.

X5.3.2 *Transcribed Data*—Field data that are transcribed from written form into computer files, such as survey locations, analytical results, or geologic logs, are checked and verified for accuracy at the time of transcription by the team's data manager. Following verification, a copy of the computer file is saved on a removable medium as a master file, together with copies of paper records from which the master files were transcribed. These master files are then handled in the same manner as original master data files.

X5.3.3 *Master Data Files*—Master data files, defined as either original data recorded on transportable media or transcriptions of original data onto transportable media, are stored in a secure work or storage location that is separate from working copies of these files. Copies of original supporting paperwork, such as field notes, laboratory reports, observer reports, and paper logs, are maintained with the master data files, either in the form of duplicate paper copies or as digital images. Master data files are labeled in a manner that includes the location name of the data source. If corrections are made to original paperwork used to generate a master file, the team member initiating the change is responsible for informing the data manager, who documents the correction of the original master file, initials the original paperwork to verify that all changes are made, and retains a copy, The corrected master file is saved with the other project master file and labeled as a corrected version. The original master file is saved in a separate folder of obsolete master files.

X5.4 *Data Processing*—To ensure that master data files are not altered or damaged, all processing of field data is performed by using duplicate copies of master files for input, not master data files. Quality assurance of processed data consists of ensuring that processing is conducted with approved methods that preserve data integrity throughout the processing sequence and that processed data are quickly made available to technical team leaders for review and verification. The QA procedures are discussed below.

X5.4.1 *Data Processing Standards*—Data are processed by technical or computer group personnel using benchmark-tested software systems. Documentation for software used in processing is maintained and available for reference. The computer group is responsible for keeping track of software and upgrade that meet quality standards and for providing documentation for software. Field data are initially preprocessed into a common format that can be imported to processing, display, and database programs. This normally is a spreadsheet format, except in the case of certain geophysical data, for which industry-standard formats are specified. Data from these files are imported to analysis and display programs to produce graphic displays of results in the field. Results are submitted to technical team members for validation. During all stages of data processing, records are backed up daily on a storage medium that is independent of the computer on which the processing takes place. This medium may be an external hard drive, a removable disk, a floppy disk, or a tape.

X5.4.2 *Review and Correction of Errors*—To minimize errors in processed field data, processing results are distributed daily for review by team members. Where possible, results are presented in graphic format to facilitate review and detection of errors. Maps are distributed showing the locations of field activities, such as soil borings, cone penetrometer sites, and soil or water samples. Analytical results are normally in the form of listings, but values are also shown on maps and cross sections where possible. Subsurface geologic and hydrologic

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[12] Taken with minor modifications from *Master Work Plan: Expedited Site Characterizations at CCC/USDA Sites in Nebraska,* Applied Geosciences and Environmental Management Sections, Environmental Research Division, Argonne National Laboratory, Argonne, Illinois, January 1994.

data are displayed in the form of well logs and cross sections. Surface geophysical data are displayed on maps, cross sections, or both, as appropriate. These displays may be made from interim or temporary processing results, provided that all displays indicate the version, date, or both, of the processing file from which the display was generated. Team members are responsible for notifying computer support personnel immediately of any erroneous or inconsistent results seen in these displays. Corrections to master data files are documented and approved by the data manager by following the procedures in X5.3.

X5.5 *Final Data Processing Results*—Whenever final results of data processing are reported in a form other than listings of raw field data, the computer files that generated these results are saved with appropriate labeling to indicate a final result. This includes files that generate graphic displays, database files, spreadsheet listings, and AutoCAD maps, for example.

X5.6 *Quality Control Tracking*—At various stages in the acquisition, processing, and reporting sequence, data files are processed into database formats for compilation and display. To ensure that only accurate data are included, each data entry, or each group of entries from single source, into the database is accompanied by an index indicating the level of QC checks through which the data have been passed. Each database entry includes the name of the data manager or other individual who verified the entry. The indices are as follows:

X5.6.1 *QC Level 1*—Data entries are tentative and subject to change (for example, unsurveyed boring locations, unverified analytical results, extrapolated stratigraphic boundaries). This category is used in the field to allow immediate display of daily results.

X5.6.2 *QC Level 2*—The data entry has been verified by the data manager.

X5.6.3 *QC Level 3*—The data entry has been verified by the data manager, and the ground location of the data source has been confirmed by an official survey.

X5.6.4 *QC Level 4*—All checks have been completed. Processed results have been reviewed and approved by technical team leaders for inclusion in reports.

X5.7 *Data Archival*—All master files, files or final results, files of significant intermediate or auxiliary results, and copies of database are archived in permanent storage, together with supporting paperwork and documents. Archival is on a removable medium, which is stored in addition to data saved on standard backup systems.

X6. EXAMPLE OF THE ESC PROCESS

X6.1 *Introduction*—The following example illustrated the use of the ESC process by Argonne National Laboratory at a landfill in New Mexico where unauthorized dumping of hazardous waste was suspected (Burton (**5**), Burton et al. (**3**)). With minimal prior information, on-site technical decision making and the use of multiple, complementary characterization methods allowed identification of contaminant sources, potential migration pathways, and contaminant distribution in two major field mobilizations without the installation of a single monitoring well. The ESC investigation at this particular site demonstrated no significant movement of contaminants from the landfill trenches and pits and no risk of groundwater contamination. The appropriate regulatory agencies accepted a recommendation of no remedial action or ongoing monitoring.

X6.2 *Background*:

X6.2.1 *Landfill Setting and History*—The Flora Vista landfill, located on federal land in northwestern New Mexico and owned by the Bureau of Land Management, covers 13 acres. It was leased and used as a modified sanitary landfill (not covered daily) by San Juan County from July 1978 through 1989. In 1986 the New Mexico Environmental Improvement Division alleged that between the 1970s and August 1985, large quantities of petroleum, industrial, or other hazardous wastes were deposited in septage waste pits at the site without BLM authorization.

X6.2.2 *Previous Investigations*—A preliminary assessment (PA) in 1986 and a site investigation (SI) by separate private contractors generated conflicting maps of previously covered trenches and pits. Surface and subsurface soil samples collected during the PA and SI programs indicated the presence of hazardous compounds (including tetrachloroethylene, toluene, benzene, acetone, 1,1,1–trichloroethane) in one septage pit area of the landfill. The SI results were interpreted by the contractor as indicating possible lateral and vertical migration from this pit, presenting a potential hazard to human health and the environment. The contractor recommended installation of five monitoring wells at the site. On the basis of the results of the PA and SI, and landfill was closed. At this stage, Argonne was asked by the BLM to initiate an ESC project to determine whether remediation of the landfill was required.

X6.3 *Phase I Investigation*:

X6.3.1 *Prior Data and Initial Site Visit*—Prior data on the disposal history of the landfill were extremely sparse at the beginning of the ESC project. Maps of previously covered trenches and pits generated during the PA and SI were conflicting. Information on regional geology indicated thick alluvium (>100 ft) with clays at a depth of 30 to 50 ft, covered the Tertiary Nacimiento Formation, a hard, lithified, fairly impermeable sandstone. The nearest subdivision and the Animas River were about 1.8 miles southeast of the site, and the nearest residence was 1.2 miles south. At the initial site visit, the core technical team found that the area had been fenced and covered with approximately 2 ft of sandy soil. The only surface indication of the locations of pits and trenches at the site was an interior fence in the southwest corner, where a septage pit was supposedly located.

X6.3.2 *Phase I Objectives*—Two major objectives based on the preliminary site model were defined for the Phase I investigation: map the now-buried source areas (trenches and pits) and define migration pathways for contaminant movement from these sources areas (bedrock surface, clay lenses, surface drainage patterns, depth to water table). When the source and migration routes were delineated, an optimal sampling project in Phase II could be designed to fully test migration from the sources.

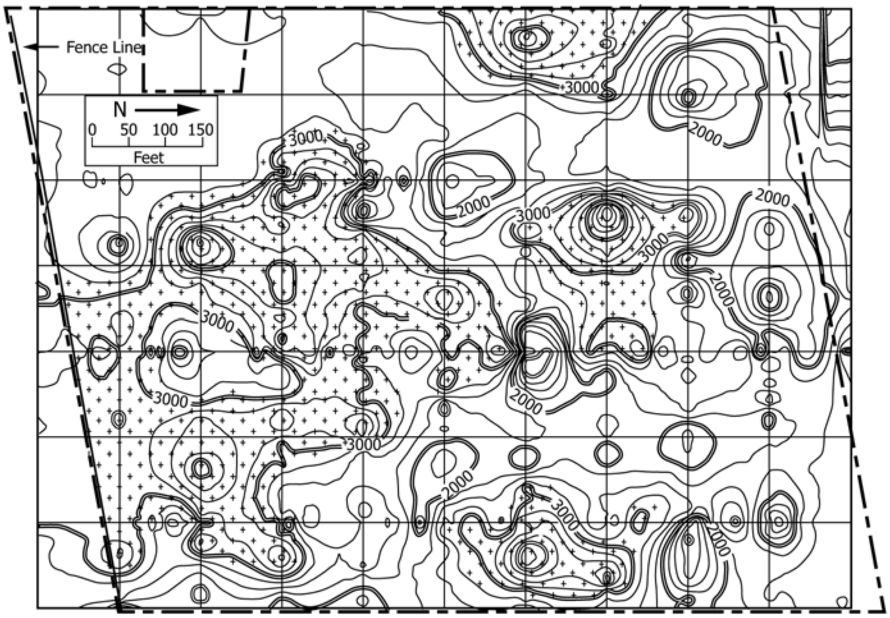
X6.3.3 *Source Area Characterization*—Surface geophysical surveys used to map trenches and pits included magnetometry to detect possible buried metallic waste and trench boundaries (see Fig. X6.1) and two frequency domain electromagnetic (EM 31 and EM 34) surveys to detect possible contaminant plumes associated with oil field wastes that might have been placed in the landfill. The chief emphasis was on the EM 31, with a penetration of about 15 ft, for mapping landfill trenches and pits (see Fig. X6.2). The results of the EM 34 survey (see Fig. X6.3), with a depth of exploration of about 50 ft, could be interpreted as either conductive contaminant plumes or clay layers, on the basis of preliminary site model. The three surveys were combined to establish probable locations of shallow and deep trenches and pits (see Fig. X6.4). Significant interpretations by the ESC core technical team of the surface geophysical surveys included the possibility of deep contaminant source areas in the north central and southeast areas of the landfill and evidence of shallow contamination extending beyond the interior fenced area in the southwest corner that was supposed to delineate the area of the septage disposal pit.

X6.3.4 *Migration Pathway Characterization*—Seismic refraction, electrical resistivity, and time domain electromagnetic (TDEM) surveys were used to evaluate potential subsurface migration pathways. After two days in the field, it was evident that the seismic refraction survey was mapping a bedrock surface at fairly shallow levels (15 to 45 ft) beneath the landfill surface. This relatively shallow bedrock had not been predicted by the regional geology data, but inspection of several nearby bedrock outcrops indicated that the Nacimento Formation could be present as an erosional bedrock surface at the landfill site. Because this surface might play an important role in unsaturated flow from the trenches and pits, the field project was altered to include a more comprehensive seismic refraction survey within and immediately around the landfill. Seismic survey profiled provided 76 depths to bedrock, which were contoured to reveal an erosional surface with potential subsurface migration pathways at the interface between the less permeable bedrock and overlaying unconsolidated materials having a generally southwesterly direction (see Fig. X6.5). The seismic surveys, combined with electrical resistivity and TDEM studies, indicated that the water table was about 150 ft beneath the surface. These surveys were confirmed when two existing wells were located near the site and the depth to water was measured at 150 ft. The TDEM and EM-31 surveys identified clay layers (aquitards) in the subsurface, dipping in a direction generally similar to that of the buried bedrock surface. A surface topographic survey of the landfill indicated a general southerly direction of surface runoff, with runoff from the eastern edge to the east (see Fig. X6.6).

X6.4 *Phase II Investigations*:

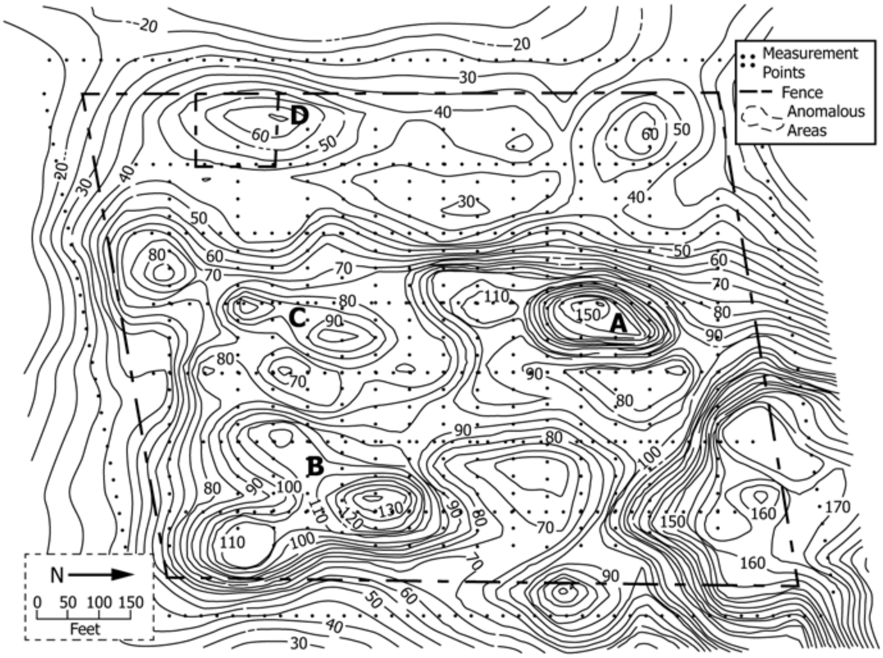
X6.4.1 *Phase II Objectives*—The site model, represented as a map showing potential trench and pit sources and the potential surface and subsurface migration pathways, was used to identify soil and soil boring sampling points to determine the distribution and concentration of contaminants in the subsurface (see Fig. X6.7).

X6.4.2 *Soil Boring and Sampling Results*—At the beginning of the Phase II field investigation, sampling and soil boring



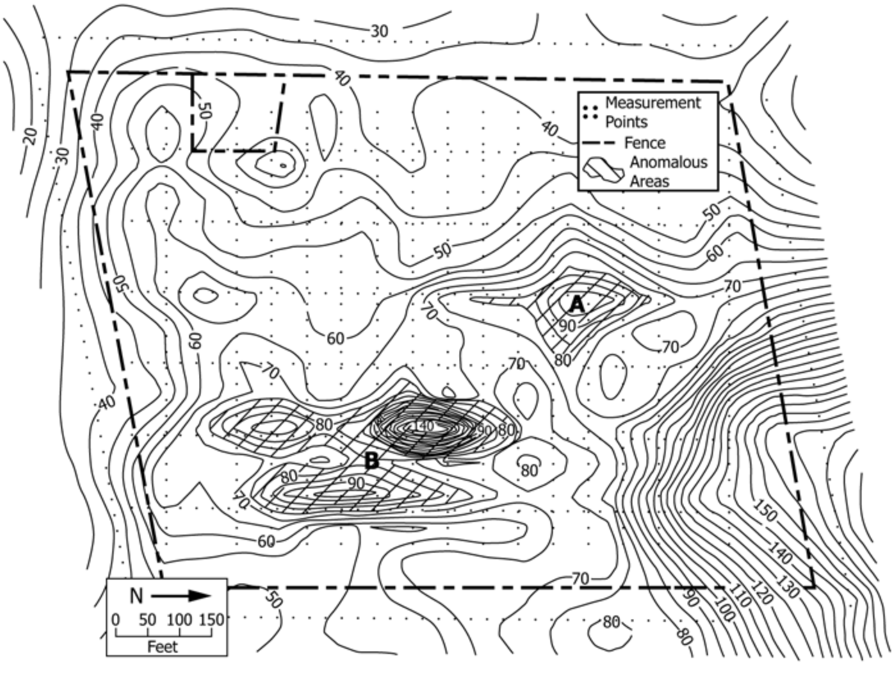
NOTE 1—Values are in gammas. Areas 200 gammas above background are marked with + symbol and represent solid waste trench locations.

FIG. X6.1 Total Field Magentic Contour Map for Flora Vista Landfill



NOTE 1—Values are in millimhos per meter. Anomalous areas A - D are possible pit or trench areas.

FIG. X6.2 EM 31 Contour Map for Flora Vista Landfill



NOTE 1—Values are in millimhos per meter. Anomalous areas A and B are trench locations.

FIG. X6.3 EM 34 Contour Map for Flora Vista Landfills

locations were chosen to observe and sample all major migration pathways without drilling into a trench or pit. This restriction avoided the possibility of introducing contamination into the subsurface by arbitrary drilling through potentially contaminated pits and trenches, as well as improving health and safety protection of the staff. Bedrock depths determined by deep drilling substantiated the general nature of the bedrock surface and indicated that the seismic bedrock depths were accurate within 10 ft. The clay layers identified by the TDEM and EM 31 surveys were also confirmed by drilling. Careful

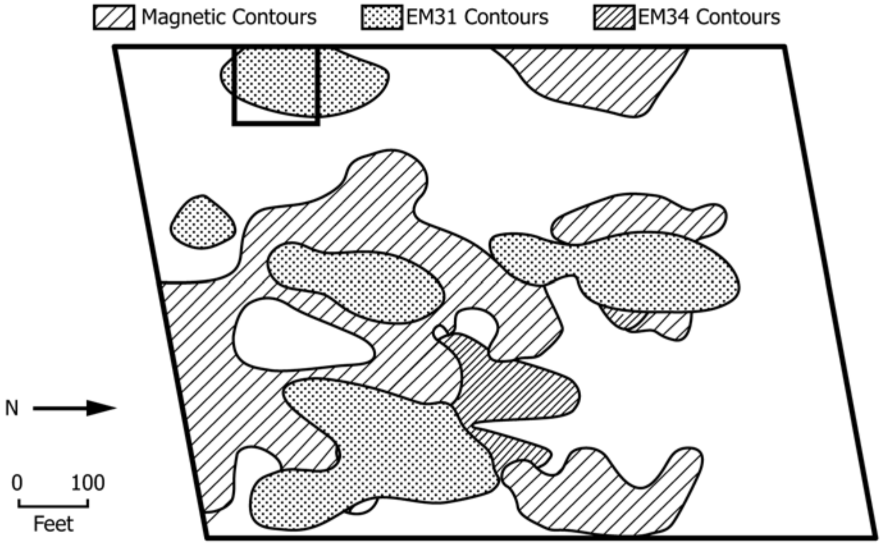
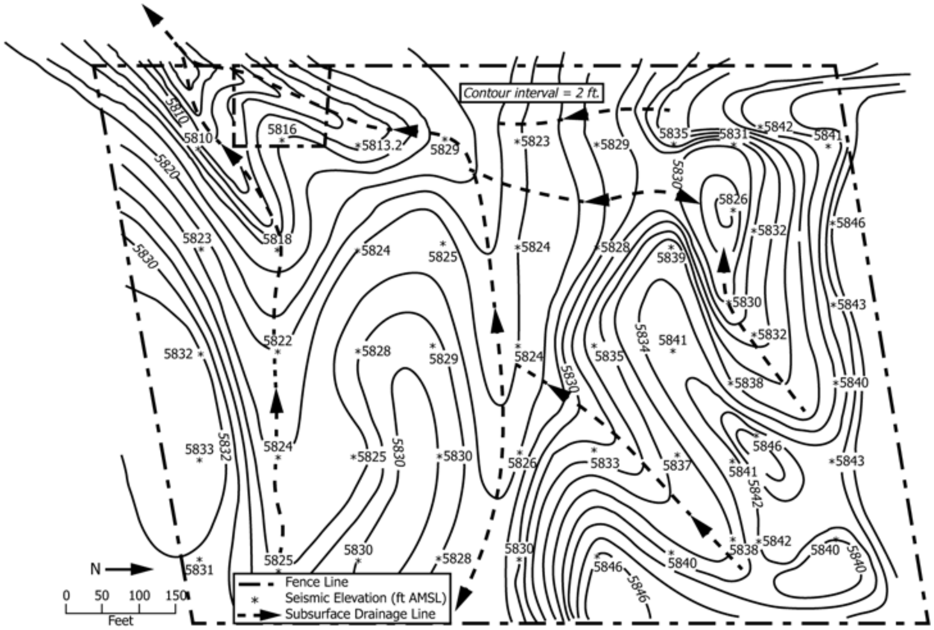


FIG. X6.4 Magnetic and Electromagnetic Data Were Combined to Establish Probable Locations of Shallow and Deep Waste Materials



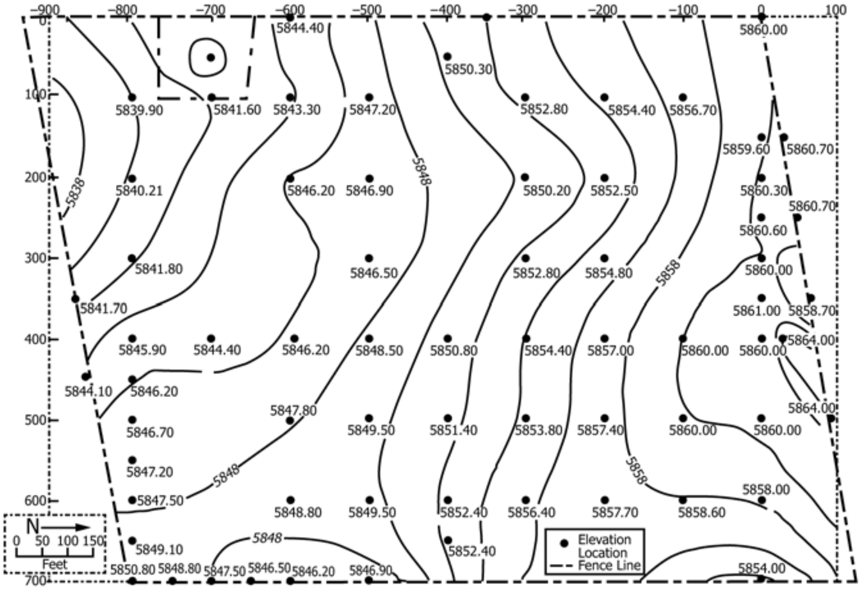
NOTE 1—Elevation in feet AMSL.

FIG. X6.5 Bedrock Topography Map of Flora Vista Landfill Showing Potential Subsurface Migration Pathways

hand augering or drilling into the near-surfaced soil substantiated the presence of pit and trench boundaries within 5 ft of the expected locations.

X6.4.3 *Waste Pit Delineation*—The only pit area actually drilled to depth was the fenced area in the southwest corner. During the SI, the contractor had drilled two soil borings (WB1 and WB2, Fig. X6.8) in the vicinity of a septage pit that was open to the surface at the time. On the basis of the analytical results from this drilling, the contractor had proposed that lateral and vertical migration of contaminants has occurred from the pit area. The EM 31 survey results, combined with information for eight borings within and adjacent to the pit and coupled with reexamination of the contractor data, showed that this is actually one large septage pit and that no lateral or vertical migration has occurred from it. Without the EM 31 data, outlining the possible boundaries of the pit, and the seismic data, giving an idea of the location of the base of the pit, considerable time and money for drilling of monitoring wells and additional soil borings would have been required in an attempt to understand this one area.

X6.4.4 *Contaminant Distribution and Risk*—Only low levels of volatile and semivolatile organic compounds and metals were found in isolated locations of the septage pit of the landfill and nowhere else on the site. No evidence was found for either lateral or vertical movement of these contaminants from the waste pit or landfill, and future movement is unlikely because the area receives <8 in. of rainfall annually. Futhermore, the depth to groundwater (about 150 ft), protection by 10 to 20 ft



NOTE 1—Elevation in feet AMSL.

FIG. X6.6 Surface Topographic Map of Flora Vista Landfill

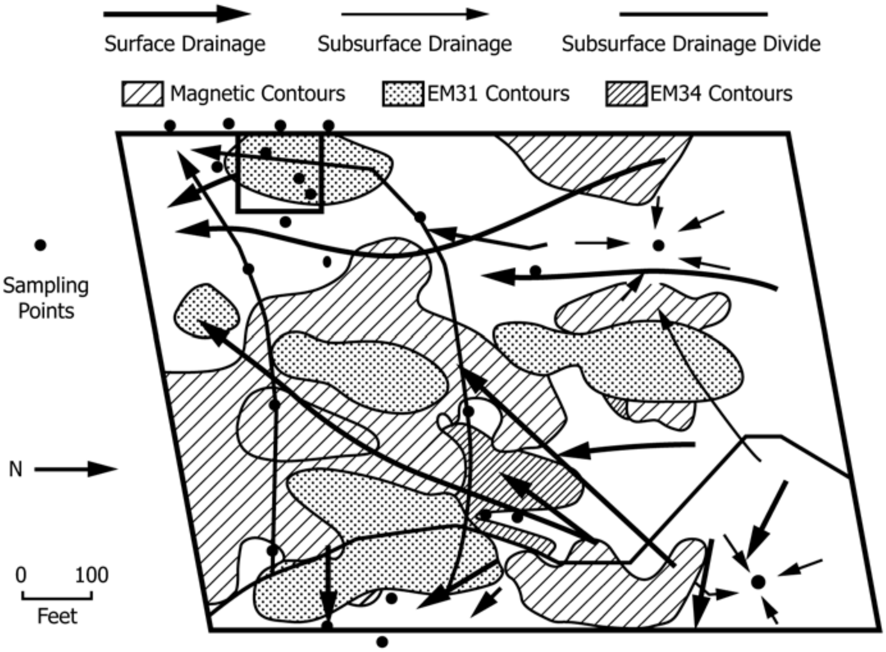
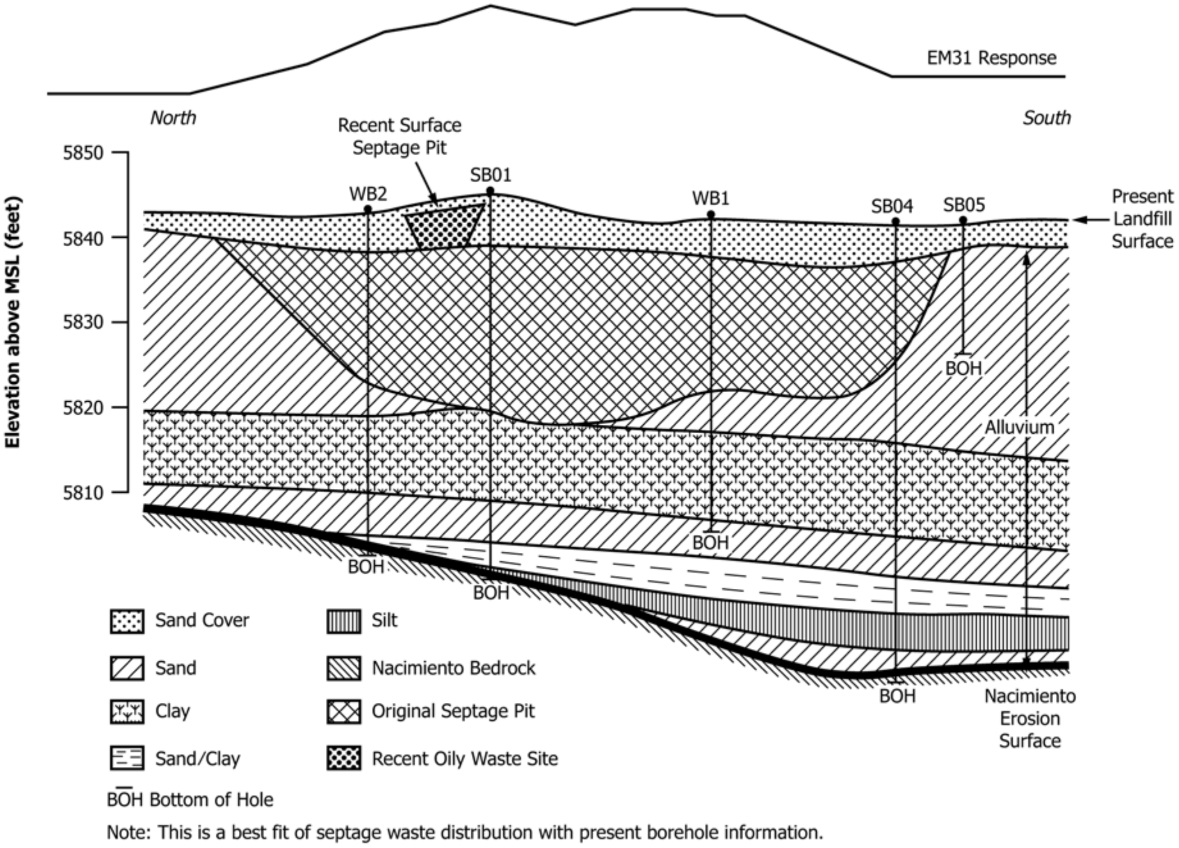


FIG. X6.7 Source Areas and Potential Surface and Subsurface Migration Pathways at Flora Vista Landfill as Defined by Geologic and Geophysical Surveys, with Soil and Soil Boring Sampling Points for Testing Contaminant Migration

of clay in the alluvium, and a bedrock thickness of 85 to 100 ft meant that the risk of groundwater contamination was negligible.

X6.5 *ESC Investigation Recommendations*—The Argonne ESC team recommended closure of the landfill without installation of monitoring wells or remediation. These recommendations were accepted by the appropriate regulatory agencies.



NOTE 1—This is a best fit of septage waste distribution with present borehole information.

FIG. X6.8 Drilling Confirmation of the One Waste Pit Predicted by the EM 31 Survey at Flora Vist Landfill

X7. SECOND EXAMPLE OF THE ESC PROCESS

X7.1 *Introduction*—The following example illustrates the use in 1995 of the ESC process at a 4-acre South Carolina site with buried waste trenches. This work was under the direction of Dr. Albert Bevolo of the Ames Laboratory with a core technical team consisting of senior personnel from Ames and the major subcontractors for the project. The two-phased ESC program resulted in the identification of a discrete source area within the trenches and the rapid, high-resolution delineation of the vertical and horizontal extent of groundwater quality impacts emanating from the source area.

X7.2 *Background*:

X7.2.1 *History*—The D-Area Oil Seepage Basin (OSB) at the DOE Savannah River Site (SRS) was known to contain buried debris in trenches as deep as 8 ft, including drums and oil, other trash, and possibly other wastes. An interim action was planned for the basin in early 1995 to remove drums, debris, and the principal threat source material, such as free product and sludge. However, a very high water table and inundation of the trenches by groundwater in early 1995 forced postponement of the interim action until the ESC investigation was completed.

X7.2.2 *Waste Trench Setting*—The D-Area OSB occupies an area approximately 240 by 440 ft (see Fig. X7.1). The site is relatively level with surface water bodies about 200 ft west and 400 ft south of the trench areas. An intermittent stream connects these surface water features (see Fig. X7.1). The regional geologic setting consists primarily of fluvial sands, some of which may be silty or clayey, with localized clay stringers and layers of cemented sands. A regional “green clay” aquitard common at the SRS, lying at the base of the shallow fluvial sand aquifer, was estimated to be 24 m (65 ft) to 50 m (150 ft) below the ground surface near the OSB.

X7.2.3 *Previous Investigations*—Prior to the ESC investigation, site investigation activities at the D-Area OSB between 1984 and 1994 included soil probings, a few cone penetrometer (CPT) pushes, a magnetic survey, several ground-penetrating radar (GPR) surveys, and a soil gas survey. In addition, six piezometers were installed to monitor water table fluctuations, and four groundwater monitoring wells were installed to provide groundwater quality data. On the basis of information obtained from these piezometers and monitoring wells, local shallow groundwater flow was generally thought to be in a southwesterly direction. The water table was found to fluctuate seasonally from a depth of 1.2 m (4 ft) to 4 m (14 ft) below the ground surface. Consequently, during seasonal high-water-table conditions, shallow groundwater was found to intersect the lower part of the trenches at a depth of 2.5 m (7

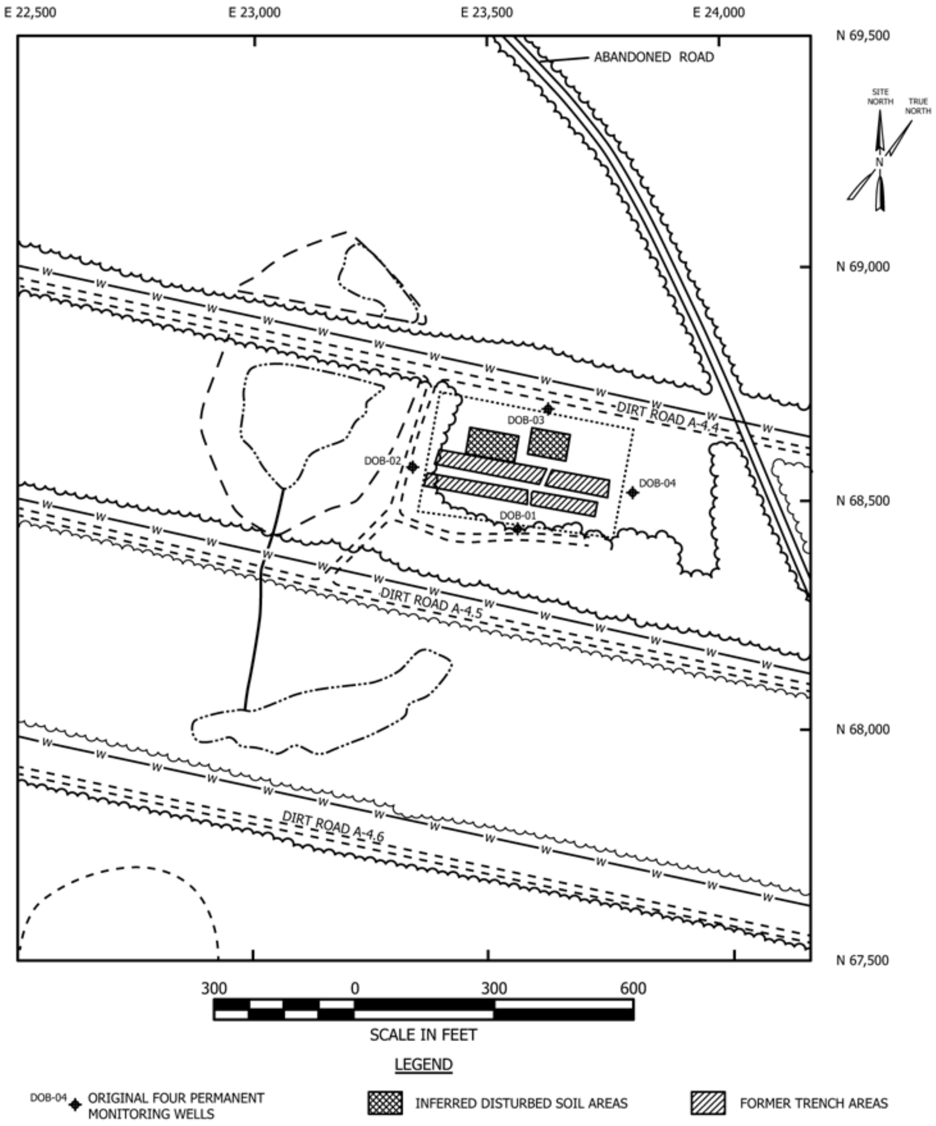


FIG. X7.1 Site Plan of D-Area Oil Seepage Basin, with the Original Four Well Locations (10)

ft) below grade. Although some environmental sampling had been completed, a specific list of contaminants of concern (COCs) had not been identified by the regulators before the ESC program began. A scoping meeting was held in April 1995 with representatives from U.S. EPA Region IV and the South Carolina Department of Health and Environmental Control (SDHEC) to obtain concurrence on the dynamic work plan strategies.

X7.3 *Phase I Investigation*:

X7.3.1 *Objectives*—The primary objectives of the Phase I investigation were to characterize the geologic and hydrogeologic conditions at the site to identify potential migration pathways, locate accurately the buried waste trenches, and establish an appropriate list of COCs as the focus for Phase II activities. Information gained in meeting the first two objectives would provide a starting point for the sampling and analysis program in Phase II, while that from the third would determine the chemical analysis program for Phase II.

X7.3.2 *Preliminary Site Model and Investigation Methods*—After completion of a visual reconnaissance of the site in April 1995 and familiarization with existing data, including aerial photo analysis of the site to identify any unusual geomorphic conditions, a preliminary site model was developed. Fig. X7.2 *(a)* shows the general direction of groundwater flow, based on available data, and Fig. X7.2 *(b)* shows a preliminary cross section of the site, along with the depths of geophysical measurements to be made. Table X7.1 identifies the types of geologic and hydrogeologic measurements made during the Phase I investigation, the preliminary objectives of the measurements, and the data obtained. The Phase I field investigation occurred in a two-week period in early June 1995 and a two-week period in early August 1995. All of the surface and borehole geophysical measurements and interpretations were made by Dick Benson and his crew from Technos, Inc., under subcontract to the Ames Laboratory. The Geoprobe conductivity measurements were conducted by Zebra, Inc. The CPT investigations were performed with an Applied Research

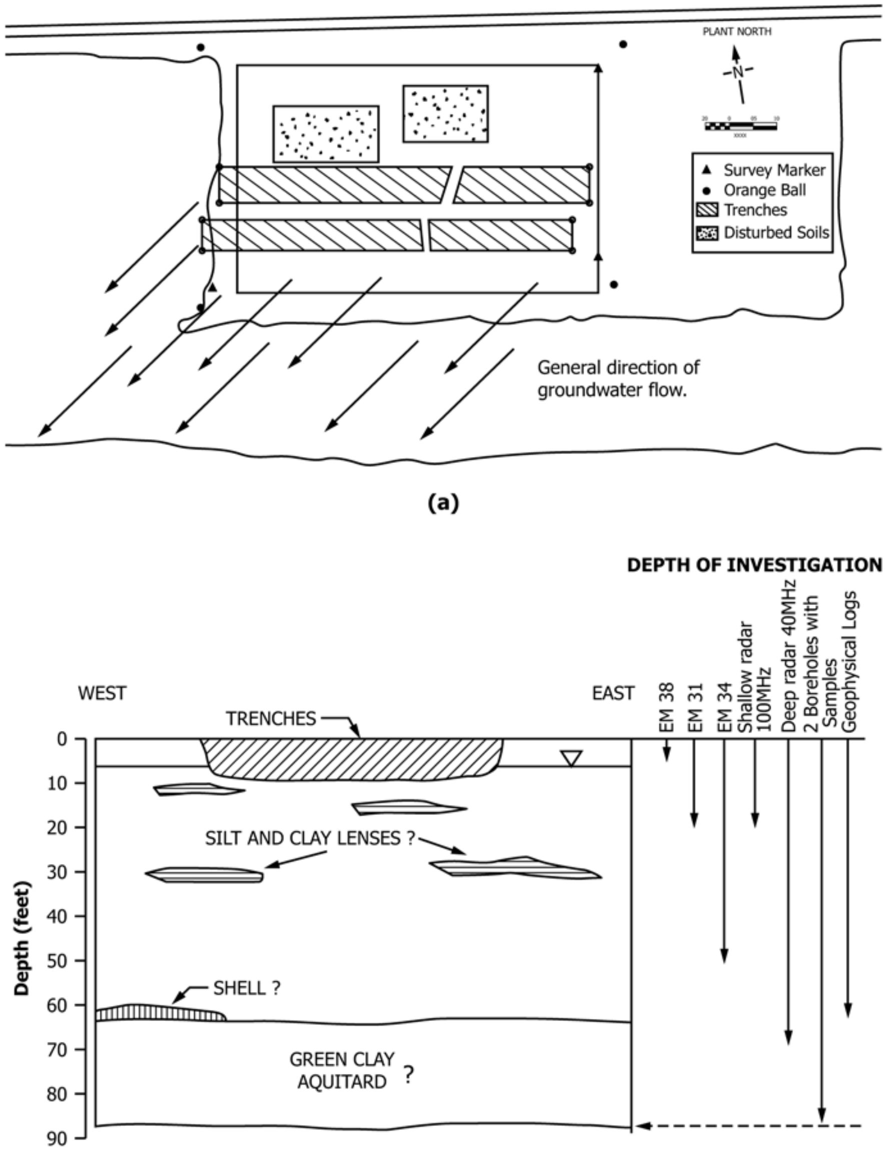


FIG. X7.2 D-Area Oil Seepage Basins Site Map Showing the Initital Conceptual Model of Site Conditions: (a) Trench Boundaries and General Direction of Groundwater Flow, (b) East-West Cross Section Along with the Depth of Geophysical Measurements to be Made (34)

Associates CPT and by an Applied Research Associates crew operating the DOE Site Characterization and Analysis Penetrometer System (SCAPS). All Phase I soil and groundwater sample collection and off-site analyses to establish the list of COCs were conducted by McLaren/Hart, Inc., under subcontract to the Ames Laboratory.

X7.3.3 *Geology*—Correlation of two geologic borehole logs drilled with the rotosonic methods to extract continuous cores with geophysical logs (see Fig. X7.3 *(a)*), GPR and electromagnetic conductivity survey results, and Geoprobe conductivity logs (see Fig. X7.3 *(b)*) indicated two high-conductivity zones at about 10 to 25 ft below ground surface. Sieve analysis data from the two cores, combined with reevaluation of the Geoprobe conductivity logs and the CPT logs, led to the conclusion that the conductive layers were associated with thin layers of silt or slightly cemented sands, or both, which were exerting some control on an inorganic leachate flowing southwest from the trenches. The green clay was found to be present at a depth of about 40 ft below grade, some 20 ft shallower than regional estimates.

X7.3.4 *Trenches*—High resolution GPR (Fig. X7.4 *(a)*) and electromagnetic conductivity surveys (see Fig. X7.4 *(b)*) with 1-m spacing were used to delineate accurately the two major east-west trench areas, several areas of disturbed soil, and local areas of buried debris outside the main trenches.

TABLE X7.1 Geophysical, Geologic and Hydrologic Measurements Made as Part of the D-Area Oil Seepage Basin ESC Phase I Investigation (modified from (51)).

Measurement	Characterization Objectives	Additional Data Obtained
Two Boreholes	• Stratigraphy • Depth and thickness of green clay	• Sieve analysis • Time series water level data from intalled piezometers
Geophysical Logging – Natural gamma – Density – Porosity – Induction (conductivity)	• Stratigraphy (correlation or lack of it between existing piezometers, wells, and the two new boreholes)	• Slightly elevated conductivity, indicating an inorganic plume in new downgradient piezometers and one existing well
– Ground-Penetrating Radar (100 MHz) to about 20 ft	• Detailed stratigraphy to 20 ft • Mapping of buried materials	• Dip of shallow strata and buried channels, which may control DNAPL flow
– Ground-Penetrating Radar (40 MHz) to 60 to 70 ft	• Deeper stratigraphy and green clay	• Insight for the site model dip of deeper strata and buried channels, which may control DNAPL flow
Electromagnetic Conductivity Measurements – EM38 to 5 ft – EM31 to 20 ft – EM34 to 50 ft	• Lateral geologic variability • Mapping of buried materials	• Detection and mapping of inorganic leachate plume extending from burial pit by EM31 and EM34
Geoprobe Conductivity Logging	• Detailed data on stratigraphy to depths of 40 to 60 ft	• Data on the distribution of inorganic contaminants • Insight for the site model
Cone Penetrometry	• Stratigraphy by soil type	• Data for reinterpretation of Geoprobe conductivity measurements
Slug Tests	• Typical values for hydraulic conductivity	. . .
Water Level Measurments	• Confirmation of the local groundwater flow direction	. . .

X7.3.5 *Revised Site Model*—Fig. X7.5 *(a)* and Fig. X7.5 *(b)* show the site model at the end of Phase I, with the two silty layers above the green clay influencing migration of the inorganic plume inferred from the various conductivity measurements. The main changes from the initial site model were the existence and nature of the nearly continuous intermediate 10-ft and 25-ft layers and their associated high conductivities, as well as the shallower depth to the green clay layer. The continuity and nature of the two shallow aquitards were determined primarily by the minimally intrusive CPT and Geoprobe conductivity measurements performed in early August 1995.

X7.3.6 *Chemical Analyses*—Soil and groundwater samples collected near the trenches were intended to characterize the contaminants present at the source area. The samples were sent off-site to fixed laboratories for definitive chemical analysis by SW-846 methods at accelerated turnaround times. The samples were analyzed for: volatile organic compounds (VOCs), total petroleum hydrocarbons (diesel and gasoline ranges), base neutral/acid extractable (BNA) compounds, pesticides and polychlorinated biphenyls, metals, and dioxins. After analysis, data validation was accelerated. Validated analytical results were then used to establish a proposed list of COCs for the Phase II program.

X7.4 *Interphase*—The ESC core technical team met with representatives from U.S. EPA Region IV and the SDHEC on July 20, 1995, to review the preliminary results of Phase I activities. Analytical results from source area sampling were compared to risk-based concentration (RBC) levels and two times the average background levels. The high quality of the data allowed a shorter list of site-specific COCs to be developed, which would be the focus of specific source area tracking within the trenches, and permitted the delineation of groundwater quality impacts down gradient of the trenches as part of Phase II activities. The final list of COCs agreed upon with the regulators included three VOCs (PCE, TCE, and vinyl chloride), seven pesticides (4,4'-DDE, 4,4'-DDT, alpha-chlordane, gamma-chlordane, alpha-BHC, beta-BHC, and dieldrin), and four metals (arsenic, antimony, beryllium, and manganese). The extension of the EM measurements to the southwest of the D-area OSB site to determine its down gradient extent was agreed upon at this meeting and completed within two weeks.

X7.5 *Phase II*:

X7.5.1 *Objectives*—The Phase II objectives were to: (1) define precisely the specific source area(s) within the waste trenches that were affecting the quality of the shallow groundwater and (2) determine the configuration and extent of both the dissolved organic and inorganic contaminant plumes in shallow groundwater down gradient of the D-Area OSB by using the hydrogeologic model derived from the Phase I investigations. Phase II field activities began in mid August 1995 and were completed in three weeks.

X7.5.2 *Chemical Characterization Methods*—Chemical characterization of groundwater during Phase II included screening level chemical analyses with water quality kits or meters to measure phosphates, dissolved oxygen, nitrates, pH, and conductivity and quantitative/definitive analyses in on-site mobile laboratories capable of performing Level III U.S. EPA methods (SW 846) for the identified COCs (for VOCs, gas

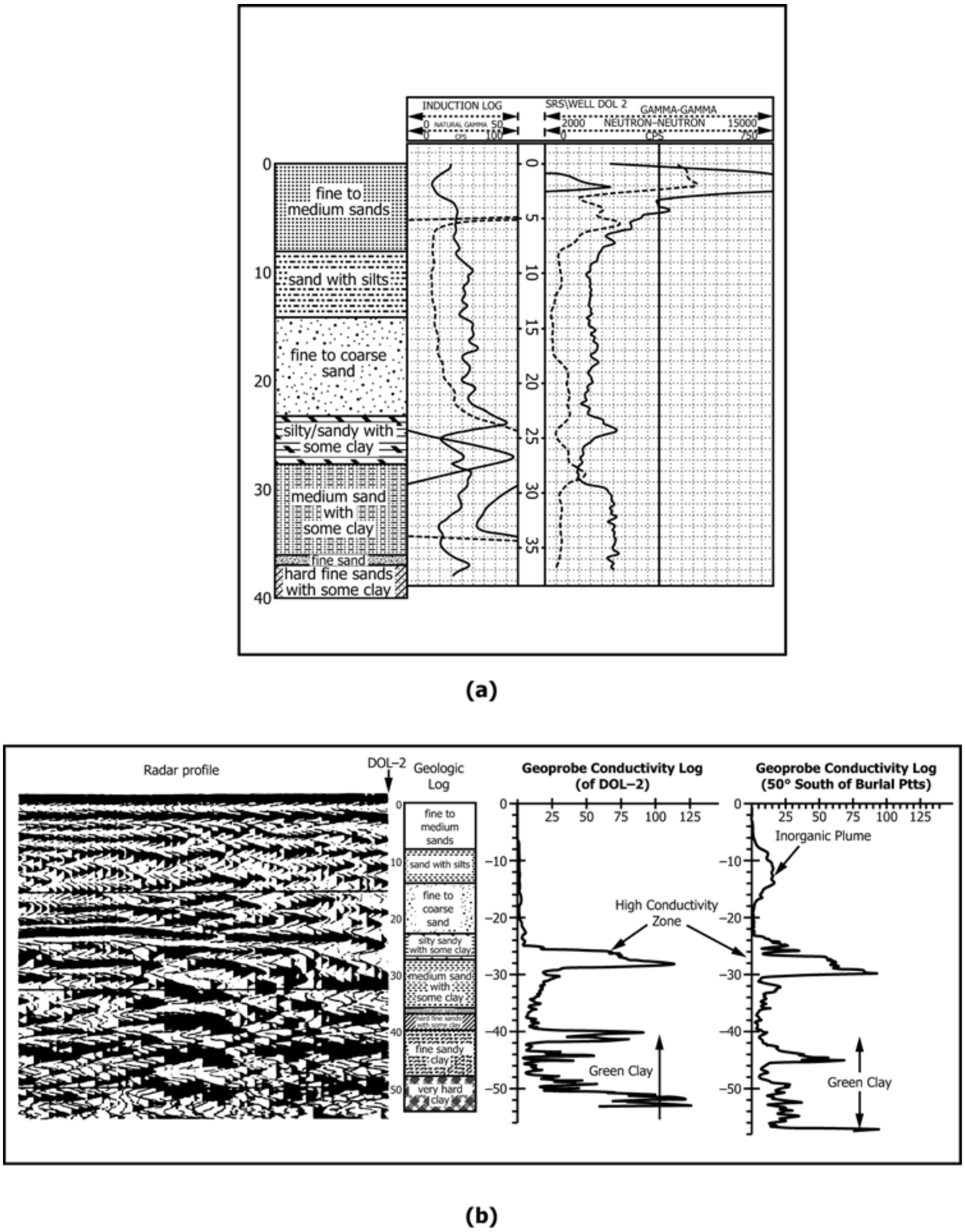


FIG. X7.3 Stratigraphic Correlation of Geologic Log in new Piezometer DOL-2 with (a) Natural Gamma, Induction, Density and Porosity Logs, and (b) Ground Penetrating Radar Profile and Conductivity Logs (33)

chromatograph Method 8021, and gas chromatograph/mass spectrometer Method 8260; for pesticides, gas chromatograph/electron capture detector Method 8080; and for metals, inductively couple plasma Method 6010 and graphite furnace atomic absorption Method 7060). Once generated, all data underwent thorough data validation with standard U.S. EPA methodology. Both the groundwater sample collection and the definitive on-site chemical analytical program, including on-site data management and validation, were managed by Steven Gelb and Todd Morgan from McLaren/Hart, Inc., under subcontract to the Ames Laboratory (52).

X7.5.3 *Groundwater Sampling*—Groundwater sample collection during Phase II was accomplished with the use of two Geoprobe direct-push sampling units mounted on four-wheel-drive vehicles to permit sampling in nearby forested areas. All groundwater samples were collected from 2-ft depth-discrete intervals with the use of slotted rods or screens. Jugdement-based sampling was used to determine the 13 possible COC plumes. The depths to be sampled were based on the hydrogeologic site model centered, on the controlling 10-ft, 25-ft, and green clay aquitards. Infield consultation with the regulators, seven vertical-profile samples were determined to be the minimum number near the trenches to ensure that no narrow plume could be missed, with the specific sample depths at each location based on the site model. Sample collection locations started near the buried waste trenches in order to find even single drum sources, and when COCs were detected in a sample, subsequent sample locations were guided by the geologic and hydrologic site model. As the sampling locations moved farther from the waste trenches, each hit above the

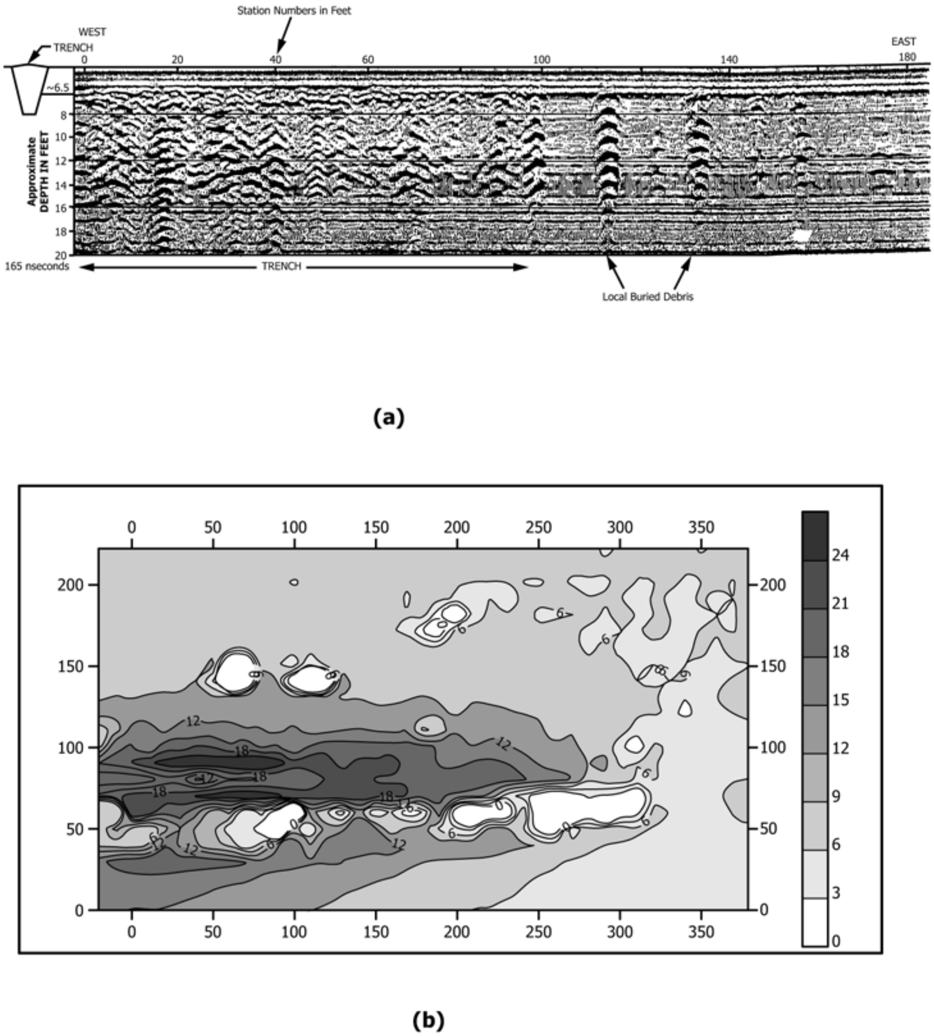


FIG. X7.4 Example Geophysical Survey Data: (a) Typical 100 MHz Continuous Radar Profile Along a West to East Line Through the Trench Area Showing Main Trench and Local Buried Debris Outside Trench (34), (b) EM31 Conductivity Contour Map (millisiemens/meter) Showing Location of Trenches, Several Apparent Outliers of Buried Waste to the North, and a Possible Inorganic Contaminant Plume Moving Southwest (33)

action level was followed down gradient until it was bounded in all dimensions by hits below the action level. When this goal was accomplished for all 13 COCs, the sampling program ended. This strategy reduced the number of depth-discrete sampling intervals at each location, as well as the analytes required per sample. Thus, only the actual number of samples needed to accomplish the goals of the program were collected and analyzed. To track all 13 COC plumes, over 200 groundwater samples were collected from a total of 65 Geoprobe sampling locations (Fig. X7.6).

X7.5.4 *Contaminant Plumes*—The dip and small discontinuities in the generally continuous 10-ft and 25-ft layers allowed complex, multileveled plumes of dissolved organic contaminants (TCE, PCE, vinyl chloride) to migrate away from the waste trenches in a southwesterly direction. No evidence of dense nonaqueous phase liquids (DNAPLs) was found. The top view of the TCE plume (see Fig. X7.7 *(a)* shows evidence of two discrete sources in the trenches. A side view, along a line through the main body of the plume (Fig. X7.7 *(b)*), shows the controlling influence of the 10-ft and 25-ft silty layers. The vinyl chloride plume closely matched the TCE plume, while the PCE plume had an additional lobe that extended several hundred feet south-southeast of the trenches and also involved both silt layers. This observation confirmed the working hypothesis that the high-conductivity inorganic leachate plume, which was mapped during Phase I was a good but not perfect indicator of the possible organic plumes. All of the four metallic COCs were shown to be in isolated locations and at depths not associated with the trenches. No pesticides were detected above the action level. Fig. X7.8 shows the final site model, with the two blacked boxes representing the only remaining pathways requiring remediation.

X7.5.5 *Savings Due to ESC*—The narrowness and tortuous shape of the actual organic plumes were such that a three-dimensional statisitical-grid approach of sufficiently fine scale to determine the plume shapes would have required well over 2000 samples. In contrast, the judgement-based sampling strategy of the ESC project, which was based on understanding

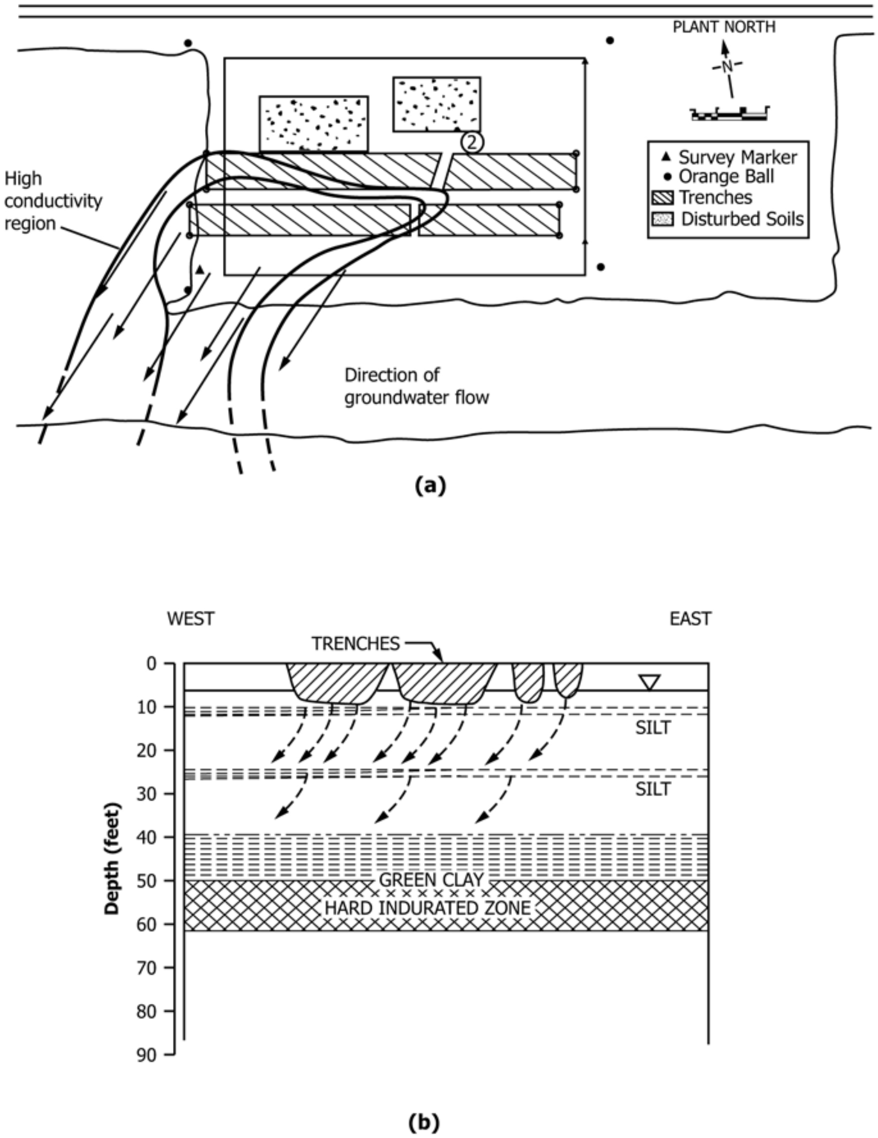


FIG. X7.5 Site Model at End of Phase I Investigation: (a) Plan View Showing High Conductivity Region to SW of Trenches, (b) East-West Cross Section Showing Two Continuous Slit Layers Above Green Clay Layer That Control the High Conductivity Regions Believed to be Due to an Inorganic Leachate Plume from the Trenches (34)

the controlling hydrogeologic features, required only 200 samples to determine 13 plumes. The cost of the Phase I measurements performed during the ESC investigation was well below the ten-fold increase in sampling and analysis costs that a statistical approach would have required.

X7.6 *Remedial Action*—Detailed groundwater quality mapping identified two locations within the buried waste trench network that were causing a vast majority of the observed groundwater quality effects. This information allowed for timely and cost-effective removal of the contaminant sources. Remedial action for the remaining contaminant plume included *in-situ* bioremediation.

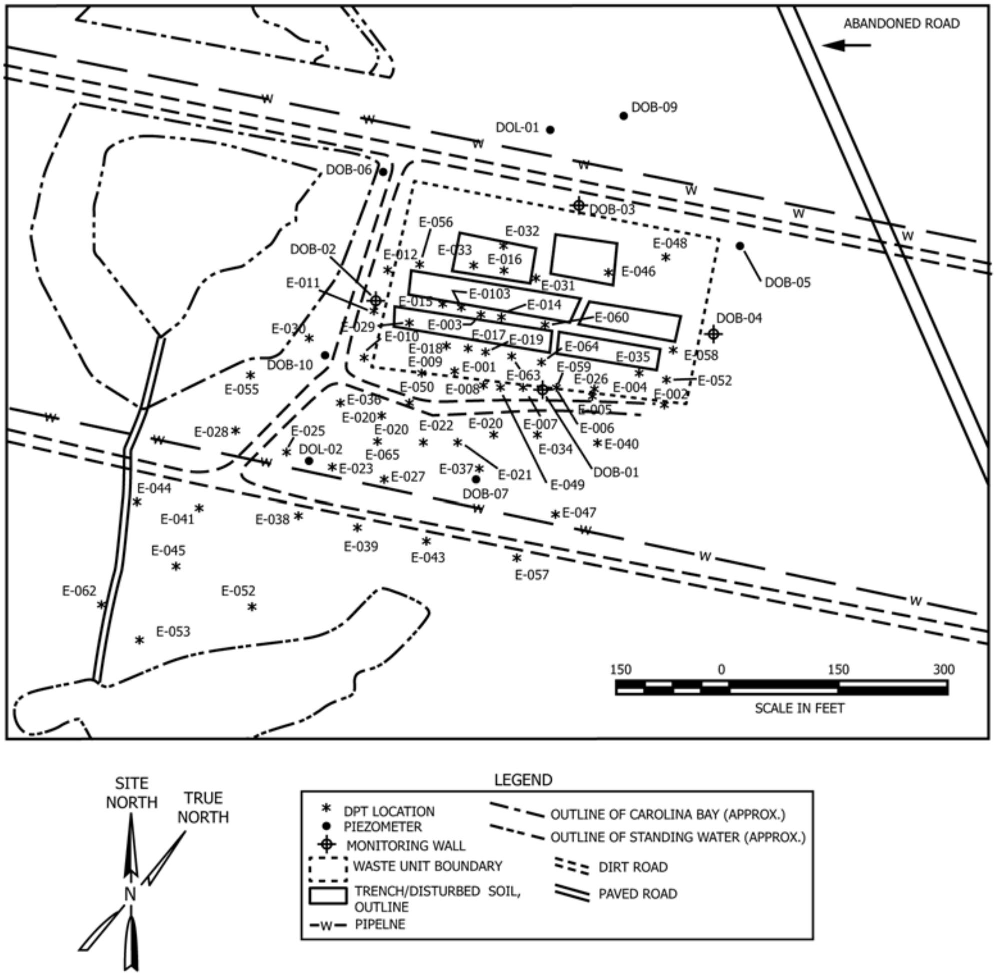


FIG. X7.6 Site-Plan D-Area Oil Seepage Basin Showing All Groundwater Sampling Locations (E-Designated Locations, Were Direct Push Samples Taken at up to Seven Depth Intervals) (4)

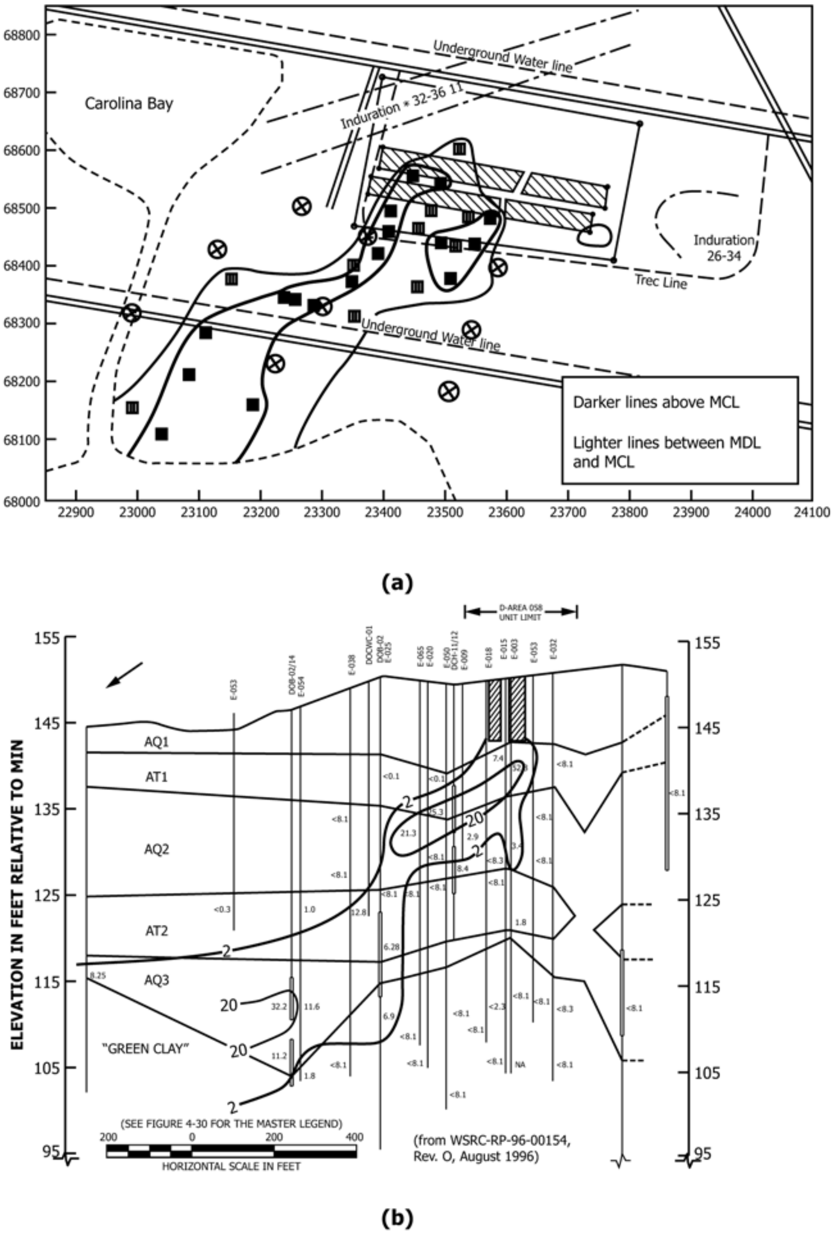
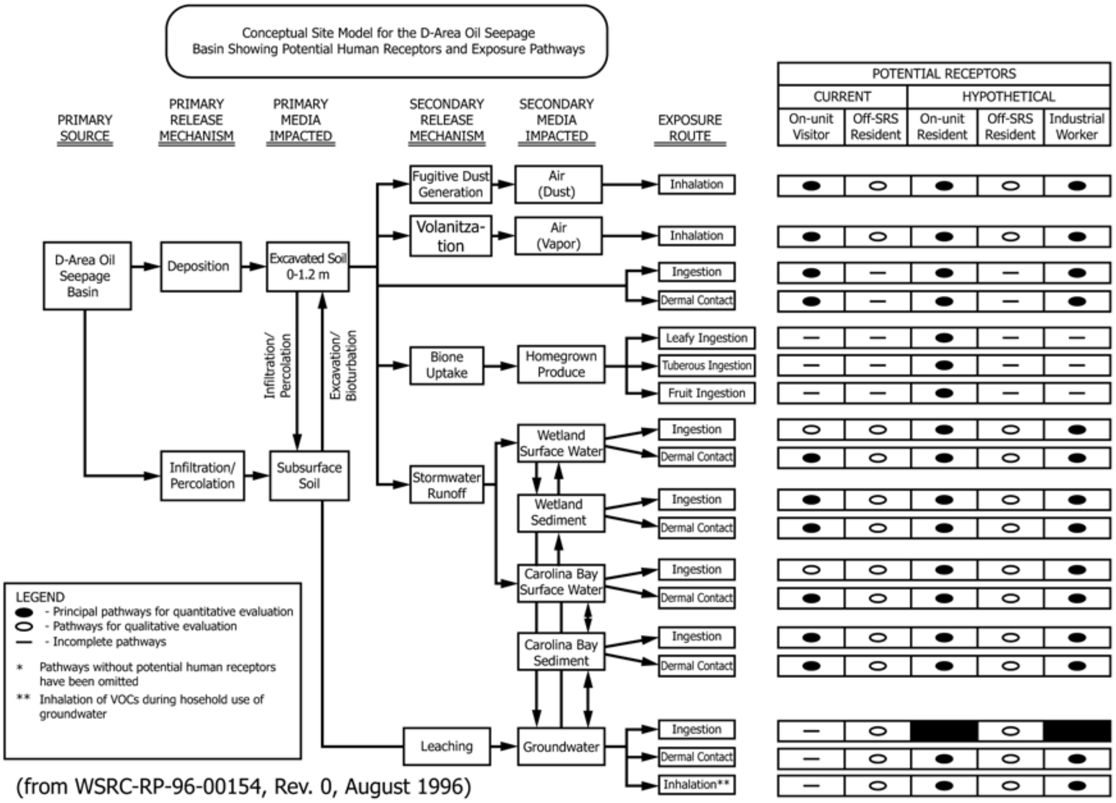


FIG. X7.7 TCE Contaminant Plume: (a) Plan View, (b) North-South Cross Section Showing Discontinuity in Lower Silt Layer and Control of Irregularities in Lower Permeability Strata on Contaminant Plume (4)



(from WSRC-RP-96-00154, Rev. 0, August 1996)

FIG. X7.8 Final Site Model Showing Two Darkened Regions that Represent the Only Two Remaining Source/Pathway/Receptor Connections That Require Further Action at the D Area Oil Seepage Basin (4)

X8. PROCUREMENT AND CONTRACTING FOR ESC

X8.1 This appendix discusses some possible approaches to procurement and contracting of an ESC project. This appendix should not be interpreted as precluding approaches that are not discussed here. U.S. EPA (**1**, Chapter III, Section 2) provides good additional guidance on determining funding need for an ESC project. U.S. EPA (**34**) provides guidance on requesting and evaluating proposals that encourage innovative technologies for brownfields investigation and cleanup.

X8.2 *Request for Proposal for an ESC Project*—The ESC client is responsible for developing a request for proposal (RFP) that gives potential ESC providers enough information to develop an ESC project proposal. In the case of CERCLA and RCRA sites this would include making available the CERCLA PA/SI or RCRA RFA (Appendix X2). For other types of contaminated sites this would include preliminary site investigation reports that provide site information and identify contaminants of concern. The ESC client should specify any special requirements for developing an ESC project proposal that are not covered in this practice.

X8.3 *Selecting ESC Provider (Competitive):*

X8.3.1 *Technical Proposal*—Where more than one ESC provider is available and interested in a project, the ESC client may find it beneficial to follow a two-phased proposal evaluation process. The first RFP would request a technical proposal only. The technical proposal may require limited review of prior data related to the project, to present a preliminary site model in the technical proposal. The initial site model could be one of the criteria used to evaluate the technical proposals. The ESC provider with the best technical proposal would meet with the ESC client, regulatory authority and stakeholders to define project objectives and then develop a Phase I cost proposal.

X8.3.2 *Phase I Cost Proposal*—The detailed cost proposal may be broken down into major components such as: (1) labor (analysis of prior data, Phase I mobilization), (2) drilling/direct push, (3) surveying, (4) geophysical surveys, (5) sample analysis. Costs for subcontractors would be estimated as described in X8.4. Cost components for which a unit cost can be assigned ($/sample, $/temporary direct push monitoring well) could be presented in terms of a maximum number (for example, "up to 30 samples for groundwater contaminant analysis, with the understanding that only the number and methods necessary to meet the Phase I objectives would be completed.")

X8.3.3 *Phase II/III Cost Proposal*—Cost proposals and negotiated fees for subsequent phases of an ESC project would follow the procedures for Phase I, with the results of the Phase I investigation providing the basis for developing Phase II project objectives and costs. If required, the Phase II results would provide the basis for defining Phase III objectives and costs.

X8.3.4 *Cost Overruns*—In the ESC process cost overruns in a given cost category may be covered by reduced costs in one or more other cost categories. If unforeseen or changed conditions cause costs to exceed the original categorized fee, any additional amount would have to be approved by the ESC client.

X8.4 *Sole-Source ESC Provider*—Where an ESC client prefers to work with a single, qualified ESC provider (presumably after going through some initial process to establish the ESC provider's qualifications) the procedure for establishing fees and handling cost overruns could be similar to that described in X8.3.3 and X8.3.4.

X8.5 *Subcontractors*—The ESC provider is responsible for financial arrangement with subcontractors. This presents some challenges when subcontractors are used for geologic and hydrologic characterization because it is not known beforehand the extent to which specific site characterization methods will be used. Time and materials contracts with reasonable upper and lower limits with corresponding upper and lower bound scopes of work and with provisions for mobilization and demobilization costs provide the flexibility required when an ESC project team includes subcontractors during the field mobilization. When an ESC provider develops a cost proposal, it would include the upper limits specified for each subcontractor, with perhaps some adjustment made to take into account the expectation that not all subcontractors will require the upper limit.

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