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16. Abstract

The purpose of this project is to provide TxDOT with an improved procedure for conducting environmental site investigations at various stages during transportation infrastructure development. The project seeks to identify modern assessment technology, procedures, and regulatory requirements that can be incorporated into a new TxDOT site assessment procedure. The major tasks for this project include a review of current literature for the procedural and regulatory aspects of conducting site investigations; a review of the technological and geophysical investigative tools used in site investigations; the development of a procedure for conducting site investigations; and a provision for training TxDOT engineers and planners in the use and application of the procedure. The project will enable TxDOT to incorporate the use of investigation techniques and procedures into right-of-way and design manuals and to promote a better understanding of the site investigation process to TxDOT divisions and districts.

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PHASE II ENVIRONMENTAL SITE INVESTIGATION PROCEDURES AND TECHNOLOGIES FOR PROPERTY TRANSFER AND PS&E DEVELOPMENT

by

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Research Project Title: Phase II Environmental Site Investigation Procedures and Technologies for Property Transfer and PS&E Development

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PROJECT BACKGROUND

The purpose of this project is to provide TxDOT with an improved procedure for conducting environmental site investigations at various stages during transportation infrastructure development. The project seeks to identify modern assessment technology, procedures, and regulatory requirements that can be incorporated into TxDOT site investigation procedures. The major tasks for this project include: a review of current literature for the procedural and regulatory aspects of conducting site investigations; a review of the technological and geophysical investigative tools used in site investigations; the development of a procedure for conducting site investigations; and a provision for training TxDOT engineers and planners in the use and application of the procedure. The study will enable TxDOT to incorporate the use of site investigation techniques and procedures into right-of-way (ROW) and design manuals and to promote a better understanding of the site investigation process to TxDOT divisions and districts.

The situations and environmental conditions encountered in TxDOT ROW are diverse. This report focuses on site investigation processes that can be used in a variety of situations and site conditions at various stages of project development. The scope of the site investigation procedures presented herein is generally referred to as Phase II environmental site assessments (ESAs) or environmental site investigations and does not include the initial site assessments (sometimes referred to as Phase I environmental site assessments). It should also be noted that the investigation procedures presented herein relate primarily to identification and delineation of potential and actual contaminated media. The primary distinction between the initial site assessment and subsequent Phase II environmental site investigations is that site investigations are generally intrusive and quantitative in nature.

Encountering contamination in existing or ROW has become increasingly burdensome and costly in the development of transportation infrastructure. One strategy to reduce the cost associated with environmental site investigations is to develop improved procedures that use modern geophysical investigative techniques and present the results in a form that clearly communicates the occurrence of contaminants in the environment as well as risks to human health and the environment.

One of the problems faced during the assessment phase of a project is that potential sources of contamination, or potential risks, may go unidentified and require repetitive assessments. The problem faced during the design phase of a project is similar; the extent and magnitude of contamination discovered in the ROW may be inadequately defined, and require increased assessment, cleanup, and waste disposal. Additionally, ill-defined risks to worker health and safety may also hamper the project. In each phase of development, project delays, project costs, and increased TxDOT liability could be reduced with improved site investigation approaches.

Ideally, a site investigation process should ensure that every reasonable action has been taken prior to ROW acquisition, design, or construction, to identify potential risks and future costs. Although site investigations can account for many foreseeable scenarios, it is impossible to foresee all occurrences of contamination and identify all environmental risks that may occur. It is also not economically prudent to expend extraordinary resources conducting exhaustive assessment activities that yield only marginal benefits. The research efforts have focused on site investigation processes and technology that are economically viable and balanced to meet regulatory and liability requirements. There is no magic bullet or process that can substitute for experience and expertise when conducting site investigations, but adherence to proven techniques can improve decision making and reduce risks associated with contaminants in ROW.

Contamination from petroleum sources is the most prevalent chemical of concern (COC) found in TxDOT ROW. Fortunately, the science of investigating and assessing petroleum contaminants is maturing. Risk-based corrective action (RBCA) and risk assessment models for petroleum contaminates in soil and groundwater are more abundant and accepted by regulators than ever before. The processes and technology presented in this study are in keeping with the risk-based approach to site investigation.

The traditional methods for assessing contamination in ROW typically involve the sample collection and chemical analysis of the suspected or affected media. The traditional remedy is to remove the contaminated media to a prescribed level or "safe" concentration in all instances. The regulated community and the regulators, realizing that these traditional approaches to assessment and remediation are often expensive and do not yield significant benefits, began using a risk-based approach to assessment. A risk-based approach to remediation and control of contaminated media is a "new end" in comparison to the "old end" of physical contaminant removal. It was discovered that a uniformly prescribed cleanup to background concentrations is not always appropriate for all settings; rather it is more effective to estimate an acceptable level of risk posed by the COC for an individual site based on site characteristics and use.

The Texas Risk Reduction Program (TRRP) proposed by the Texas Natural Resource Conservation Commission (TNRCC) is an attempt to unify several existing risk-based regulatory programs. The TRRP will have an effect on ROW investigations and transportation infrastructure development. Site remedies under this proposed plan will vary with respect to their setting and use because Texas highways encounter a diversity of geological and environmental settings. Traditional assessment tools as well as innovative assessment tools can still yield meaningful information; however, all of these assessment tools must be used with the "new end" in mind. The range of available assessment tools was selected based on the ability of each tool to provide the information which contributes to the construction of a conceptual model, or picture, of the risks posed by the COC, and not just to strictly identify the occurrence of the COC.

Since many forms of transportation development begin with obtaining ROW, and generally end with construction and ultimately operation and maintenance, then each step of the environmental investigation during development should begin with the new end in mind. The site investigation should identify the contaminants that pose the greatest risks to the project. The progression of investigation from the initial site assessment to site investigation should build a conceptual model of the problem based on the findings. Site investigations should not necessarily produce more data indicating the occurrence of the COC but a more complete conceptual picture of the risk which is present.

Environmental site investigation techniques and processes can also be useful in the management and disposal of contaminated soils and groundwater during construction. In some instances, disposal of contaminated soils and groundwater can be minimized or even avoided using the risk-based approach and the TRRP. However, the planning, data collection, and regulatory requirements in order to achieve the reductions in soil and groundwater disposal are more sophisticated and will likely require greater care and scrutiny.

SUMMARY OF RESEARCH TASKS

The literature search was the major focus of the research effort. A computerized information search of the Transportation Research Board (TRB) bibliographic database was conducted to ensure consideration of previous work on the subject. The literature search found limited information in transportation databases using risk-based assessment in this process. The bulk of the literature on site investigation procedures used in this report is not from transportation databases. Most of the innovative information came from the U.S. Environmental Protection Agency (EPA), Department of Defense (DOD), and Department of Energy (DOE) resources. Publications and guidance from the TNRCC regarding site investigation procedures were also utilized. The TRRP proposed rules (Title 30 TAC, Chapter 350), the Petroleum Storage Tank Risk-Based Corrective Action Rules (Title 30 TAC, Chapter 334), and the Risk Reduction Rules for Industrial and Hazardous Waste Management (30 TAC Chapter 335, Sub-chapter S) were reviewed to ascertain regulatory requirements.

Information from the American Society for Testing and Materials (ASTM) and the DOE provided a foundation for site investigation procedure recommendations and investigative processes. Site investigation technology was readily available in traditional geophysical, geological, and environmental sciences literature. Resources from the Environmental and Engineering Geophysical Society and the Symposium on the Applications of Geophysics to Environmental and Engineering Problems (SAGEEP) provided valuable insight into geophysical survey methods used in site investigations.

The literature review and information search consisted of 1) the regulatory, administrative, and procedural aspects of assessment; and 2) the technological aspect of site assessment. Both of these components have been investigated to provide a foundation for the research effort. Although the TRRP was expected to play a greater role in the development of the project, its role was ultimately limited. This occurred because the TNRCC withdrew the proposed rules from consideration very late in the project and did not reissue them until after the draft research report was submitted.

In addition to the review of literature and Internet resources, researchers conducted limited telephone interviews with engineering and environmental consulting firms that specialize in site investigations and that have worked for TxDOT. The interviews confirmed the nature of contamination encountered in ROW and the investigation methods currently used. Limited telephone interviews were also conducted with the Dallas Area Rapid Transit Authority and with a consultant for the regional commuter rail (Trinity Express) about their experiences. Software and technology vendors were visited to identify products with potential applications during the TNRCC Trade Fair and Conference. The interviews generally indicated that there is a willingness among consultants to use new site investigation technologies but the opportunities to do so are limited.

The task to develop site investigation procedures was primarily based on the *accelerated site characterization* process and the *expedited site characterization* process. These processes are derived from a combination of resources and recommended guidance from the TNRCC, ASTM, and DOE.

RESEARCH RESULTS

The results of the research are presented in this report. The procedures and technology reviewed and presented in this report generally represent the current state of the practice in Phase II environmental site investigations in Texas.

Chapter One reviews the basic concept of risk assessment which is used as the basis for most environmental site investigation processes and new regulations. In addition, Chapter One presents information on the characteristics of contaminated sites in Texas, and the current regulatory framework.

Chapter Two presents the approach to conducting Phase II environmental site investigations and the standards and guidelines that form the foundation for the process. First, a screening process to determine if a site investigation is necessary is presented, followed by the planning steps prior to conducting a site investigation. The investigation procedures that follow are based primarily on the accelerated site characterization process and selected TNRCC guidance documents for the investigation of leaking petroleum storage tanks (LPST). In addition to the accelerated site characterization process, a review of the data quality objectives and dynamic work plans process is presented to enhance the site investigation process.

Chapter Three presents relevant geophysical and geotechnical site investigation technology. A summary of the geophysical survey methods is presented in a matrix to allow easy comparison of the strengths and weaknesses of the various methods. In addition, the steps in planning a geophysical survey are presented to help ensure successful execution. Direct push technology is reviewed, along with the use of cone penetrometer testing as a new method of subsurface characterization that can speed up the site investigation.

INTRODUCTION

All transportation projects have the potential for encountering hazardous material contamination during ROW acquisition or construction. The purpose of environmental assessment is to identify potential environmental hazards early in project development in order to avoid or minimize impacts as the project advances. The advanced planning and environmental documentation stages of project development incorporate the interests of the Texas Department of Transportation (TxDOT), the Federal Highway Administration (FHWA), and the National Environmental Policy Act (NEPA)*(1)*.

The purpose of this research project was to develop environmental site investigation procedures for use by the TxDOT in ROW acquisition and development of plans, specifications, and estimates (PS&E). The scope of the investigation procedures presented herein is generally referred to as Phase II environmental site assessments (ESA) or environmental site investigations and does not include the initial site assessments (sometimes referred to as Phase I ESA). It should also be noted that the investigation procedures presented herein relate primarily to identification and delineation of potential and actual contaminated media. The primary distinction between the initial site assessment and subsequent site investigations is that the site investigations are generally intrusive and quantitative in nature. A Phase II environmental site investigation seeks to identify, and in some cases delineate and characterize, contamination suspected or identified during Phase I. When it is determined at the conclusion of the initial site assessment (Phase I) that *no further investigation is needed*, then no site investigation (Phase II) should be conducted unless subsequent information or discoveries are made which warrant further investigation.

This report addresses three fundamental aspects of the Phase II environmental site investigation process as it relates to TxDOT:

1. the regulatory background and requirements for conducting Phase II site investigation (why do we do it?),
2. the process and procedural aspects of conducting a Phase II site investigation (how do we do it?), and
3. the technology and investigative techniques used in conducting site investigations (what tools do we use?).

Each of these aspects—the regulatory requirements, the process, and the technology—evolve over time. Sometimes this change occurs very rapidly and coincides with developments in technology or new regulations; other times the technology and recommended site investigation processes stay relatively unchanged. Therefore, it is important to recognize that certain laws, regulations, rules, and regulatory guidance are subject to changes that may affect the investigation process. Also, advances in the technology or the economic viability of certain technologies may change quickly, so it is incumbent upon those who conduct Phase II environmental site investigations to refresh their knowledge of the regulations and technology. Finally, site investigation procedures are frequently modified to compensate for regulatory changes and advances in technology.

Perhaps the most recent change in the regulatory outlook towards environmental site investigation has been the development of risk-based assessment and risk-based corrective action. The concept of ***risk assessment*** will be incorporated throughout this document. This term has evolved from the implementation of regulatory guidelines that, in some cases, have been promulgated into rules relating to the assessment, characterization, and remediation of contaminated sites. In most instances, the purpose of a Phase II environmental site investigation is to collect data and build a conceptual model of the site for use in a risk assessment.

Risk assessment entails the evaluation of scientific information on hazardous properties of environmental agents and the extent of human exposure to those agents *(2)*. The product of the evaluation is a statement regarding the probability that a population so exposed will be harmed and to what degree. The probability may be expressed quantitatively or in a relatively qualitative way.

The risk assessment process involves the following four components *(2)*:

1. hazard identification,
2. dose-response assessment/toxicity assessment,
3. exposure assessment, and
4. risk characterization.

The objective of **hazard identification** is to determine whether the available chemical-specific data describe a causal relationship between exposure to the chemical and adverse human health effects. In other words, is exposure to the COC found in the investigation harmful to human health or the environment?

The **dose-response assessment** quantifies the relationship between the dose (amount of COC) that the organism is exposed to and the response (adverse health effects). Or, how much of the chemical does it take to cause harm?

The objective of the **exposure assessment** is to analyze site-specific information to estimate the most likely dose to potential human receptors. The exposure assessment involves determining how, or if, the COC enters the body, whether through ingestion, inhalation, dermal absorption, injection, or any combination.

The **risk characterization** uses information from the previous three steps to estimate adverse human health effects. In other words, all the information is analyzed to determine if, and approximately what chance there is, harm may come to human health and the environment as a result of the occurrence and exposure to a chemical.

Risk assessment is followed by the ***risk management*** step which answers the question, "What should be done with the risk that has been quantified?" Risk management is a term used to describe the process by which risk assessment results are integrated with other information to make decisions about the need for, method of, and extent of risk reduction. Policy considerations derived largely from statutory requirements dictate the extent to which risk information is used in decision making *(2)*. **Risk-based corrective action** (RBCA) is one example of risk management.

Understanding the risk assessment process is now an integral part of conducting environmental site investigations. New regulatory approaches to dealing with contamination use the Phase II site investigation to analyze the risk posed by contaminants and derive site-specific cleanup objectives, taking into account land use and exposure pathways. Before, the Phase II environmental site investigation would gather as much information as possible incrementally, with the knowledge that further assessment would likely be needed to define the extent of contamination precisely before it was removed. Now, the objective of most environmental site investigations is to gather enough of the right information early to develop a conceptual model of the site that often prevents future mobilization. The conceptual model is then used to evaluate the potential risk posed by the contamination and in most cases, manage contamination instead of removing it. The risk-based approach focuses more on the quality of data than on the quantity of data. The objective of the environmental site investigation is not to see what we find but to confirm what is thought to exist based on the review of existing information.

CHARACTERISTICS OF CONTAMINATED SITES IN TEXAS

In order to select the appropriate site investigation technology and approach, it is important to recognize the nature of the contamination that occurs most often in the environment. Petroleum hydrocarbon contamination resulting from leaking petroleum storage tanks (LPSTs) are the most commonly encountered COCs. The Texas Groundwater Protection Committee reported that through 1996 there were 6,427 documented groundwater contamination cases, and over 98% of those cases were regulated by the TNRCC *(3)*. Most of the groundwater contamination (86%) resulted from gasoline, diesel, and other petroleum products. Less common contaminants reported included organic compounds (such as phenol, trichloroethylene, carbon tetrachloride, dichloroethylene, and napthalene), pesticides (such as alachor, atrazine, bromacil, dicamba, and prometon), creosote constituents, solvents, heavy metals, and sodium choride *(3)*.

The Bureau of Economic Geology (BEG) conducted a study that quantified the general soil, hydrogeologic, and plume characteristics of LPST sites in Texas based on LPST site information from the TNRCC *(4)*. This study contributed to a better understanding of the extent, mass, and duration of hydrocarbon plumes. This study is also useful in that the findings of the BEG report and the plume characteristics that were described are also representative of the LPST sites that would be potentially encountered in TxDOT ROW and areas of highway construction.

By understanding the general characteristics of hydrocarbon plumes that will likely be encountered at a site, the selection of appropriate Phase II environmental site investigative techniques can be more effective. The BEG study results may also be useful when developing scopes of work. The BEG *(4)* report indicated that:

- Twenty-five percent of sites have contaminated soil that extends beyond the property boundary.
- Almost 40% of the groundwater benzene plumes extend beyond the property boundary.
- About 45% of sites have hydraulic conductivities greater than 1 m per year.
- The median depth to top, depth to bottom, and the thickness of contaminated soil are 1.3 m (4.4 ft), 5.3 m (17.5 ft), and 3.3 m (11 ft), respectively.
- The median minimum, maximum, and average depth to water are 1.4 m (4.6 ft), 4.9 m (16.2 ft), and 2.9 m (9.4 ft), respectively.

The BEG *(4)* reported on the geometry of plumes associated with LPST sites by indicating that:

- At most sites, contamination extends less than 9 m (30 ft) from the boundary.
- Most plumes (80%) are stabilized, decreasing in mass and length, or are nearly exhausted.
- Seventy-five percent of the plume lengths (defined by the 10 ppb benzene contour) are less than 76 m (250 ft), and plume areas are less than 4,552 m^2 (49,000 ft^2).
- Ninety percent of plumes are less than 116 m (380 ft) long and have a median length of 55 m (180 ft).
- The median areal extent of contaminated soil is 627 m^2 (6,750 ft^2).
- Ninety percent of plumes have areas less than 11,150 m^2 (120,000 ft^2).
- The median area of groundwater plumes are 2,415 m^2 (26,000 ft^2).

Figures 1 and 2 present the distribution for plume length and plume areas for 217 of the 605 LPST sites reviewed in the BEG study. The plumes were defined by the 10 ppb contour as determined by the exponential plume model used in the study.

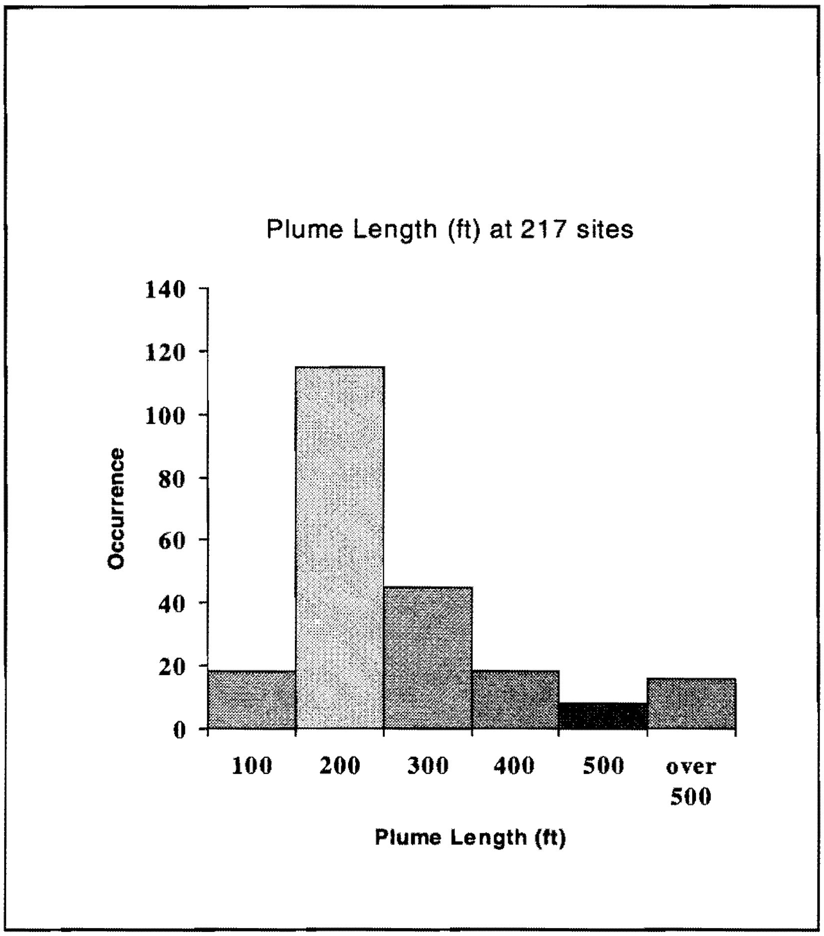


Figure 1. Plume Length Defined by 10 ppb Contour. Source: BEG *(4)*.

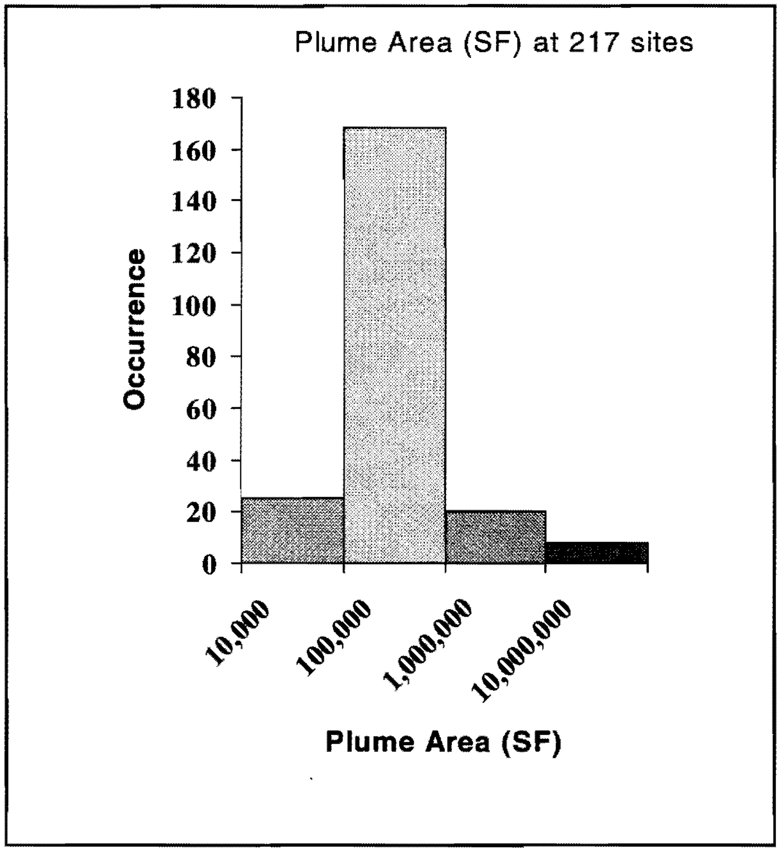


**Figure 2. Plume Area Defined by 10ppb Contour.
Source: BEG *(4)*.**

It is important to remember that the BEG report describes conditions only at leaking petroleum storage tank sites in Texas in a regional context. These same conditions may not be true for other hazardous materials or at specific sites. The fate, transport, concentration, and duration of contaminant plumes is dependent on a variety of factors including soils, geology, hydrogeology, rainfall, and surrounding infrastructure. This is why it is important to develop a conceptual model of the site to be investigated that accounts for all the various surface and subsurface conditions. The BEG report also provided support for the use of risk assessment which is used by the TNRCC.

The range of investigative techniques and technologies reviewed in this report are generally limited to those methods that could be used prior to ROW acquisition and construction and applied to the site conditions most often encountered. The site investigation techniques could also be used during construction when unanticipated contamination is encountered.

TEXAS REGULATORY FRAMEWORK

The most recent regulatory development is the proposed rules for the ***Texas Risk Reduction Program*** (TRRP) originally released by the TNRCC for comment in April 1998. The rules were subsequently withdrawn and revised. The proposed TRRP rules were released again in March 1999 and will establish a uniform set of risk-based, performance-oriented technical standards to guide response actions at affected properties regulated via the TNRCC's Office of Waste Management program areas and other applicable program areas. The rule was promulgated as a new chapter (i.e., 30 Texas Administrative Code (TAC) Chapter 350). (The following discussion is based on the proposed rule and preamble which are subject to change pending the publication of the final rule *(5)*).

Currently, several different rules govern corrective actions, closures, and post-closure care within the agency's waste management programs. The State Superfund Program, the Industrial and Hazardous Waste Program, and the Voluntary Cleanup Program (VCP) use the existing Risk Reduction Rules in 30 TAC Chapter 335, Subchapters A and S, for risk-based corrective action. Any person who stores, processes, or disposes of hazardous waste is also subject to the closure and post-closure care requirements in 30 TAC Chapter 335, Subchapters E and F. The Petroleum Storage Tank (PST) program uses 30 TAC Chapter 334, Subchapters D and G, for risk-based corrective action. The adoption of the existing Risk Reduction Rules in 1993 and the PST risk-based rules in 1995 established the commission's philosophy that risk-based cleanups are an acceptable remedial response to affected environmental media because risk-based corrective action ensures protection of human health and the environment while making response actions more economically feasible than complete, or background, cleanups.

Prior to 1993, TNRCC required all affected media to be restored to background levels or to be closed as a landfill with post-closure care. The agency recognized for the first time in the Risk Reduction Rules that a limited quantity of COCs could remain within an environmental medium and not present an unacceptable risk to human health or the environment.

The goals of the proposed TRRP are:

- to create a unified, performance-based approach to corrective action which will be the same regardless of which of the agency's program areas review the adequacy of a proposed response action;
- to complete the movement away from background as a cleanup standard; and
- to implement a consistent, streamlined approach that will expedite the remediation of affected properties.

The proposed Chapter 350 is subdivided into Subchapters A through F:

Subchapter A	General Information, §§350.1-350.5.
Subchapter B	Remedy Standards, §§350.31-350.36.
Subchapter C	Affected Property Assessment (PCLs), §350.51-350.55.
Subchapter D	Development of Protective Concentration Levels (PCLs), §350.71-350.78.
Subchapter E	Reports, §350.91-350.96.
Subchapter F	Institutional Controls, §350.111.

A tiered process is provided to establish both human health and ecological protective concentration levels (PCLs): Tier 1, 2, and 3. This tiered process for human health PCLs is patterned after the tiered process of the American Society of Testing and Materials (ASTM) *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites* ES-1739-95. The first tier is based on conservative, generic models that do not account for site-specific factors. These Tier 1 protective concentration levels are published and updated by TNRCC. Tier 2 allows persons to apply site-specific data and use the TNRCC lateral transport equation which may increase risk-based protective concentration levels. Tier 3 allows for the use of site-derived natural attenuation factors and alternative models in development of PCLs. In all cases, the person must identify "critical" PCLs, which is the cleanup level for a COC within a media considering all of the exposure pathways and other media.

The general process is summarized below:

- Persons conduct an affected property assessment to:
  - determine groundwater resource classification;
  - determine land use classification;
  - notify affected landowners;
  - locate human and ecological receptors;
  - characterize the nature, degree, and extent of contamination; and
  - evaluate exposure pathways and determine the concentration of the COC for human and ecological receptors at the point of exposure (POE).

- Determine the extent to which COCs exceed Tier 1 protective concentration:
  - determine protective concentration limits (PCLs) for all media,
  - determine POEs,
  - determine critical PCLs, and
  - compare COC levels to PCLs.

- Once PCLs are determined and COCs exceed the Tier 1 PCLs, then the person must choose a remedy standard under Subchapter B. The person may choose one of two remedy standards—Remedy Standard A or Remedy Standard B:

- Remedy Standard A is a pollution cleanup approach and does not allow a person to use either physical or institutional controls, other than requiring a deed notice/restrictive covenant for commercial/industrial land use. Remedy Standard A requires that all media be removed or decontaminated to the applicable PCLs.
- Remedy Standard B allows exposure prevention approaches which rely on physical and/or institutional controls to protect human health and the environment. Persons may base remedy standards on residential or commercial/industrial land use as appropriate for the particular affected property.

Additional key concepts and terms associated with the TRRP are discussed below.

Affected Property Assessment

Section 350.51 of the draft TRRP requires that persons conduct appropriate assessments of the affected property. The goal of the assessment is to define the vertical and horizontal extent of COCs above the critical Tier 1 PCLs within soil and groundwater and above the applicable source medium PCLs for other environmental media. The affected property assessment is the equivalent of a Phase II site investigation. The assessment (investigation) must also define the maximum concentration and distribution of COCs within environmental media at the affected property. Persons must investigate to the critical Tier 1 PCLs in soil and groundwater and must show declining values beyond the critical Tier 1 PCLs to demonstrate that the presence of COCs has been adequately characterized. Depending upon the planned response objective, additional assessment may be necessary.

Ecological Risk Assessment

A new component of the draft TRRP is the ecological risk assessment (ERA). It is a process which evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors *(6)*. The purpose of an ERA is to characterize the ecological setting of the affected property, identify complete and reasonably anticipated exposure pathways and representative ecological receptors, scientifically eliminate COCs that pose an acceptable risk, and develop PCLs for ecological receptors where warranted.

TNRCC also uses a tiered approach for ERAs. A Tier 1 exclusion criteria checklist assessment is provided in Appendix A. This checklist is a standardized form consisting of a series of property-related questions and exclusion criteria designed to determine the existence of complete ecological exposure pathways through descriptions of the affected property setting and/or the presence and distribution of COCs within environmental media.

The intent of the checklist is to determine whether or not further ecological evaluation is necessary at an affected property where PCLs are being determined.

Self Implementation

The TRRP may be self-implementing for Remedy Standard A. This means that TxDOT, or other persons, may choose to begin a response action after notifying TNRCC at least 10 days in advance. The form is called a Self-Implementation Notice (SIN) and must be sent to the TNRCC district office where the action will occur and to the central office in Austin. This option is not available for Remedy Standard B.

Soil and Groundwater Management Options During Construction

Soils and groundwater that are affected by COCs must be managed in accordance with TRRP, in addition to other applicable regulations. Although the disposal of contaminated soils and groundwater under the draft TRRP may entail a more sophisticated characterization and assessment, it may also provide more flexibility during construction.

Section 350.36. of TRRP sets forth the rules for soil reuse. This particular section is presented because it may affect situations most commonly encountered in highway construction and maintenance. A person must comply with this section when relocating soils for reuse purposes from an affected property (on-site or off-site) which is undergoing or has completed a response action under Remedy Standard A or B and the soils contain COCs in excess of background concentrations. The relocation of soils which contain COCs may also be subject to additional requirements or limitations (e.g., land disposal restrictions) within other program areas. Additionally, the person must treat excavated soils containing non-aqueous phase liquids (soils containing liquid product) to applicable levels prior to relocation or else manage the soils as wastes.

The importance of this section to highway construction applications relates to actions that are **not** considered reuse. The excavation of contaminated soils by non-responsible parties during construction activities (e.g., installation, repair, removal of telephone lines or other utilities, but not closures, remediations, or PST tank removal actions) and the subsequent replacement of those soils into that same excavation **shall not be considered** to constitute relocation or reuse and **shall not be subject** to the provisions of Section 350.36.

For soils that are subject to the provisions of this section of TRRP, soils intended for reuse at residential properties must meet the critical residential soil PCLs, and soils intended for reuse at commercial/industrial properties must meet the commercial/industrial soil PCLs. Additionally, soil reuse must be protective of ecological receptors at the new location. When situations are encountered where the reuse of soils containing COCs is considered, please refer to Section 350-36 of the TRRP to determine the applicability to these and other requirements.

Soils are generally not considered wastes if the soils:

- do not contain sludges, industrial or municipal solid waste, or listed hazardous wastes (as defined in 40 CFR Part 261, Subpart D);

- are not characteristically hazardous due to ignitability, corrosivity, reactivity, or toxicity characteristic (as defined in 40 CFR Part 261, Subpart C); and

- do not contain concentrations of COCs in excess of the residential Tier 1 surface soil PCLs, and do not contain concentrations of COCs which are ecologically unprotective at its location.

The solid waste determination is dependent on the location of the soil. Each time the location of the soil changes, the solid waste determination must be made again. Soils which are solid wastes must be evaluated for waste classification in accordance with Chapter 335, Subchapter R, prior to being sent for reuse at any location which is beyond the limits of the on-site or off-site property which contains the affected property and must be managed in accordance with any resulting waste classification, unless the soils which contain COCs meet the definition of petroleum substance wastes as defined in Section 334.481 (see definitions).

The management of petroleum substance wastes should comply with the provisions of Chapter 334, Subchapter K, relating to petroleum storage tanks. Finally, if soils that contain concentrations of COCs above naturally occurring background levels resulting from an unauthorized release are to be relocated for reuse on property not owned by the person, then the person shall obtain the written consent of the landowner prior to relocation of the soils.

PCLs for groundwater discharges to the surface are addressed in Section 350.74 of the TRRP. In order to discharge COC-affected groundwater, the person must determine the applicable risk-based exposure limit (RBEL) for each COC using a prescribed formula in conjunction with stream designations and limits set forth in Chapter 307. However, discharges of petroleum-affected groundwater will continue to be covered under Chapter 321 - Control of Certain Activities by Rule, particularly Subchapter H - Discharge to Surface Waters from Treatment of Petroleum Substance Contaminated Water.

CHAPTER TWO - ENVIRONMENTAL SITE INVESTIGATION

ENVIRONMENTAL SITE INVESTIGATION PROCESSES AND PROCEDURES

Environmental site assessments or site investigations are typically divided into three distinct phases of investigation.

- **Phase I-initial site assessment is a qualitative investigation** that consists primarily of a visual survey and a records search to determine if any suspected hazards may exist on the site. Phase I initial site assessments are generally conducted on existing and proposed ROWs or on easements that may be used in the project.

- **Phase II-environmental site investigation is a quantitative investigation** if environmental hazards are discovered or suspected at the site. The purpose of the Phase II Environmental site investigation is to confirm the existence and nature of the hazard or contamination through the collection of site-specific data, and if possible, to determine the extent of the hazards. Phase II site investigations include invasive and non-invasive subsurface investigation, chemical analysis of various media, and some form of risk assessment. An environmental site investigation is complete when sufficient data have been collected to allow the user to build an accurate conceptual understanding of the site which can then be used for making sound decisions regarding human and ecological risk, as well as regulatory and liability issues.

- **Phase III** generally involves collecting additional data about the site in order to develop a plan to manage or remediate the site.

The divisions between the phases of assessment may sometimes overlap. The point where a Phase I stops and Phase II begins is not always clearly defined. In fact, many Phase I assessments include sampling on a limited basis, and Phase II investigation may include revisiting qualitative factors as well as development of management plans for dealing with hazards that are discovered. The content and scope of site investigations should be dependent on the objectives of the investigation and the site, but strict adherence to the divisions between phases of assessment is not as important as getting the most from assessment budgets. The performance and outcome of ESAs are ultimately based on the judgments made by those involved in the process and not on the terminology of whether the investigation is Phase I, II, or III. The purpose of examining the Phase II environmental site investigation process is to provide a framework for sound decision making when dealing with and investigating environmental hazards.

Reference Documents

Because there can be wide variation within the scope and content of Phase II environmental site investigations, standardized processes and guidance documents have been developed by various organizations to improve the efficiency and effectiveness in site assessments and site characterizations. Most notable and prolific of these organizations is the American Society for Testing and Materials (ASTM). Additionally, since the purpose of conducting many Phase II environmental site investigations is to meet regulatory requirements, TNRCC and EPA often prescribe procedures in the form of a rule or guidance in order to achieve their regulatory objectives. The Phase II environmental site investigation processes described for this report rely primarily on these organizations as the framework and foundation. The standards, rules, and guidance documents listed below are the primary references used in describing the Phase II environmental site investigation process. These documents may be ordered from the organization, and in many cases are available for either viewing or downloading from the organization's Internet web site.

Table 1. Phase II Environmental Site Investigation and Assessment Reference Documents.

Organization	Title of Document	Type of Document	Internet Availability
ASTM	Environmental Site Assessments: Phase II Environmental Site Assessment Process. E 1903-97	Standard	http://www.astm.org/index.html
ASTM	Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases. PS 3-95	Standard	http://www.astm.org/index.html
ASTM	Risk-Based Corrective Action Applied at Petroleum Release Sites. E 1739-95	Standard	http://www.astm.org/index.html
ASTM	Developing Conceptual Site Models for Contaminated Sites.	Standard	http://www.astm.org/index.html
ASCE	Environmental Site Investigation Guidance Manual (Practice No. 83).	Guidance Manual	http://www.asce.org
TNRCC	Texas Risk Reduction Program (TRRP), Title 30 TAC, Chapter 350.	Draft Rule	http://www.tnrcc.state.tx.us/
TNRCC	TNRCC Title 30 TAC Chapter 335, Subchapter S (Risk Reduction Rules).	Rule	http://www.tnrcc.state.tx.us/
TNRCC	Guidance for Risk-Based Assessments at LPST Sites in Texas. RG-175	Guidance	http://www.tnrcc.state.tx.us/ waste/pst/rpr/download.htm

Table 1. Phase II Environmental Site Investigation and Assessment Reference Documents. (continued)			
TNRCC	Risk-Based Corrective Action for Leaking Storage Tank Sites. RG-36	Guidance	http://www.tnrcc.state.tx.us/waste/pst/rpr/download.htm
EPA	Expedited Site Assessment Tools for UST Sites: A Guide for Regulators. EPA 510-B-97-001	Guidance	http://www.epa.gov/swerust1/cat/samconts.htm
EPA	Technology Innovation Office, Various Assessment Guidance Documents and Links on this Site.	Guidance	http://www.clu-in.com/

EVALUATING SITES

The desired approach for the environmental investigation process is to discover all contamination problems as early in the project development process as possible. If the discovery is identified early in project development, the contamination may be avoided or mitigated more easily with less project impact.

How much evaluation of a potential or known contamination problem is dependent on what stage of development the project is in, who owns the land, and how much time and money are available. The FHWA Technical Advisory T 6640.8A provides the following *(7)*:

> "Hazardous wastes sites are regulated by the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). During early planning, the location of permitted and nonregulated hazardous waste sites should be identified. Early coordination with the appropriate Regional Office of the EPA and the appropriate state agency will aid in identifying known or potential hazardous waste sites. If known or potential waste sites are identified, the location should be clearly marked on a map showing their relationship to the alternatives under consideration. If a known or potential hazardous site is affected by an alternative, information about the site, the potential involvement, impacts and public health concerns of the affected alternatives and the proposed mitigation measures to eliminate or minimize impacts or public health concerns should be discussed in the Draft EIS. If the preferred alternative impacts a known or potential hazardous waste site, the final EIS should address and resolve the issues raised by the public."

The initial site assessment should hopefully provide enough information to identify known or suspected areas/sites with contamination. The next step is to determine if further action is required. At that point, one should screen the known and suspected sites to determine if the suspected area impacts the project. Each area suspected of posing a threat to human health and the environment and that would affect the proposed project should be evaluated for possible Phase II environmental site investigation.

Screening Evaluation for Phase II

Each property within or adjacent to the proposed ROW limits for each alignment or activity should undergo a determination for potential contamination. A generalized rating system can aide in that property evaluation. Phase II environmental site investigations should generally be conducted only on those projects identified for property acquisition or construction. If the suspected site would not be affected by construction activities or acquisition, there is usually no need to conduct a Phase II investigation. However, it is important to remember that consideration must be given to contaminated soils and groundwater that may be encountered during construction from sources outside the project boundaries.

The following is a generalized rating system that can be used to determine the need for Phase II environmental site investigations. When concentrations of COCs are available, compare the values with Tier 1 PCLs in the TRRP.

Very Low Potential for Project Impact

No further assessment is needed. After a review of all available information, there is no indication that contamination would affect the project or health and safety of workers. An example of this would be a gas station that has undergone assessment and has been closed, or no further action is required by TNRCC, and there is documentation that no contamination exists. Another example would be a closed facility that stored hazardous material in sealed containers with no record of violation or indications of releases. It should be noted that a closed facility does not necessarily indicate that no contamination exists.

Low Potential for Project Impact

No further assessment is needed. Contamination may exist, but there is no reason to believe there would be any involvement in the project. After review of all available information, there is no indication that there would be any involvement with contamination or the contamination is very limited and proven not to extend beyond the site. This would be a site that may contain hazardous material within its boundaries but is managed appropriately.

An example would be an operating gas station which is in full compliance with regulations, or an operating facility that stores hazardous material and is in full compliance with no record of releases that affect off-site properties. This would also be a site where known contamination is reviewed and is below TRRP Tier 1 PCLs. It should be noted that special considerations during ROW acquisition of these properties may be required.

Medium Potential for Project Impact

Possible site investigation is needed. After a review of all available information, documentation indicates that known contamination exists, but the problem does not require remediation or is undergoing remedial action, and continued monitoring is required. The details of remediation and the extent of contamination should be reviewed to evaluate if the property should be avoided or if it will impact the project.

An example of this would be an LPST site with known contamination that has undergone assessment and corrective action, and is being monitored or remediated. COCs detected at the site may exceed Tier 1 critical PCLs, but action is being taken by the individual responsible.

High Potential for Project Impact

Site investigation is needed. After a review of all available information, there is a high potential for contamination problems to affect the project. Further investigation will be required to determine the actual presence or need for future action to address the contamination. Also, known contamination exists where there is no responsible party or action by individuals to assess or address the contamination.

An example would be a closed landfill or a gas station with known contamination that was closed and was not evaluated or assessed, or a gas station with known contamination that extends beyond the site and would affect the project, or the contamination exceeds Tier 1 PCLs, and regulatory action is required.

One way to assign and compare the risk associated with properties in ROW is to evaluate them in a tabular presentation as in Table 2. One can list the properties or areas associated with each alternative and assign each a relative indication of potential for project impact.

Table 2. Example Project Comparison Matrix.

Potential for Project Impact	Alternative A Site 1, 2, 3,...	Alternative B Site 1, 2, 3,...	Alternative C Site 1,2,3,...
High	x	x	x
Medium	x	x	x
Low	x	x	x
No	x	x	x

Table 3 lists examples of activities that typically have low potential for encountering hazardous materials.

Table 3. Low Risk Projects.

- Pavement reconstruction, resurfacing, and placement of seal coat
- Work on bridge structures and appurtenant facilities, such as traffic or control devices (beware of existing lead base paints)
- Repair and maintenance of the highway and all appurtenant facilities
- Landscaping within highway ROW
- Addition or replacement of devices such as glare screen, median barrier, fencing, guardrail, safety barriers, energy attenuators, guide posts, markers, safety cables, ladders, signs
- Installation of noise barriers and alteration to existing buildings to provide for noise attenuation (beware of friable asbestos)
- Projects to eliminate hazards within the operating areas
- Modifying existing features such as curbs, dikes, headwalls, slopes, ditches, etc., within the ROW to improve safety
- Maintenance of existing landscaping, native growth, and water supply reservoirs
- Minor operational modification of traffic control systems and devices including addition of new elements such as signs, signals, controllers, etc.
- Installation, removal, or modification of regulatory, warning, and information signs, including new copy on existing on-and-off premise signs
- Minor alteration or widening of existing grade separation structures

Source: Table adapted from the California State Department of Transportation (Caltrans) Project Development Manual, Chapter 18.

After a review of all the available information, if it is determined that a Phase II is needed, then the next step is to define the purpose and objective of the Phase II investigation.

PLANNING A PHASE II ENVIRONMENTAL SITE INVESTIGATION

Taking the time to plan before undertaking a Phase II environmental site investigation will ultimately save time, money, and improve the effectiveness of the investigation activities. Effective planning steps prior to undertaking a Phase II environmental site investigation should generally include:

- determining the purpose and objective of the investigation;
- reviewing existing information, site conditions, and limitations;
- developing a conceptual model of the site/area;
- developing a work plan, or scope of work; and
- establishing project management and budget guidelines *(8)*.

Determine the Purpose and Objective

The first question to ask in planning an investigation is, "Why are we conducting the investigation?" The purpose of any investigation would be to understand the site's geology, the nature and extent of all contamination, and hazards at the site and their associated risks. However, it may not be possible to fully accomplish all of this within the time and money available for the project. Therefore, try to make the objectives of the assessment realistic and specific, and avoid the "see what we find" approach to assessment. If, for example, the purpose is to determine if the corner gas station has leaked into the ROW, then the objective should be to determine the presence and extent of petroleum COCs within the area of concern (AOC) and focus on that aspect of the investigation.

The proposed investigation may also need to satisfy regulatory requirements, establish limits of a known plume, gather groundwater data, or any combination of site characteristics. Determining the purpose and objective of the proposed assessment should be the first step. Here are some other factors to consider:

- regulatory requirements that need to be met,
- end user of the information,
- schedule and timing requirements,
- budget limitations, and
- roles and responsibilities of those directing the site investigation action.

Reviewing Existing Information, Site Conditions, and Site Limitations

Reviewing the existing information before conducting a Phase II site investigation is probably the most important step in the planning process. Finding out as much as possible about the area, previous activities, and adjacent areas will help make decisions on the scope of work.

Ideally, the Phase I initial site assessment would provide adequate information to proceed with a Phase II site investigation, but this is rarely the case because the scope of Phase I initial assessment is generally limited. The information contained in a Phase I initial assessment report that actually describes site conditions beneath the surface is usually stated in general terms and not in the detail needed for Phase II. Therefore, one should review as much information as is practicable and available in order to gain an understanding of the site and its setting.

It is impractical, in many cases, to review all of the information available about a site or region in which the assessment will be conducted. However, enough information should be reviewed to be able to prepare a scope of work that will meet your objectives and develop a conceptual model of the site. The list provided below offers suggestions on the type of documents that may be available for review. The list also includes questions a reviewer might ask in seeking relevant information about the study area.

1. <u>Previous Phase I Reports</u>

   If available, Phase I initial site assessments should be reviewed, at a minimum, to determine if there is a potential for contamination in the study area, the location of the contamination, and the source of the contamination. One should also identify any gaps of information or areas of concern in the reports and consider a follow-up Phase I or updating any report older than one year. Ask the following questions:

   - How recently was the initial site assessment conducted?
   - Have the conditions changed?
   - Are there other Phase I initial site assessment reports that have been conducted in the area?
   - What are the known or potential COCs or hazards identified in the Phase I initial site assessment report?
   - What and where are the potential sources of the COCs?
   - Have there been more recent spills or releases?

2. <u>Regional/Site Setting and Previous Phase II Environmental Site Investigation Reports</u>

   Reviewing results from existing and even ongoing Phase II environmental site investigations in the area can be very helpful, especially when formulating a sampling plan or selecting an investigative technology to use. If COCs are encountered, it is likely that the report has been sent to TNRCC and may be available for review.

When reviewing a Phase II report, try to identify the following characteristics of the area:

- What is the source of the COCs?
- What COCs were identified and analyzed?
- In what zones/media were the COCs found?
- What were the concentrations of COCs?
- What are background concentrations?
- What is the depth to groundwater?
- What is the groundwater gradient and direction of flow?
- What is the depth to bedrock?
- What type of soils and/or rock formations were encountered?
- What investigation tools were used? Were they successful?
- What sensitive receptors or conduits were identified belowground?
- Where is the nearest surface water body or aquifer?
- What potential exposure pathways were identified?
- What migration pathways were identified? Which way?
- Were there off-site impacts?

3. <u>Other Reports</u>

Other helpful sources of information may be available from non-environmental investigations. It may also be helpful to speak with consultants, contractors, and local environmental regulators who have worked in the area and have site-specific knowledge of the area. This type of information may be from:

- construction documents showing trenching, borings, or utility installations;
- geotechnical reports from various engineering or construction activities;
- city, county, or other government activities such as construction reports, fire and emergency response reports;
- water well driller's reports and information;
- TNRCC publications on water quality and availability; and
- university research and studies.

4. <u>Regulatory Review</u>

When planning for a Phase II environmental site investigation, it is always important to begin with the end in mind, especially when meeting regulatory requirements. For example, formulating a sampling plan and having defensible data are critical to the success of the assessment. Therefore, be mindful of all your regulatory requirements from the earliest planning stages. For example:

- What methods of laboratory analysis are accepted or needed for any samples collected?
- What regulatory forms and notification requirements are needed?

- What format should be used for the final report?
- What are the corrective actions being taken by other responsible parties (RPs) nearby?
- Are there ordinances which prevent or influence the future installation of water wells at the site or surrounding area?

5. Existing Site Conditions and Receptor Survey

Even with all the review of reports and documents, it is important to understand the site conditions as they exist firsthand. The identification of potential receptors and exposure pathways is of paramount importance. The receptor survey includes a field survey and a water well records inventory. A thorough survey is an important component of the preliminary planning phase. This information should be clearly presented on a vicinity map or existing aerial photograph of appropriate scale. If a sensitive receptor is identified, then the potential for impact must be evaluated. When the sensitive receptor is off-site, consider the need for property access prior to mobilization. Sensitive receptor(s) known or suspected to be impacted requires immediate action. This may include initiating abatement measures, providing alternative water supply, and/or plans for sampling.

- What are the sensitive receptors or habitats aboveground? A field survey within a 500 ft radius of the facility should be conducted to identify unregistered water wells, schools, hospitals, residences, basements, day-care centers, nursing homes, businesses, etc. Other sensitive receptors such as surface water bodies, parks, recreational areas, wildlife sanctuaries, wetlands, and agricultural areas must also be identified in the field survey.
- What are the potential exposure pathways?
- What are the potential migration pathways (utilities and underground structures)?
- What is the current and future land use (commercial, industrial, or residential)?
- What is the adjacent zoning, or off-site land use (identify schools, churches, hospitals, and other sensitive receptors)?
- Water well inventory of all water wells located within 0.5 miles of the site .
- What site conditions would preclude the use of certain investigative tools?
- Is access to the site or study area limited?
- If the predominant land use of the area is residential, is it considered a minority/non-minority and/or low income neighborhood?
- What are ongoing site activities?
- What ongoing activities nearby will affect your study area?

6. Limitations

Finally, try to determine the aspects of the site or study area that may prevent or preclude a certain action or investigative technique.

- What underground and overhead utilities are located in the area?
- How do we best access the area of study?
- Are there restricted or inaccessible areas? Do I need/have right-of-entry?
- Where can I stage equipment?
- Where can I store waste materials such as drill cuttings or purged water?
- What are the expected weather conditions and seasonal factors?
- When and how long will it take to mobilize?

Develop a Conceptual Model for the Study Area

The information obtained during the preliminary planning phase, in conjunction with considerations for regulatory requirements, should be used to develop a conceptual model. A conceptual model is a three-dimensional representation of the study area or site conditions. The model is a general understanding or working hypothesis of the relationship between the contaminant source areas (e.g., contaminated soils and groundwater), transport mechanisms (e.g., leaching, groundwater transport, etc.), receptors (e.g., residents, groundwater users, surface waters, etc.), and exposure routes (e.g., inhalation, ingestion, dermal contact, etc.). A conceptual model of the site should include the following:

- the contaminant concentrations and distribution;
- the background concentrations and PCLs;
- the source(s) of contamination;
- migration pathways (groundwater, surface water, soil, biotic pathways);
- the factors affecting contaminant transport (including direction and rate);
- the potential receptors (human and ecological); and
- the potential for contaminants to reach a receptor.

Corrective action decisions must take these characteristics into account. During the investigative process, the conceptual model must be re-evaluated to reflect the actual site conditions.

Develop a Scope of Work (Data Collection and Analysis Plan)

The next step after reviewing the existing information and developing a conceptual model of the site is to develop a scope of work that will accomplish the objectives of the investigation. The scope of work is the plan, derived from the conceptual model, used to complete the site assessment and is developed on a site-by-site basis. The scope of work should include answers to many of the questions and issues raised during the planning stage.

The level of detail needed in the scope of work will depend on the complexity of the project but should be sufficient to minimize uncertainty and satisfy data requirements.

In many instances, the scope of work is in the form of a proposal submitted by the consultant and includes tasks being performed by a subcontractor. Therefore, it is important for the environmental consultant to have the benefit of available reports and site information so that they can have a conceptual understanding of the site and develop a scope of work (or proposal) that meets the objectives of the investigation much in the same manner. Whether developing a scope of work for the project, or reviewing a proposal, the same general requirements should be met. When reviewing a proposal, check to see if it addresses all the issues raised in the assessment planning stage as outlined below.

To meet the minimum requirements of the Phase II environmental site investigation, the scope of work must place emphasis on characterizing source area, determining maximum concentrations of the contaminants, and delineating the vertical extent of contaminants exceeding critical PCLs. The scope of work should include selecting sampling technology/tools and analytical methods, locating sampling points, obtaining off-site access if needed, evaluating presence of COCs, non-aqueous phase liquids (NAPLS), vapor-phase hydrocarbons and surface water receptors, and determining waste management options.

Dynamic work plans and data quality objectives are detailed systematic process guidelines for environmental projects to better meet data requirements *(9, 10)*. These processes are summarized at the end of this section and can be used and adapted to develop scopes of work and sampling plans that will meet project objectives.

The following are recommendations for developing a scope of work for a Phase II environmental site investigation based on the accelerated site characterization process *(11)*:

1. Provide a general description of the proposed project that includes:
   - statement of the problem and nature of contamination under investigation;
   - study boundaries;
   - specific limitations of the study; and
   - data requirements.

   Provide the type of investigation to be undertaken (subsurface, surface, multi-media):
   - media to be sampled; and
   - nature and composition of the contamination.

2. Describe the methods of investigation to be used:
   - equipment to be used (Direct push - Geoprobe, GPR, rotary auger, etc.)
   - expected size and depth for the installation of soil borings; and
   - size, construction, and completion of wells.

3. Present a sampling plan or strategy which includes:
    - analytical methods and parameters;
    - frequency and depth of samples;
    - chemical analysis—analytical parameters for samples; and
    - allowances and contingencies for additional sampling.

4. Action plan for unexpected conditions:
    - establish who makes the field decisions—name and contact of field supervisor;
    - establish who should be notified or consulted when unexpected conditions are encountered;
    - contingency plans for emergencies;
    - maximum dollar amount of additional work that may be needed as a result of unexpected conditions; and
    - downtime expenses.

5. Schedule for completion of work:
    - working hours; and
    - access schedule.

6. Baseline assumptions of expected conditions and responsibilities:
    - responsibility for regulatory notifications;
    - responsibility for locating utilities;
    - disposal of wastes;
    - site access; and
    - safety plan.

7. State in the scope of work information about the report format (see TNRCC and ASTM for standard reporting formats):
    - establish the information to be reported;
    - establish the regulatory body or intent the report should be used for;
    - state the purpose of the report, why it is being prepared;
    - establish the number of copies of the report needed;
    - determine who will receive the report;
    - determine how may additional copies of the report are needed; and
    - determine the need for review or draft reports.

Although it is not always possible, a kick-off meeting is recommended prior to mobilization. If conditions at the site are complicated and require detailed coordination, a meeting on the site may also be necessary to answer questions, eliminate confusion, and verify the conditions at the site.

TNRCC and ASTM Reporting Formats

Depending on the objective of the assessment, the report format may take different forms. The proposed TRRP outlines its reporting requirements in Subchapter E, §§350.91-350.96, for reports submitted to TNRCC. As the TRRP is implemented, reporting forms and formats will likely be developed. TNRCC has numerous reporting forms for LPST investigations and reports in TNRCC Recommended Guidance Document RG-175. The TNRCC reporting requirements appearing in the proposed TRRP rules are presented in Table 4.

ASTM E 1903-97 also has a recommended reporting format for Phase II assessments. A recommended table of contents follows the TNRCC reporting requirements in Table 5.

Table 4. Draft TRRP - Affected Property Assessment Report.

Subchapter E : Reports

§350.91. Affected Property Assessment Report.

(a) The person shall include the contact and identifications as described below in an affected property assessment report (APAR):

(1) the name, mailing address, and telephone number of the contact person or office for the on-site affected property;
(2) the program and identification numbers for the project, if any (e.g., Solid Waste Registration number, Leaking Petroleum Storage Tank identification number, Voluntary Cleanup Program number, etc.); and
(3) the physical address or location of the affected property, including an accurate latitude and longitude.

(b) An APAR shall document descriptions of procedures and conclusions of the assessment and shall include all information required to meet the requirements of §350.51 of this title (relating to Affected Property Assessment), §350.52 of this title (relating to Groundwater Resource Classification), and §350.53 of this title (relating to Land Use Classification). This includes, but is not limited to:

(1) the classification of the groundwater(s) at an affected property including all supporting data and results;
(2) the classification of the land use(s) of the affected property;
(3) the identification and characterization of all source areas (e.g., NAPLs);
(4) a characterization of the local geology and hydrogeology;
(5) the direction and rate of movement, composition, and representative concentrations of COCs in environmental media (including the potential for migration to other media);
(6) an identification of all potential human receptors and exposure pathways;
(7) as required, a completed Tier 1 Exclusion Criteria Checklist, or as required a Tier 2 screening-level ecological risk assessment, and/or a Tier 3 site-specific ecological risk assessment as specified in §350.77 of this title (relating to Ecological Risk Assessment and Development of Ecological Protective Concentration Levels);
(8) summaries of sampling methodology;
(9) all analytical data in accordance with §350.54 of this title (relating to Data Acquisition and Reporting Requirements);
(10) documentation that the data necessary to support the development of PCLs and remedy selection have been adequately and appropriately collected;
(11) documentation of the derivation of all RBELs and PCLs and the determination of the critical PCLs for environmental media including all associated assumptions and calculations;

Table 4. Draft TRRP - Affected Property Assessment Report. (continued)

(12) a tabular comparison between concentrations of COCs and the critical PCLs. If statistical or geostatistical methods are used to develop representative concentrations of COCs, then the person shall include the following:

(A) A discussion of the data collection effort from an environmental medium to support this determination (e.g., judgmental samples, random sampling design, etc.);

(B) The statistical or geostatistical methodology applied; and

© The assumptions of the statistical or geostatistical method and how those assumptions are met.

(13) graphical representations (e.g., maps and cross-sections) of the soil and/or groundwater PCLE zone(s), location of other environmental media which exceeds the respective critical PCLs, and the plume management zone if applicable;

(14) proof of attempt to notify or proof of receipt by the parties of any notices or information required to be provided to parties in accordance with §350.55 of this title (relating to Notification Requirements Pertaining to Off-Site Properties and Leased Lands); and

(15) any other reasonable information required by the executive director.

The APAR shall be submitted in a format and according to a schedule established by the executive director.

Table 5. ASTM Phase II Environmental Site Assessment Process.
E 1903-97, Recommended Table of Contents

TABLE OF CONTENTS (Summarized)

Characterizing the Site

All Phase II environmental site investigations will involve characterizing the soil, groundwater, surface water, land use, and potential receptors to some degree. The detail of the characterization needed will depend on the purpose of the investigation. Generally speaking, the investigation will involve using either screening methods and/or confirmation methods to characterize the soil and groundwater during Phase II environmental site investigations. For soils and groundwater, characterization is generally accomplished through the use of intrusive investigative methods such as direct push or rotary drilling techniques to obtain representative samples of the soil and groundwater. For characterizing surface features, it will generally involve site reconnaissance and records search. The following is a brief description of the site conditions to be characterized during a Phase II investigation.

Soil Assessment

The horizontal and vertical extent of COC in the subsurface should be determined. However, it is not necessary for all sampling points to extend to the maximum vertical extent of contamination. Sampling points should be strategically placed to confirm the zone of greatest contamination (based on field screening) and its depth. That is, the contaminant zone's depth to top, depth to bottom, and thickness should be determined *(12)*.

Soil assessment may also involve sampling for the physical properties as well as COCs. This is especially important for risk-based assessments because the physical properties of soils can affect the fate and transport of the contaminant. The sampling plan for measuring soil parameters should be adequate to determine average soil properties across the contaminant source area. The samples must also be representative of the soils that contaminants migrate through to reach groundwater. These parameters must be determined using samples not contaminated by the release (particularly in the case of fraction organic carbon). Additional samples should be collected if multiple lithologies are present which might affect transport of the contaminants or if contaminants are contained within multiple lithologies. The physical (geotechnical) properties to be considered include *(12)*:

- Dry Bulk Density (g/m^3),
- Effective Porosity (%),
- Fraction Organic Carbon (g/g),
- Intrinsic Permeability (cm^2), and
- Water Content (cm^3/cm^3).

Other physical soil properties known to be indicators of biodegradation that may be collected during the assessment include the distribution of oxygen content (O_2), carbon dioxide (CO_2), and methane (CH_4) *(12)*.

Table 6 summarizes the information generally needed when characterizing soil conditions.

Table 6. Soil Characterization Checklist Summary.

- ☐ Method of obtaining sample
- ☐ Soil description and characteristics
- ☐ Chemical constituents analyzed for the COC (e.g., benzene, toluene, etc.)
- ☐ Geotechnical analysis (e.g., bulk density, fraction organic carbon, etc.)
- ☐ Soil samples from the following depths:
  - 0-2 ft if affected soil is not covered
  - 2-15 ft
  - greater than 15 ft (if depth to water is less than 15 ft)
- ☐ Percent of affected soil zone covered with impervious cover
- ☐ Public access to the affected surface soil (0-2 ft) that is not covered
- ☐ Affected soil zone thickness
- ☐ Affected soil zone surface area dimensions
- ☐ Maximum depth of contamination exceeding appropriate screening levels (PCLs)
- ☐ Estimated volume of soil exceeding screening levels (PCLs)
- ☐ Distance from affected soil zone to property boundary
- ☐ Distance contaminated soil extends beyond property boundary

Source: Summarized from TNRCC recommended Guidance Document RG-175.

Groundwater Assessment

The information needed for groundwater characterization is similar to soil characterization. Groundwater samples should be collected if the vertical extent of subsurface soil contamination extends to groundwater (saturated zone). As with soil samples, inorganic biodegradation parameters may be analyzed to indirectly determine the affected area. Samples should be collected to determine the source area(s), plume boundaries, and the upgradient (non-impacted) area. A sufficient number of permanent wells should be installed to document contaminant migration and groundwater flow. Properly completed, permanent small-diameter well point(s) may suffice for monitoring purposes, if adequate water can be recovered for sample collection. Well placement and design should consider the concentration of contaminant(s) in the source area, the proximity to potential or impacted receptor(s), hydrogeologic conditions, and the beneficial groundwater use category *(12)*.

Table 7. Groundwater Characterization Checklist Summary.

- ☐ Method of sampling
- ☐ Description of water bearing zone
- ☐ Number of wells sampled
- ☐ Chemical constituents analyzed for the COC (e.g., benzene, toluene, etc.)
- ☐ Depth, base, and thickness of water bearing zone
- ☐ Distance from edge of plume to property boundary
- ☐ Areal extent of water bearing zone
- ☐ Groundwater quality/total dissolved solids
- ☐ Groundwater classification (see chart)
- ☐ Inorganic parameters (e.g., dissolved oxygen)
- ☐ Aquifer type (perched, confined, unconfined)
- ☐ Water level fluctuations
- ☐ Gradient (ft/ft)/direction
- ☐ Saturated hydraulic conductivity (ft/day)
- ☐ Approximate well yield (gpd)
- ☐ Geologic formation/major/minor aquifer name

Source: Summarized from TNRCC recommended Guidance Document RG-175 & TRRP.

The categories are based on the potential beneficial use of the groundwater in question. Category I groundwater applies to sites where water supplies are threatened or high quality water is affected. Category II is designed to protect groundwater which has potential beneficial use as a drinking water source. Category III applies to groundwater with a low potential for beneficial use as a drinking water supply. The distinction between categories is made primarily using the concentration of total dissolved solids (TDS) present in the groundwater and the ability of the source to yield sustainable quantities. The classification applies to each groundwater bearing unit which is affected by contaminants and contains COCs equal to or greater than the residential groundwater assessment level.

Table 8. TNRCC Groundwater Categories.

GROUNDWATER CLASSIFICATION	
The Groundwater Resource Classification (Class I, II, or III) is used to classify each groundwater bearing unit which contains COCs at concentrations greater than residential groundwater assessment level. If a groundwater bearing unit meets the criteria for more than one of the classifications, then the higher classification should be used.	
Class I - Groundwater Resource if one of the following are met	• groundwater bearing unit is within 0.5 mi of public water system drinking water well and COCs are likely to migrate to the groundwater production zone • groundwater bearing unit is only reliable source of water at a depth of < 800 ft, < 1,000 TDS mg/l, and can produce a sustainable rate of > 5,000 gpd with a 4 in diameter casing • groundwater bearing unit with TDS ≤ 3,000 mg/l, sustainable rate ≥ 144,000 gpd to a well 12 in diameter casing, and a natural quality meeting primary drinking water standards
Class II - Groundwater Resource if one of the following are met	• groundwater bearing which is a groundwater production zone for an existing well located within 0.5 mi of an affected property and which is used to supply groundwater for human consumption, agricultural purposes, or any purpose which could result in exposure to human or ecological receptors • groundwater bearing unit capable of producing water with a naturally occurring TDS < 10,000 TDS mg/l at a sustainable rate > 150 gpd with a 4 in diameter casing
Class III - Groundwater Resource	• any groundwater bearing unit which produces water with a naturally occurring TDS of >10,000 mg/l or at a sustainable rate < 150 gpd to a well with a 4 in diameter casing

TDS=Total Dissolved Solids, mg/l =milligrams per liter, gpd =gallons per day.

Surface Water Assessment

Surface water samples should be collected when contaminant migration is known or suspected to affect a surface water body, especially if the project may use or impact surface waters. Sample selection should consist of sediment and/or water up and downstream, and/or radially from the discharge point(s). The extent of contamination must be defined to levels established in Title 30 TAC 307, to the MCL, or to health-based concentrations. For more details on sample requirements, refer to Title 30 TAC Chapter 307 and the TRRP.

Receptor Survey

A receptor survey is critically important to risk-based assessment. It is conducted to identify potential receptors and exposure pathways and is the basis for determining continued investigation and corrective action. The receptor survey includes a field survey and a water well records inventory. The water well survey should encompass an 800 m (0.5 mi) radius of the site and be displayed on a U.S. Geological Survey topographic map. The field survey should identify receptors and pathways within 150 m (500 ft) of the site and identify schools, hospitals, day-care centers, businesses, surface water bodies, parks, wetlands, and other sensitive receptors. Migration pathway identification should include the location of subsurface utilities and structures that may affect the fate and transport of the contaminants.

Ecological Risk Assessment

Although not required at this time by TNRCC, an ERA is included in the proposed TRRP. An ERA is a process which evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors (EPA 1992). The purpose of an ERA is to characterize the ecological setting of the affected property, identify complete and reasonably anticipated exposure pathways and representative ecological receptors, scientifically eliminate COCs that pose an acceptable risk, and develop PCLs for ecological receptors where warranted.

TNRCC proposed a tiered approach for ERAs wherein a Tier 1 exclusion criteria checklist assessment would be required for all affected property assessments. The proposed checklist is a standardized form consisting of a series of property-related questions and exclusion criteria designed to determine the existence of complete ecological exposure pathways through descriptions of the affected property setting and/or the presence and distribution of COCs within environmental media. The checklist is summarized in Table 9.

Table 9. Ecological Checklist Summary.

☐	Provide a description of the specific area of the corrective action and the nature of the release
☐	Identify environmental media known or suspected to contain chemicals of concern (COCs)
☐	Provide the information for the nearest surface water body
☐	Identify where COCs have migrated via runoff or groundwater discharge
☐	Identify the affected property
☐	Identify if COCs are in the soil below the first 5 ft beneath ground surface or barriers that prevent migration

Source: Summarized from TNRCC recommended Guidance Document RG-175 and TRRP. For the actual checklist, refer to the TRRP (see Section 350.77).

Sampling and Analytical Methods

Selecting the appropriate analytical methods to be used in a Phase II environmental site investigation requires an understanding of how the information is obtained and how it is to be used. In general, field screening (qualitative) methods assist in the assessment process but cannot replace quantitative analytical methods. Field screening methods are generally less accurate than laboratory analysis but may be sufficient to locate source areas, provide gross determinations of the extent of contamination, and determine the sample selection and/or placement of sampling points. Ultimately, laboratory analysis of samples will generally be required to confirm field screening methods, conduct risk assessments, meet regulatory requirements, and withstand the test of litigation. The advantage of screening methods are that they can be obtained at relatively lower costs and provide almost immediate results.

As a general rule, more numerous sample points at a lower level of data quality can provide a better understanding of site conditions than fewer data points at a higher data quality level. As such, field screening can offer a bigger bang for the buck, especially when assessing large areas. The more quantitative and elaborate the analysis, the lower the detection limit, the more accurate the results, and the more costly the analysis is to perform. The *Data Quality Objectives* (DQO) process is one tool used to select the appropriate mix of qualitative (screening) and quantitative (laboratory analysis) methods (i.e., data quality levels).

The primary considerations in selecting an analytical method and data quality level are:

- purpose of the sample (e.g., needs for prioritization, risk evaluation, regulatory requirements),
- contaminant(s) of concern,
- media of concern,
- analytical turnaround time, and
- detection limits.

Field screening methods must be supported by EPA-approved quantitative analytical methods. Typically, the need for quantitative analysis is more important when low detection limits are needed to verify the presence or absence of COCs. In areas of high contaminant concentration where low detection limits are unnecessary, more reliance may be placed on field screening methods. However, EPA-approved methods must be used to analyze a sufficient number of samples of greater and lesser contamination to verify conclusions regarding contaminant distribution.

If groundwater is encountered, samples should be collected and analyzed for appropriate COCs. As with soil sample analysis, total petroleum hydrocarbons (TPH) will be used as a screening tool for determining the analysis of specific indicator compounds in groundwater. For samples with elevated TPH concentrations, analysis of poly-cyclic aromatic hydrocarbons (PAH) should be considered for evaluating toxicity. If PAH is not detected in samples collected from the source area(s), then it is not necessary to continue PAH analysis. (PAHs are a group of over 100 different chemicals that are formed during the *incomplete* burning of coal, oil and gas, or other organic substances. Some PAHs are manufactured, but most PAHs are found in petroleum-derived substances like coal tar, crude oil, creosote, and roofing tar. PAHs are sometimes referred to as polynuclear hydrocarbons [PNA]).

Groundwater samples may also be analyzed for inorganic components (e.g., oxygen [O_2], nitrate [NO_3], or sulfate [SO_4]) as an inexpensive screening tool for an indirect measurement of hydrocarbon distribution (i.e., biodegradation indicators). Concentrations of these inorganic compounds are significantly influenced by microbial activity that metabolize petroleum hydrocarbons.

The physical properties of the soils that affect the fate and transport of the COCs may also need consideration. Soil properties such as soil bulk density, porosity, water content, fraction organic carbon, and hydraulic conductivity may be required for the risk assessment. ASTM or other common geotechnical methods may also be used to determine the soil parameters. Default values are used when site-specific soil property information is not collected *(13).* (See *Risk-Based Corrective Action for Leaking Storage Tank Sites* [RG-36], and TRRP Chapter 350).

Table 10 contains some examples of analytical techniques that can be used to analyze the affected media. Table 11 lists the TNRCC-required analysis and approved method for selected petroleum substances. For specific sample collection, handling, analysis, and reporting requirements, refer to TNRCC publication RG-14: *Soil and Groundwater Sampling and Analysis, EPA Manual of Solid Waste 846,* and the TRRP.

Table 12 presents typical analytical requirements for soil, groundwater, or air samples collected at sites where various petroleum substances have been released. For example, soil samples collected at LPST sites should at a minimum be analyzed for concentrations of BTEX and TPH, using EPA method 8020 and TNRCC method 1005, respectively. The sampling plan should seek to correctly identify the concentrations of the COCs that are most likely to occur at the site in addition to meeting regulatory requirements.

Table 13 presents what are referred to as action levels for BTEX and selected PAH constituents at leaking petroleum storage tank sites. Analytical results that exceed these levels *generally* indicate that some additional investigation or corrective action is needed. These levels are not used as cleanup levels; they are simply levels that indicate a release is likely to have occurred, and additional site investigation may be required. Sample results should be compared to PCLs as described in the TRRP. Since the location and depth of the sample may also affect the appropriate corrective action, it is important to use the sample results to develop a conceptual model of the site as discussed earlier in this chapter.

Location of Sampling Points

Prior to the site investigation, the general location of initial sampling points should be chosen. Consider the following when selecting sampling point locations:

- point of release(s) or suspected area of major sources of contaminants,
- locations of potential receptors,
- physical characteristics of the surface and subsurface as determined in the preliminary planning,
- off-site access, and
- contingencies for additional sampling points.

While the investigation is in progress, target risk-based concentrations, and analytical results should be compared to determine the placement of the next sampling and/or permanent well point(s). Comparison of results will assist in refining the conceptual understanding of the site and may suggest modification to the scope of work *(13)*.

Table 10. Sample Collection Tools[1].

METHOD	ACCESS[2]	SUITABLE MEDIA			SAMPLE DEPTH[3] (meters)	COMMENTS
		Soil	Soil Vapor	Ground-Water		
Grab samplers (trowels, scoops, shovel, post-hole digger)	M, B	X			< 1	Low cost. Loss of volatiles. Minimal equipment.
Hand augers	M	X			< 3	Slow. Labor intensive. Shallow depth. Can be used near utility/product lines.
Split spoon	DP, DR	X			10-100	Minimal sample disturbance. Difficult to use below water table.
Sample sleeve	DP	X			10-100	Difficult in cobbles or hardpan. Visual observations of sample. Can be used below water table. Minimal sample disturbance.
Other core samplers[4]	M	X			< 2	Equipment-specific capabilities and limitations.
	DP	X			10-100	
	DR	X			10-100	
Active gas samplers (vacuum pumps and tubing)	OH, DP, DR		X		10-100	Large sample volume possible. Loss of volatiles. Low cost.
Passive gas samplers	M		X		< 1	
Pneumatic depth-specific samplers	OH		X	X	10-100	
Check valve and tubing	OH			X	10-100	Limited sample volume. Low cost.
Exposed-screen sampler	DP			X	0-100	
Bailer	OH			X	10-100	Labor-intensive.
Peristaltic pump	OH			X	< 10	
Gas-drive/displacement pump	OH			X	10-100	
Gas-drive/piston pump	OH			X	10-100	
Bladder pump	OH			X	10-100	
Helical rotor pump	OH			X	10-100	

1 Some commonly used tools for shallow and intermediate depth investigations (generally <50 m) are listed. Many other tools are available. Refer to "Subsurface Characterization Monitoring Techniques: A Desk Reference Guide, Vols. I and II," (EPA/625/R-93/003a&b).

2 Access to the sample for collection or installation of sample tool via the listed approaches. M =manual (hand-operated equipment). B =backhoe (mechanical excavating equipment). OH =open hole (unobstructed access to the sample medium via a pit or cavity, a cased well, or narrow-diameter sampling point). DR=drill rig (mechanical boring equipment, such as hollow-stem auger, mud/air rotary). DP=direct-push (mechanical, hydraulic, pneumatic, or vibratory devices which push or drive narrow diameter sampling points into the subsurface, such as cone penetrometer, microwell devices, laser-induced fluorescence).

3 Sample depth refers to practical depth limitation range, depending upon the sampling device used and the lithologic conditions.

4 Numerous types and sizes available for different soil conditions. Drill rig is the only sample access equipment listed in this table which can be used readily to sample consolidated material.

Source: TNRCC RG-175, Guidance for Risk-Based Assessment at LPST Sites in Texas.

Table 11. Sample Analytical Techniques[1].

Method	Analyte	Media			Detection Range			Limitations	Result Time
		Soil Vapor	Soil	Ground-Water	Soil Vapor	Soil	Ground-Water		
PID- or FID-headspace[2]	TOV[3]	X	X	X	ppmv[4]	ppmv	ppmv	Temperature. Humidity. Instrument flowrate.	Immediate.
Draeger tube	Specified compound	X	X		ppmv	ppmv			
O_2	Oxygen	X	X		%	%			
CO_2 meter	Carbon dioxide	X	X		%	%			
pH meter	pH			X			1-14		
DO meter[5]	Dissolved oxygen			X			mg/l[6]	Temperature. Active fouling by materials that react, coat, or clog.	
REDOX meter	REDOX potential			X					
Conductivity meter	Electrical conductivity			X					
Ion-specific meter	Indicator compounds			X			mg/l		
Laser-induced fluorescence	Indicator compounds		X			mg/kg[7]			
Infrared (IR) spectrometer	Indicator compounds		X	X		mg/kg	mg/l	Low bias for aromatics.	Minutes.
Colorimetric methods	Indicator compounds		X	X		mg/kg	mg/l		
Immunoassay kits[8]	Indicator and specific compounds		X	X		mg/kg	ug/l[9]	Cross-reactivity.	
Portable GC[10]	Specific compounds	X	X	X	ppbv[11]	ug/kg	ug/l	Moderate peak resolution.	
Lab-grade GC (on-site)	Specific compounds	X	X	X	ppbv	ug/kg	ug/l	Negligible.	Minutes to hours.
Lab-grade mass spec (on-site)	Specific compounds	X	X	X	ppbv	ug/kg	ug/l	Negligible.	
Lab-grade GC (off-site)	Specific compounds	X	X	X	ppbv	ug/kg	ug/l	Negligible.	Days to weeks.
Lab-grade mass spec (off-site)	Specific compounds	X	X	X	ppbv	ug/kg	ug/l	Negligible.	

1 Some commonly used techniques for analyzing environmental media are listed. Many other techniques are available. This list was generated using "Field Analysis Manual," New Jersey Department of Environmental Protection and Energy, May 1994, and "Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide, Vols. I and II," (EPA/625/R-93/003a&b), USEPA, May 1993.
2 PID = Photoionization Detector and FID refers to Flame-Ionization Detector.
3 TOV = Total Organic Vapors.
4 ppmv = parts per million vapors.
5 Most "down-hole" Dissolved Oxygen (DO) probes deplete oxygen during measurement. Considerations should be given to sampling and analysis procedures that provide more accurate readings (for example, using flow-through cells).
6 mg/l = milligrams per liter.
7 mg/kg = milligrams per kilogram.
8 Analytical techniques which utilize a field extraction may provide less accuracy and precision for silty and clayey soils.
9 ug/l = micrograms per liter.
10 GC = gas chromatography.
11 ppbv = parts per billion vapor.
12 ug/kg = micrograms per kilogram.

Source: TNRCC RG-175, Guidance for Risk-Based Assessment at LPST Sites in Texas.

Table 12. Analytical Requirements for Various Petroleum Substances.

Released Substance	Media			EPA Approved Methods[1]
	Groundwater	Soil	Air	
Gasoline	BTEX[2] TPH[2] MTBE[2] TDS[3]	BTEX TPH	BTEX	EPA 8020 (GC/PID) TNRCC 1005 EPA 8020 EPA 160.1
Diesel, Jet Fuels, No. 1, 2, and 4 Fuel Oils	BTEX PAH[5] TPH TDS	BTEX PAH TPH	BTEX	EPA 8020 (GC/PID) EPA 8100 or 8310 TNRCC 1005 EPA 160.1
Hydraulic Fluid, Lubricating Oils, No. 6 Fuel Oil	PAH TPH TDS	PAH TPH		EPA 8100 or 8310 TNRCC 1005 EPA 160.1
Waste Oil, Other Unknown Petroleum Products	BTEX PAH VOC[5] TPH TDS	BTEX PAH VOC TPH Total Metals[6]	BTEX VOC	EPA 8020 (GC/PID) EPA 8100 or 8310 EPA 8240 (GC/MS) TNRCC 1005 EPA 160.1
Hazardous Substances	*Refer to EPA publication SW-846 for the appropriate test methods for the constituent of concern. Hazardous substances should be evaluated on a case-by-case basis.*			

1 The listed methods have been approved by TNRCC. For analyses listed without recommended EPA standard methods, consult EPA publication SW-846. Detection limits should not exceed the risk-based target concentrations.

2 BTEX=benzene, toluene, ethylbenzene, total xylene; TPH = total petroleum hydrocarbons; MTBE = methyl tertiary butyl ether.

3 TDS =total dissolved solids; the sample should be collected from the least-contaminated well.

4 VOC =volatile organic compounds; VOC initially should be analyzed only from the boring/well located closest to the source.

5 PAH =polycyclic aromatic hydrocarbons; PAH should be analyzed from samples with the most elevated TPH. At minimum, the chemicals to be included are: acenapthene, anthracene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(a)pyrene, chrysene, dibenzo(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3cd)pyrene, naphthalene, pyrene.

6 Total metals analyses include arsenic, barium, cadmium, chromium, lead, mercury, seleniu, and silver. The EPA Toxicity Characteristic Leachate Procedure (TCLP) is required when any analysis exceeds 20 times the EPA regulatory limit for that metal as defined in 40 CFR §261.24.

Source: TNRCC RG-175, Guidance for Risk-Based Assessment at LPST Sites in Texas.

Table 13. Generalized Action Levels and Screening Levels.

CONSTITUENTS	SOIL ACTION LEVELS (mg/kg)		GROUNDWATER ACTION LEVELS (mg/l)
	Fine-Grained Soil*	Coarse-Grained Soil*	
Benzene	0.50	0.50	0.005
Ethylbenzene	70	10	0.70
Toluene	100	20	1.0
Total Xylenes	560	70	10
Acenaphthene	314	314	.010
Anthracene	13	13	.010
Benzo(a)anthracene	.877	.877	.010
Benzo(b)fluoranthene	.877	.877	.010
Benzo(k)fluoranthene	8.77	8.77	.010
Benzo(a)pyrene	.0877	.0877	.010
Chrysene	7.2	7.2	.010
Dibenz(a,h)anthracene	.0877	.0877	.010
Fluoranthene	156	156	.010
Fluorene	247	247	.010
Indeno(1,2,3-cd)pyrene	.877	.877	.010
Naphthalene	389	389	.010
Pyrene	99	99	.010
SCREENING LEVELS			
Total Petroleum Hydrocarbons (TPH) for Middle Distillate Releases**	500	500	5
Total Petroleum Hydrocarbons (TPH) for Gasoline Releases**	100	100	5

* Apply the fine-grained soil standard to sites dominated with clays and silts. Apply the coarse-grained soil standards to sites dominated with sands, gravels, and rock units.

** Apply the middle distillate TPH standard to diesel, kerosene, jet fuel, hydraulic oil, and waste oil releases. Apply the gasoline standard to gasoline and aviation gasoline releases. At sites where both gasoline and middle distillate releases have occurred in the same area or tank hold, the gasoline standard will apply.

NOTE: The listed action levels do not apply when:

- surface water is known or suspected to be impacted by the release,
- a water well or surface water intake is impacted or threatened,
- buildings or utilities are impacted with vapors; there are nuisance conditions such as odors, or discoloration or taste degradation to water supplies; or NAPL is present.

Source: TNRCC RG-17, Action levels for LPST Sites.

Construction Worker Safety

Table 14 is compiled from TNRCC guidance documents using default values and is intended only as a screening tool for threshold values of construction worker exposure to BTEX/PAH constituents typical of PST facilities. There are many physical and chemical properties that affect the health risks to workers from exposure to COCs; therefore, exceeding a target level does not necessarily constitute an unacceptable risk. Exposure and risk should be evaluated on a site-by-site basis, using accepted methodologies.

Table 14. Target Concentrations for Construction Worker Exposure.

SCREENING CHECKLIST				
CONSTITUENTS (COCs)	**Target Soil Concentration (mg/kg)**	**Target Groundwater Concentration (mg/l)**		
BTEX and PAH	Combined Inhalation, Ingestion, and Dermal	Based on Time Average/ Combined Inhalation, Dermal	meets	exceeds
Acenaphthene	101.e+04	6.30e-01		
Anthracene	5.90e+04	1.41e+01		
Benzene	1.20e+01	2.01e+01		
Benzo(a)anthracene	6.27e+01	1.14e-03		
Benzo(b)fluoranthene	6.15e+01	5.80e-04		
Benzo(k)fluoranthene	6.02e+01	5.05e-03		
Benzo(a)pyrene	6.30e+00	5.10e-05		
Chrysene	6.23e+03	1.13e-01		
Dibenz(a,h)anthracene	6.32e+00	2.32e-05		
Ethyl-benzene	1.35e+03	2.17e+01		
Fluoranthene	6.73e+03	6.67e-02		
Fluorene	7.87e+03	1.55e+00		
Indeno(1,2,3-cd)pyrene	6.32e+01	2.30-04		
Methyl Ethyl Ketone	1.24e+03	3.02e+02		
Naphthalene	7.87e+03	8.35e+00		
Pyrene	5.04e+03	4.89e-02		
Toluene	2.76e+02	4.88e+01		
Xylenes	4.33e+02	1.27e+02		

Source: Adapted from TNRCC, March 6, 1997 Memo: Clarification and Amendments for Implementation of RG-36. Also see TRRP.

PLANNING TOOLS FOR PHASE II ENVIRONMENTAL SITE INVESTIGATIONS

Project Management

Effectively managing a Phase II environmental site investigation requires that certain project controls and general guidelines be followed. Although controlling direct project cost is very important, it is also important to consider other factors that may affect the outcome of the assessment. The project manager or coordinator should consider:

- estimated cost and cost contingencies,
- roles and responsibilities of the assessment team and the decision-making process,
- project personnel qualifications and experience,
- subcontractors to be used,
- site safety,
- emergency numbers,
- laboratory needs, and
- schedule of activities.

Recently, many organizations have developed ways to improve the traditional Phase II environmental site investigation process. The focus of these efforts involve improving the time it takes to complete the investigation and the quality of data that are obtained during the investigation. As a result, new approaches to Phase II environmental site investigations have been developed that involve the use of "expedited" or "accelerated" site characterization techniques.

Two tools which can be used within the context of expedited site characterization are *Dynamic Work Plans (9)* and *Data Quality Objectives* (DQO) *(10)*. These tools are being applied to environmental assessment projects to better meet data requirements and are summarized below *(9, 10)*. Many of the concepts within these processes are applicable to the assessment of ROW.

Accelerated Site Characterization

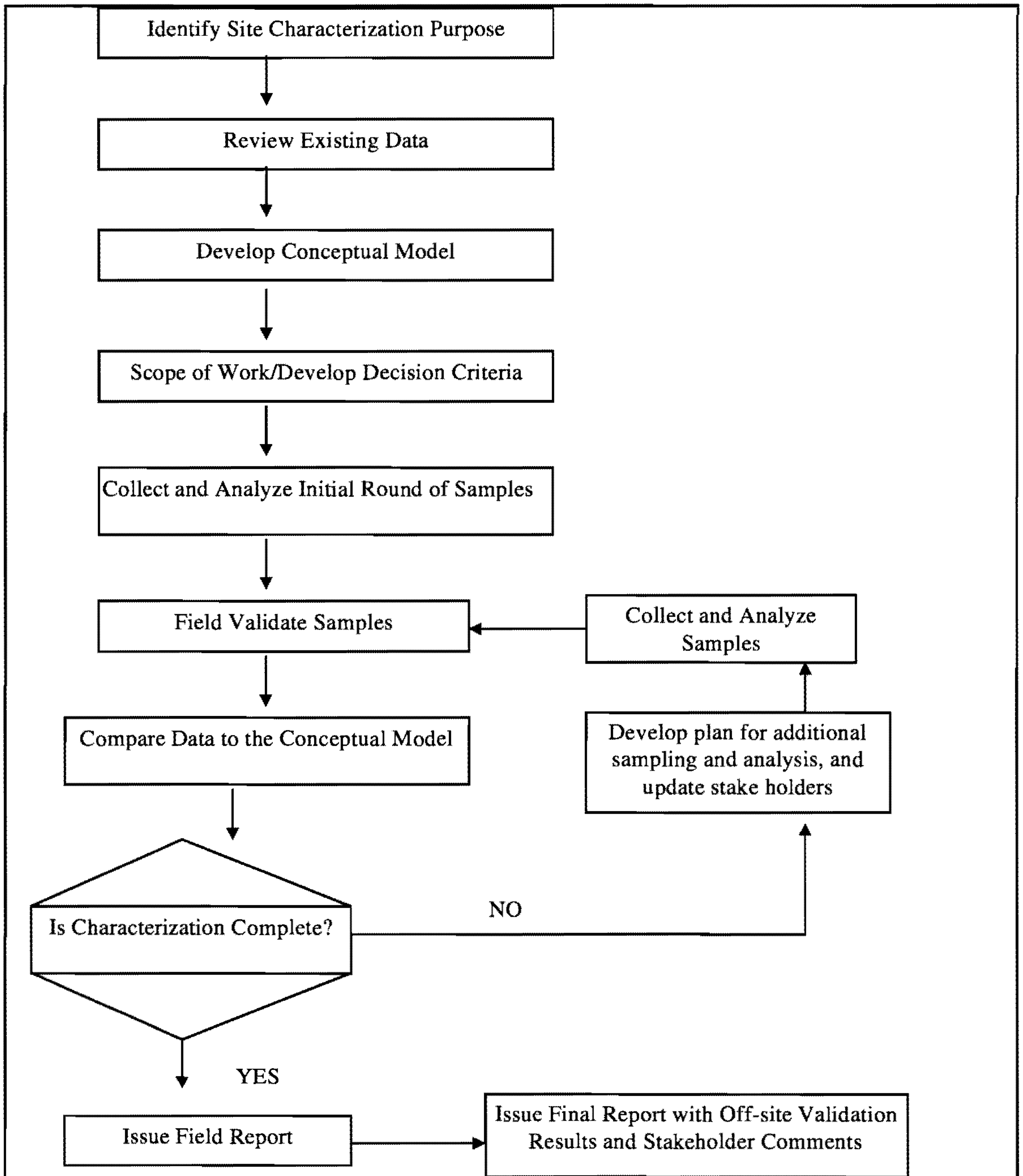
The purpose of this section is to briefly describe the accelerated site characterization (ASC) process *(11)*. ASC is used to generate near real-time information about the nature and extent of contamination at a site by: 1) generating enough data of the right kind and quality to allow decisions to be made concerning the appropriate level of cleanup, and 2) to gather the data and information in a single mobilization *(11)*.

The typical approach to site characterization may involve visiting the site two or more times to collect information necessary to make remediation decisions. This iterative characterization process is necessary because analytical results are often provided to the decision makers weeks or months after sample collection. Data generated by field analytical technologies are not relied on as much as data generated by off-site fixed laboratories. When information gaps are discovered, then additional mobilizations may be required to fill in the information gaps. Since a work plan needs to be prepared and approved for each site visit, multiple visits to a site can delay decision making or action for months.

The accelerated site characterization is an expedited assessment process for delineating the source, extent, and concentration of COCs to the fullest extent possible in a more timely and cost-effective manner. The approach is not a panacea, nor are the field analytical methods used in ASC intended to replace fixed analytical laboratories. The field analytical techniques used in ASC produce near real-time results that allow decision makers to identify additional sampling locations during the mobilization and prevent the need to re-mobilize to fill in information gaps.

One of the keys to effective implementation of this process is an on-site field manager who can interpret results, communicate with the stakeholders, and who is empowered to make decisions in the field. Involvement of the stakeholders early and continuously in the process is critical to the success of the process. In addition, generating the proper documentation is also necessary so that decisions made in the field can be defended at a later date.

Many of the analytical techniques and investigative tools discussed in this report can be incorporated into the ASC process. A detailed discussion of accelerated site characterization is available from ASTM in *Provisional Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases*, PS-95 (11). Additionally, ASTM has published a *Standard Guide for Developing Conceptual Site Models for Contaminated Sites*, E 1689-95 *(14)*, and *Standard Guide for Environmental Site Assessment: Phase II Environmental Site Assessment Process. E1903-97 (15)* .



*Characterization is complete when the conceptual model of the site generally incorporates all of the site data; the conceptual model can be used to make accurate predictions; and sufficient detail and delineation of the chemicals of concern have been achieved to fulfill the requirements of the stakeholders; or constraints prevent collection of any additional data.

Source: *Provisional Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases*, PS 3-95

Figure 3. Accelerated Site Characterization.

Data Quality Objectives (DQO)

The DQO process is a strategic, systematic process for planning scientific data collection efforts *(10)*. By using the DQO process, investigators ensure that the data collected for decision making are of the right type, quantity, and quality. The DQO process helps investigators answer the following basic questions:

- Why do we need data?
- What must the data represent?
- How will we use the data?
- How much uncertainty is tolerable?

Provided below is a summary of the steps involved in the DQO process. A complete and detailed explanation is available from the EPA in "*Guidance for the Data Quality Objectives Process*," EPA/600/R-96/055 (EPA QA/G-4, September 1994). DQO document and software are also available on the World Wide Web at: *http://www.epa.gov*; *http://www.rti.org/units/ese/cemqa/erpd/dqo.html*, and http://terrassa.pnl.gov:2080/dqo.

The DQO process consists of seven steps:

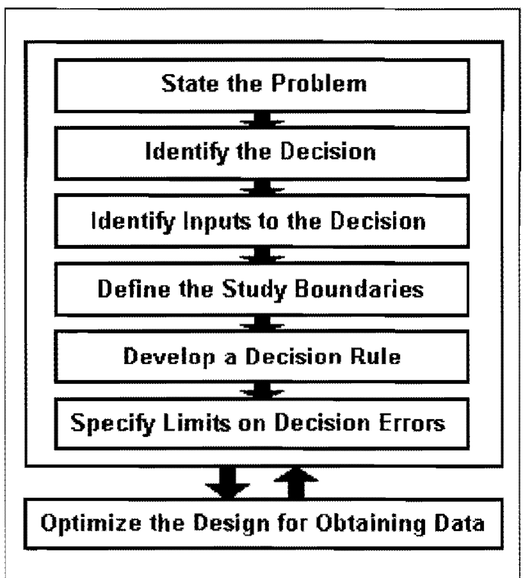


Figure 4. DQO Process.

Dynamic Work Plans

The dynamic work plan is an alternative approach to traditional site investigation techniques which can be used to expedite the assessment process by incorporating field analytical equipment and adaptive sampling *(9)*. The dynamic work plan was developed by the Center for Field Analytical Studies and Technology at Tufts University with funding and cooperation from EPA. The process specifies the decision-making logic used in the field to determine which chemical compound requires analysis rather than dictating the location and number of samples to be analyzed in advance. The following summary is excerpted from *"A Guideline for Dynamic Work Plan and Field Analytics: The Keys to Cost Effective Site Characterization and Cleanup"* which should be reviewed for a complete explanation of the dynamic work plan *(9)*.

Dynamic work plan investigations are site dependent and include field-based technologies and methods that produce chemical, physical, geological, and hydrogeological information about the site. The data generated must be of sufficient quality, with respect to measurement precision, accuracy, sensitivity, and completeness to support the objectives of the site investigation or cleanup. It is intended to lay the foundation for incorporating an iterative process into the static but widely used DQOs framework for decision-making planning. The guideline outlines field analytical instrument implementation, an adaptive sampling and analysis strategy, and site requirements. (See ASTM Draft Provisional Standard Guide for Expedited Site Characterization of Vadose Zone and Ground Water Contamination, July 1996.)

The Dynamic Work Plan Process

In the traditional approach, major decisions concerning the direction of the site investigation or cleanup are generally made by the project manager after the field work has been completed. A report is prepared presenting the findings to the appropriate regulatory body.

Discussions begin about whether sufficient information has been obtained to address the scientific and engineering questions of concern. Typically, several field mobilizations occur and reports are written, with many meetings held between the site owner and its environmental consulting company *and* the site owner and federal and/or state regulatory agencies. In contrast, these same decisions are made in the field in an adaptive sampling and analysis program. In constructing the dynamic work plan, it is important to determine prior to mobilization what decisions will be made, how these decisions will be made, and who will make them in the field.

Characteristics	Advantages
- Real-time sample analysis	- Reduce cost per sample
- Rapid field decision-making	- Increase number of samples
- Dynamic work plans	- Reduce number of field visits
Requirements	
- Field analytical methods	
- Decision support in the field	

Figure 5. Dynamic Work Plan Characteristics.

The dynamic work plan approach involves the following steps:

Step 1 - Select technical team
Step 2 - Develop the initial conceptual model and decision-making framework
Step 3 - Develop standard operating procedures
Step 4 - Develop data management plan
Step 5 - Develop quality assurance project plan
Step 6 - Prepare health and safety plan

For more information on dynamic work plan, see "A Guideline for Dynamic Work Plan and Field Analytics: The Keys to Cost Effective Site Characterization and Cleanup," Center for Field Analytical Studies and Technology, Tufts University/EPA Region I Office of Site Remediation and Restoration and Office of Environmental Measurement and Evaluation, Boston, MA *(9)*. This information is also available on the Internet through the Hazardous Waste Clean-up Information site http://www.clu-in.com.

Table 15 presents the general divisions between the degree of data quality required to meet an investigation's objective. The data quality classification is based on the New Jersey Department of Environmental Protection (NJDEP) Field Analysis Manual, Site Remediation Program, July 1994. The document is available at http://www.state.nj.us/dep/srp/regs/guidance.htm#fam and provides required deliverables to meet data quality levels.

Table 15. Data Quality Classification.

Data Quality Classification Modified from NJDEP Field Analysis Manual, July 1994		
Data Quality Level	Potential Applications	Example Methods or Instruments
1 - Screening: 1A - Qualitative 1B - Semiquantitative	Finding the nature and source of contamination (1A/1B) Tracking the long-term effectiveness of remediation systems (1B)	portable PID, portable FID, PID/FID, colorimetric analysis, headspace analysis
2 - Delineate: Quantitative	Determining the extent of contamination Determining the type of clean-up option(s) required	portable GC, portable IR, immunoassay, USEPA SW-846 field methods, mobile laboratories
3 - Clean Zone: Quantitative	Confirming the level of risk (human health and the environment) posed by the contamination Gaining a no further action or site closeout approval	standard laboratory analyses with SW-846, QA/QC mobile laboratories using standard methods
4 - Nonstandard: Quantitative specialty analysis	Constituent surveys of unknown contamination	Survey instrumentation, modified laboratory methods with full QA/QC

CHAPTER THREE - SITE INVESTIGATION TECHNOLOGY

GEOPHYSICAL SURVEYS

Geoscientists have developed many tools to characterize surface and subsurface features that have become an integral part of environmental site investigations. Geophysical methods that were initially developed for mineral exploration have been adapted for use in engineering and environmental applications. Many geophysical methods are found to be increasingly useful in environmental site characterization, hydrogeolgic investigation, and remediation of contaminants. The primary use for surface geophysics includes the location or identification of relatively shallow features such as shallow groundwater, buried objects (i.e., tanks and drums), buried infrastructure and utilities, and contaminant plumes. The following discussion summarizes the most commonly used geophysical survey technologies used in environmental assessment and site investigation.

Of the geophysical survey methods presented, the most commonly used are electromagnetic conductivity (EM) surveys, resistivity surveys, and ground-penetrating radar (GPR). This is primarily because of the relatively lower cost in comparison to other geophysical methods such as seismic survey methods. Additionally, EM, resistivity, and GPR are relatively mature technologies that are not intrusive and have broad applicability. These methods also typically do not generate waste or require extensive decontamination or equipment mobilization.

Most, if not all, geophysical methods should be used as a screening method that will ultimately need to be verified with an intrusive method of site characterization such as conventional drilling and sampling. However, geophysical methods have the advantage over conventional search and find techniques because they can gather large amounts of data over broad areas and, in many cases, do so more rapidly than conventional methods. The geophysical methods described here can provide a larger picture of a site's condition in advance of more detailed investigation. The methods summarized in this report should be viewed as another investigative tool which can be used to save time and money on the project.

The methods to be summarized include:

- electromagnetic conductivity (EM),
- resistivity methods,
- ground-penetrating radar (GPR),
- magnetic surveys,
- gravity surveys, and
- seismic surveys.

Electromagnetic (EM) Conductivity

Terrain Conductivity

Electromagnetic (EM) induction is the most common geophysical technique used for contaminated site investigations. An EM survey is performed by generating an electromagnetic field using a transmitter coil and alternating current. A magnetic field is generated around the transmitter coil and produces the primary field which penetrates the ground and induces a voltage which causes current to flow into a conducting subsurface. The subsurface currents, in turn, create a secondary magnetic field which is measured by a receiver. The electrical field travels through the subsurface at different strengths which is dependent on the ground's conductivity. The presence of metals, ions, or clays increases the ground conductivity *(16)*.

The most commonly used equipment in terrain conductivity is the Geonics EM-31 (with an exploration depth of 5.5 m [18 ft]), the EM-34 (with a variable exploration depth of 8 to 30 m [25 to 100 ft]), and the EM-16 (VLF). This commonly used transmitter/receiver in one, consists of a long pole with the transmitter and receiver separated by a fixed distance of 4 m (12 ft) and a reader meter. The unit can be operated by a single person who walks along a line, called a survey line, reading the meter continuously or at intervals. Conductivity is measured in milli-Siemens per meter (the equivalent of millimhos per meter). (Metal detector readings are generally reported in parts per thousand of the total field *(17.)*

The primary purpose of the conductivity logging system is for the determination of variation in soil conditions with depth, which can then be used to aid in the interpretation of subsurface geology and groundwater or contaminant movement. Cone penetrometer systems also have been used to measure soil resistivity.

Two different electrode arrays can be used with the system—the Schlumberger array and the dipole array. The Schlumberger array reacts linearly to variations in formation conductivity and yields good vertical resolution. The dipole array does not react linearly but has improved vertical resolution due to the more closely spaced electrodes and has the added benefit of only requiring two of the four electrodes, thus allowing the second pair to be used as backup *(18)*.

Penetration/Resolution The detection depth of EM instruments is a function of the transmitter-to-receiver coil separation and the coil orientation (horizontal to vertical). Small coil separation, as in metal detectors and pipe locators, may "see" 1-2 m (2-6 ft) below the surface. Larger coil separations can be used to detect conductive materials up to 100 m (several hundred feet). For the Geonics instruments EM-31, EM-34, and EM-38, the sensitivity dissipates at depths greater than one coil spacing.

Presentation The data is usually plotted in plan view as contours, or in 3-D perspective.

Application EM surveys are used for locating buried metal objects, tanks and drums, utility lines, landfills and trenches, and contaminant plumes. Most EM methods are relatively easy to use, portable, and provide quick results.

Constraints Measurements are affected by power lines, metal objects and debris, metal fences, and utilities.

Metal Detection

Metal detection operates under the same basic principles as other EM surveys. Most metal detection equipment used in site characterization is similar to the common metal detectors found at Radio Shack but are much more refined and much more effective. The most commonly used equipment is the Geonics EM-61 which consists of electronics mounted in a backpack, worn by the operator, that generates a primary EM field in one of two rectangular coils mounted on a trailer *(16)*.

Presentation The data is usually plotted in plan view as profile lines. Some manufacturers have software to plot profile lines.

Application Locating buried metal objects (USTs), or tanks and drums in clay-rich soils may preclude the use of GPR.

Constraints Reinforced concrete is considered problematic for the device. Measurements are affected by metal objects, debris, and utilities. It works best in detecting ferrous metals.

Horizontal Loop EM

Horizontal Loop EM (HLEM) is similar to terrain EM, but it does not read apparent conductivity directly and utilizes in-phase and quadrature data. It is primarily used as a mining exploration tool. It typically has greater depth penetration than terrain EM where overburden is greater than 30 m. HLEM should be considered where the delineation is below 30 m, and the overburden is fairly conductive and relatively uniform *(17)*.

The Apex Parametrics MaxMIN I is the most commonly used HLEM unit used. HLEM is performed by a two-person crew. The penetration is determined by the coil separation. Presentation is generally made in "stacked" profiles *(17)*.

Time Domain EM

Time domain EM (TDEM) is able to "see" through very conductive overburden and is usually applied to environmental problems in the deeper subsurface such as salt water invasion associated with oil field production. TDEM penetration can reach hundreds of meters if the overburden is not excessively conductive.

VLF-EM

Very low frequency (VLF) EM is an inductive technique which measures very low frequency horizontal EM signals from remote military transmitters. VLF-EM can best detect linear, steeply dipping conductors, and large mineralized zones. Its application in site characterization is limited *(17)*.

Resistivity Methods

Resistivity is defined as the resistance to the flow of electrons, or current, caused by the interaction of electrons with the media through which the current flows. Electrical resistivity geophysical methods introduce a known electrical current into the ground and measure the resistance of soils or media over a given distance. Resistivity methods are fundamentally different from EM methods because they require introducing a current into the ground through electrodes. EM methods induce a current in the ground and do not typically require physical contact.

Resistivity methods are among the oldest geophysical techniques. A current of very low frequency (less than 100 Hz) is generated in the field and introduced into the ground using metal electrodes (current electrodes). Additional electrodes (potential electrodes) receive the current at a specific distance from the introduction point. Since the introduced current is known, the difference in current equals the resistivity of the soils. The patterns of the current flow reflect the resistivity of the subsurface.

The resistivity of soils and rock varies substantially, making the resistivity method very useful for differentiating thicknesses of strata and mapping contaminant plumes. For example, porous non-clay materials, such as gravels, have much higher resistivity than silts or clays under similar moisture conditions because the charged surfaces of the fine particles in the clay and silt matrix are much better conductors of electricity. Dry soils typically have higher resistivity than moist soils because the moisture also increases conductance. In the absence of metals, which conduct electronically, formation conductivity is related to the volume and conductivity of thewater in the media. In saturated zones, groundwater conducts through its ions, and so its conductivity depends strongly on the total dissolved solids.

There are three different arrangements of the electrodes in resistivity surveys which are commonly used, known as arrays. The Wenner array consists of four electrodes evenly spaced with the current electrodes on each end. The Schlumberger array consists of the same four electrodes but with the potential electrodes spaced closely and the current electrodes placed at a distance equal to five times the potential electrodes. The dipole-dipole array closely spaces the current electrodes and the potential electrodes; the depth of penetration can be changed with the distance between the current electrode pair and the potential electrode pair (see Figures 9 and 10).

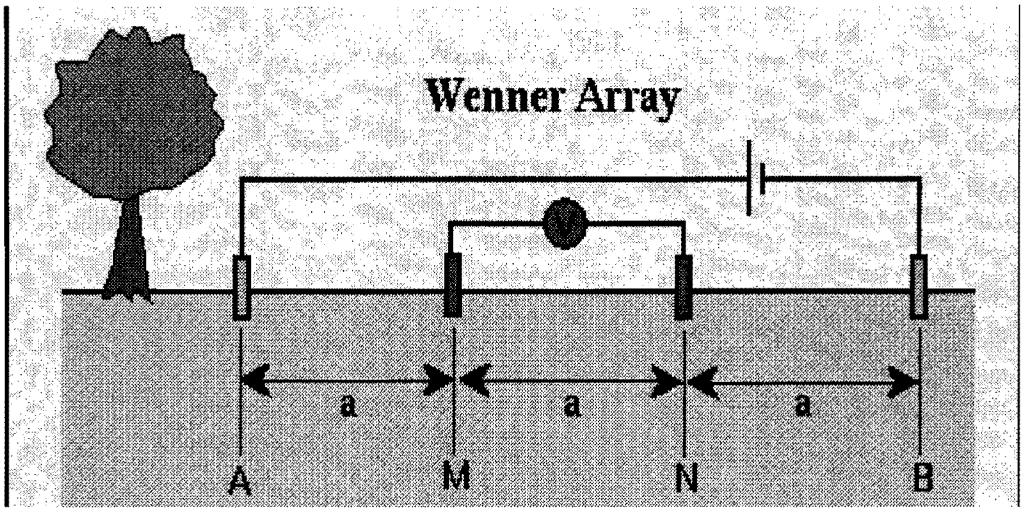


Figure 6. Wenner Array *(18)*.

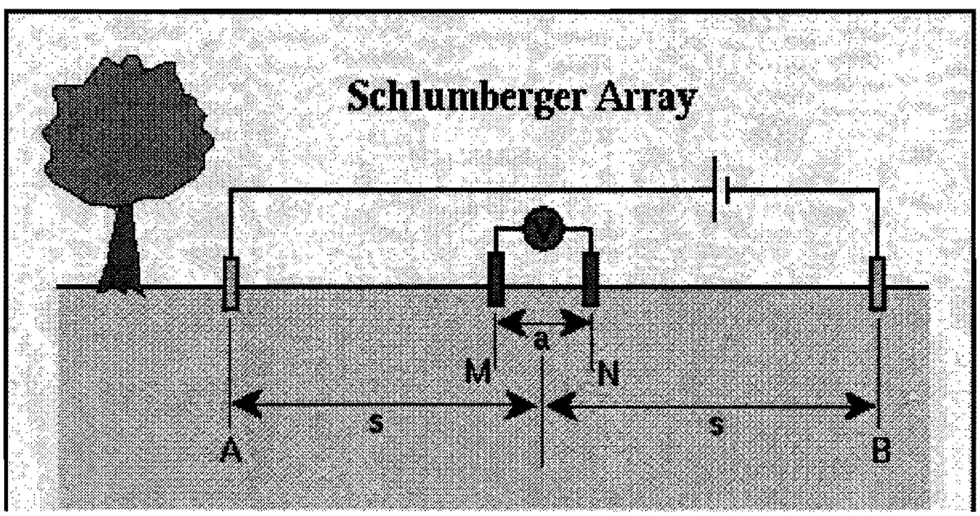


Figure 7. Schlumberger Array *(18)*.

Equipment Compared to the equipment required for gravity surveying and magnetic surveying, requirements for DC resistivity surveying are much less exotic. The equipment used in resistivity methods is relatively inexpensive compared to some other geophysical methods, such as seismic equipment, and usually consists of a power supply (battery pack or generator), transmitter/receiver, wire cable, and current/potential electrodes. Manufacturers include ABEM, Androtex, Bison, Campus, OYO, and Soiltest, but there are many other companies that make this type of equipment. A slowly varying AC current or battery-driven source can be employed for DC resistivity surveys commonly used in engineering and environmental applications.

Soundings and Profiles The resistivity method can detect variations in resistivity that occur solely with depth. In fact, this method is most commonly applied to look for variations in resistivity with depth. Surveys that are designed to determine resistivity variations with depth above some fixed surface location are referred to as **resistivity soundings**. In these experiments, electrode spacing is varied for each measurement. The center of the electrode array, where the electrical potential is measured, remains fixed.

Resistivity surveys can be employed to detect lateral variations in resistivity. Unlike soundings, profiles employ fixed electrode spacings, and the center of the electrode spread is moved for each reading. These experiments thus provide estimates of the spatial variation in resistivity at some fixed electrode spacing. Surveys that are designed to locate lateral variations in resistivity are referred to as **resistivity profiles**.

When doing **resistivity sounding surveys**, one of two survey types is commonly used. For both of these survey types, electrodes are distributed along a line, centered about a midpoint that is considered the location of the sounding. The simplest in terms of the geometry of electrode placement is referred to as a Wenner survey. The most time effective in terms of field work is referred to as a Schlumberger survey.

The current electrodes are at equal distances from the center of the sounding, s. The potential electrodes are also at equal distances from the center of the sounding, but this distance, $a/2$, is much less than the distances. Most of the interpretational software available assumes that the potential electrode spacing is negligible compared to the current electrode spacing. In practice, this is usually interpreted to mean that a must be less than 2s/5 *(18)*.

Penetration using resistivity soundings and profiling is linked to the separation of the current electrodes. Lateral resolution is limited by the spacing of the potential electrodes as well as current electrodes. Vertical resolution is dependent on the type of the conducting environment, but it is typically stated that it is difficult to resolve a layer that is thinner than the depth to its upper surface.

Presentation Profile data are plotted as apparent resistivity versus distance, and sounding data (VES data) are plotted on log-log scaled paper as apparent resistivity versus array. Most interpretation of resistivity data is modeled using software for personal computers.

Constraints The presence of buried pipes or chain-linked fences will act as current sinks. Because of their low resistivity, current will preferentially flow along these structures rather than flowing through the earth. The presence of these nearby conductors essentially act as electrical shorts in the system.

Just as nearby conductors can act as current sinks that short out an electrical resistivity experiment, if the very near surface has a low resistivity, it is difficult to get current to flow more deeply within the earth. Thus, a highly conductive near-surface layer, such as a perched water table, can prevent current from flowing more deeply within the subsurface.

Variations in geology or water content localized around an electrode that produce near-surface variations in resistivity can greatly influence resistivity measurements. In addition, rugged topography will act to concentrate current flow in valleys and disperse current flow on hills.

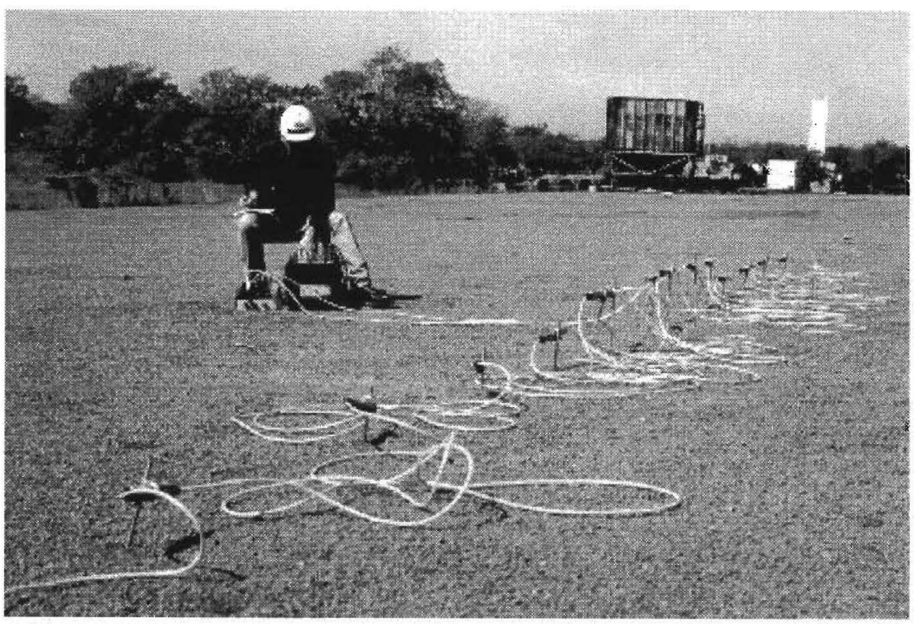


Figure 8. Example of Resistivity Survey.

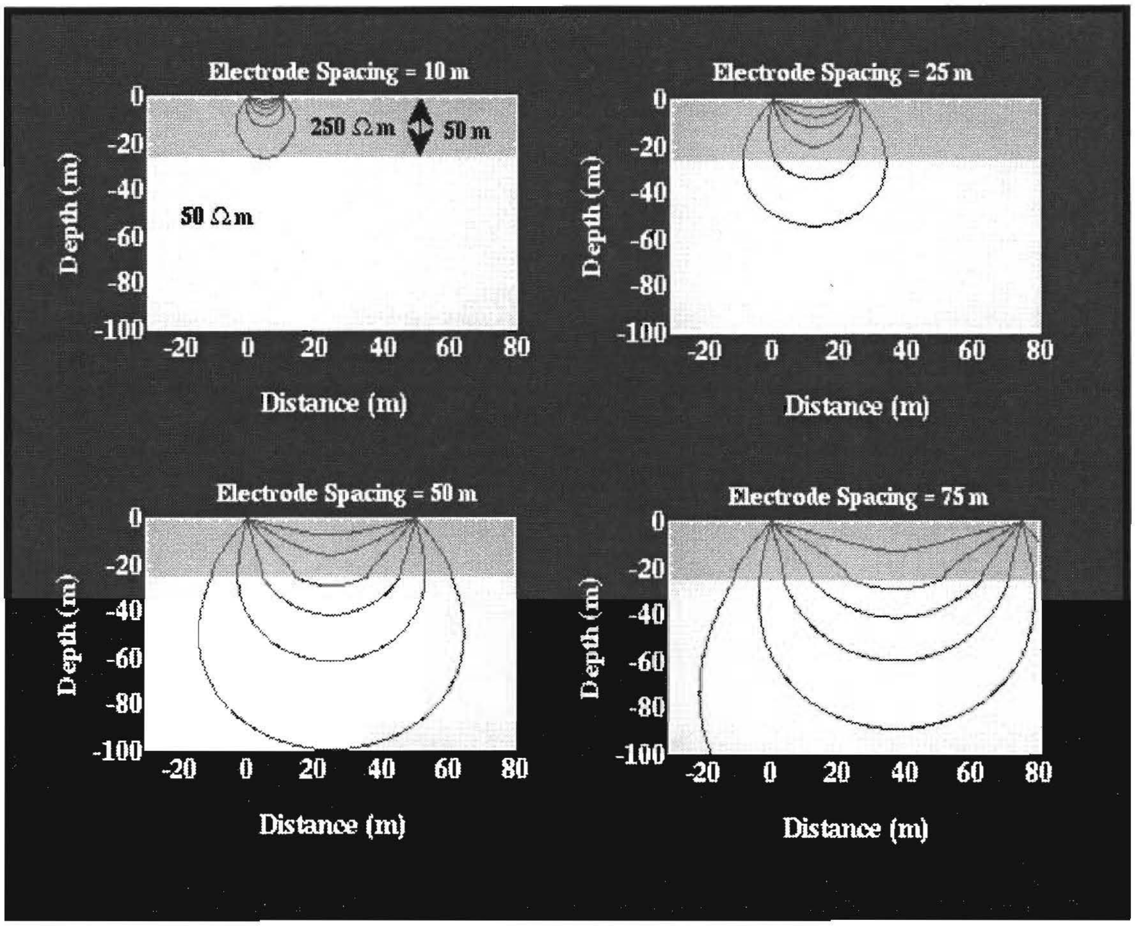


Figure 9. Comparison of Electrode Spacing (18).

Ground-Penetrating Radar (GPR)

Ground-penetrating radar (GPR) evolved from the military applications of radar used during World War II. It is now used for exploration of the subsurface and as a non-destructive testing method. GPR uses pulses of electromagnetic energy emitted into the subsurface and compares the rate of electromagnetic wave propagation through the subsurface to discriminate between earth materials. GPR is commonly used as part of Phase II site investigations to locate underground features such as tanks, pipes, utilities, or other objects. GPR can provide rapid real-time information about the subsurface.

The pulses of electromagnetic energy emitted in GPR are in the range of 10 MHz to 1,000 MHz range (or about 1 to 100 nanoseconds in pulse width), at frequencies where the displacement currents dominate (which depend on the dielectric properties of a material) as opposed to EM methods where conduction currents dominate. The reflected signals are detected by a receiver and recorded as a function of time. The time delay of each wavelet is a function of the propagation of the wavelet through the subsurface media which is dependent on the electrical and magnetic properties of the subsurface. The reflection of radar waves occurs at interfaces having contrasting electrical properties, which is controlled mostly by the materials composition (bulk density) and moisture content. Examples of these reflecting surfaces include soil horizons, soil-rock or air-rock interfaces, water tables, and solid metallic or non-metallic objects *(17)*.

Equipment

GPR equipment consists of a transmitting/receiving unit, a control unit, and a display unit. The transmitter generates short pulses of EM energy into the ground through an antenna. The energy is reflected back to the receiving antenna and the receiver, where the signal is amplified, formatted, stored, and displayed. Most systems operate between 100 MHz and 500 MHz where the frequency is chosen to provide the desired balance between penetration and resolution. The equipment is usually pulled or towed across the ground surface, so a relatively smooth surface is required. The resulting image is a graphic profile of the subsurface, with reflecting surfaces appearing as bands on the profile.

Presentation

The end product is a continuous graphic profile. When travel time/depth relations are known, a depth scale can be substituted for travel time scale on the profile allowing estimation of absolute depths. Data is in a similar format to that of seismic reflection. The degree of data processing is dependent on the objective of the survey, but a simple map that detects anomalies is common for search and locate type surveys. A map showing the traverses should also be included.

Application

GPR can be used to locate buried tanks, utilities, pipes, and drums, and assist in geologic mapping and archeology. It is used in mapping utilities, landfill trenches, caves, sinkholes, re-bar, fill thicknesses, water table, aquifers, fractures, and non-destructive testing.

Figure 10. Hand-Pulled GPR.

Figure 11. Truck-Pulled GPR.

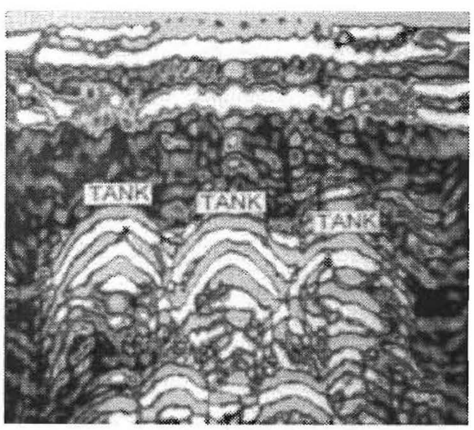


Figure 12. GPR Image No.1.

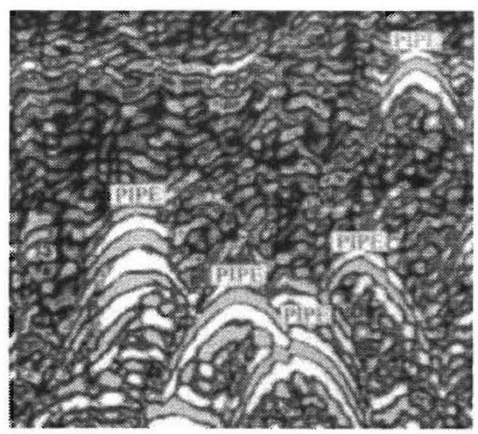


Figure 13. GPR Image No. 2.

Penetration/Resolution

The depth of penetration for GPR is determined by the frequency of the signal pulse. Low-frequency pulses penetrate deeply but do not have the best resolution, whereas higher frequencies will not penetrate as deeply but provide greater resolution. Penetration in low conductivity conditions is to approximately 10 m (32 ft) with most GPR surveys but can extend to as deep as 20 m (65 ft) depending on the antenna and receivers. Antennas with higher frequencies of from 300 to 1,000 MHz obtain reflections from shallow depths (0 to about 30 ft) and have high resolution. These high frequency antennas are used to investigate surface soils and to locate small or large, shallow-buried objects.

GPR penetration is primarily limited by the attenuation of the radar pulse which is determined by the conductivity of the ground. For example, penetration is greater in clean, dry sandy conditions (low conductivity) than in wet clay conditions (high conductivity) where penetration may be less than 1 m. Metal can be seen deeper than concrete or clay objects, which can be seen deeper than plastic, and large objects can be seen further than small objects.

Constraints

Penetration depth can be limited by soil or water with high conductivity, as in wet clays. Clean, non-metallic sands and non-conductive soils yield very good results. Conductive soils like clay, especially wet clay, typically yield bad results. Clean water is practicable, but salt water is very problematic. A relatively smooth surface is needed and as with many geophysical methods, prior knowledge of the site's geology aids significantly in interpreting the results. Surface vegetation can also affect the results. Data interpretation can be complex, and experienced analysis is required.

Magnetic Surveys

The primary objective of magnetometer surveys in relation to environmental site investigations is to locate buried magnetic objects. Magnetometer surveys measure the strength of the earth's magnetic field and are able to detect magnetic anomalies. Magnetometer surveys are a relatively rapid and efficient geophysical method which can be used to detect buried ferrous metal objects. When a ferrous material is placed within a magnetic field, such as the earth's magnetic field, it develops an induced magnetic field. The induced field is superimposed on the earth's field creating a magnetic anomaly. Small objects generate small anomalies (several hundred gammas), and large objects create larger anomalies (over 1,000 gammas). Detection is dependent on the amount of magnetic material present and its distance from the sensor *(17)*.

Because magnetic surveying is generally cheaper than other geophysical methods, magnetic observations are commonly used for reconnaissance. These surveys can cover large areas and are used to identify the locations of targets for more detailed investigations. Because of their cost effectiveness, magnetic surveys usually consist of areal distributions of data instead of single lines of data.

Equipment

Most magnetometer surveys are conducted by a single operator on foot using a hand-held proton or fluxgate magnetometer over a specified grid. For land-based magnetic surveys, the most commonly used magnetometer is the proton precession magnetometer.

The survey can be made over a single line or over a series of parallel traverses with readings taken every 2 to 10 m (6 to 30 ft). The spacing of traverses and readings depends on the width of the expected anomaly. For example, a search for a tank would be conducted at a 2 m (6 ft) spacing, whereas geologic mapping would be on a 20 m (60 ft) spacing.

Penetration/Resolution

The size of the anomaly decreases very rapidly with a depth of the target and limits most single barrel surveys to a depth of about 2 m (6 ft). The horizontal resolution is limited by the width of the anomaly. As a general rule, the anomalous field should be sampled at a spacing no larger than one-half the shallowest depth to the target that is to be resolved. For example, drums buried at 1 m (3 ft), should be made on a half meter grid.

Application

The magnetometer is used to locate buried tanks and drums, geologic mapping, and archeology.

Constraints

Utilities, power lines, buildings, fences, railroad lines, and metallic debris can affect the results. Solar magnetic storms can cause fluctuations in readings. Because any ferromagnetic substance can produce an induced magnetic field in the presence of the earth's main field, the field crew running the magnetic survey must divest itself of all ferrous objects. As a result of this, proton precession magnetometers are typically placed on 2 to 3 m poles.

Gravity Methods

Gravity methods are relatively slow and expensive to undertake for environmental site characterization. They measure the variations in the subsurface resulting from the varying mass and density of differing rock types. The primary application of gravity surveys in site investigations are to delineate buried valleys and overburden troughs in glaciated terrain or locate cavities, but it can also be used in landfill location. The application of gravity methods is generally on a much larger scale to detect large rock masses, bedrock, and very large buried objects. Survey data are easily gathered if a gravity station is established, but the reduction and correction of the data is complex. The measured values must be compared to reference data, and correction must be calculated. The resulting values are called Bouger anomaly values which are mapped using gravity contours. *(19)*

Seismic Survey Methods

The environmental and engineering communities use seismic techniques less frequently than other geophysical techniques. When seismic methods are used in these communities, they tend to emphasize the **refraction** methods over the **reflection** methods. Each of these techniques has specific advantages and disadvantages when compared to each other and when compared to other geophysical techniques. For these reasons, different industries apply these techniques to differing degrees. For example, the oil and gas industries use the seismic reflection technique almost to the exclusion of other geophysical techniques. Of all of the geophysical methods described, the acquisition, processing, and interpretation of seismic observations are the most time, equipment, and manpower intensive. As a consequence, compared to the other geophysical techniques, seismic methods tend to be rather expensive. Because of the expense of these methods, discussion of their use within this report is limited *(17)*.

Refraction Seismology

Refraction experiments are based on the times of arrival of the initial ground movement generated by a source recorded at a variety of distances. Later arriving complications in the recorded ground motion are discarded. Thus, the data set derived from refraction experiments consists of a series of times versus distances. These are then interpreted in terms of the depths to subsurface interfaces and the speeds at which motion travels through the subsurface within each layer. These speeds are controlled by a set of physical constants, called elastic parameters, that describe the material.

Reflection Seismology

In reflection experiments, analysis is concentrated on energy arriving after the initial ground motion. Specifically, the analysis concentrates on ground movement that has been reflected off of subsurface interfaces. In this sense, reflection seismology is a very sophisticated version of the echo sounding used in submarines, ships, and radar systems. In addition to examining the times of arrival of these, reflection seismic processing extracts information about the subsurface from the amplitude and shape of the ground motion. Subsurface structures can be complex in shape but like the refraction methods, are interpreted in terms of boundaries separating material with differing elastic parameters.

Borehole Geophysical

There are several borehole applications for geophysical surveys. The most common are EM induction, resistivity, and SP—self potential. These surveys are conducted most frequently in conjunction with direct push and cone penetrometer testing (CPT) investigative techniques described in the following section.

PLANNING AND IMPLEMENTING GEOPHYSICAL SURVEYS

The result of a geophysical survey is typically a map or image depicting some physical property in space or time. The map itself is not likely to answer any questions about the site but should provide one piece in the puzzle. Most geophysical surveys are used to provide a screening level analysis. A successful survey requires:

- a competent and experienced geophysical consultant/contractor,
- a clear objective, or what information is to be obtained (plume boundaries),
- a realistic expectation and understanding of the results for client and consultant/contractor,
- an understanding of the geologic setting in which the survey will be conducted, and
- an understanding of the contaminant or target in question.

Before undertaking a geophysical survey of any kind there are several fundamental considerations to be made. With the specialization in many tasks and aspects of environmental investigation, it is difficult for an engineer or project manager to have an in-depth understanding of all of the technologies and techniques that can be used to carry out an effective Phase II environmental site investigation and have the expertise to evaluate the proposed methods critically. In many cases, the actual geophysical survey will be conducted by a specialty subconsultant. Therefore, a discussion of these considerations is provided below to assist the engineer, project manager, or consultant in deciding whether to use a geophysical survey method in an environmental site investigation and what to consider when using geophysical methods.

Questions to ask before considering a geophysical survey include:

- What are the limitations of this geophysical survey?
- Do you have proven experience and examples using this geophysical method?
- Exactly what do we want to know about the site?
- What is the objective of the survey? What will the survey tell me?
- Can the target or contaminant be detected using this approach?
- What is the scope, cost, and product to be delivered ?
- What is the timing, duration, and sequence of the survey?
- What contract provisions can provide quality assurance?

Detection and Resolution

The first and most important issue in undertaking a geophysical survey is deciding if the target of the survey can be detected. In order to detect a target (i.e., buried drum, tank, or contaminant), there must be a strong contrast between the physical properties of the target and the medium in which it lies in relation to scale and shape. For example, a metal detector can detect a ferrous nail at 10 cm (4 in), but not at 10 m (30 ft), and a 2 m (6 ft) contaminant plume may be detected in a shallow, unconfined aquifer at a depth of 5 m (15 ft) but not in a confined aquifer at 50 m (150 ft) beneath the surface. Therefore, determine if the target of the survey can be detected.

Once a target is detected, it can also be difficult to obtain an adequate resolution to provide useful detail about the target. For example, detecting the presence of buried drums may be achievable, but the number and size of the drums cannot be determined with the method's resolution. Also, detecting conductivity changes with time in a subsurface groundwater plume can be obtained, but resolving the precise depth at which the changes occur is difficult. One should consider both the horizontal and vertical resolution that can be expected from a particular method.

Sampling, Interference/Noise, and Penetration

As with other methods of site investigation, the interval, spacing, and number of survey lines of geophysical survey sampling play a critical role in detecting the target. Spacing too widely could miss the target, and spacing too narrowly may be expensive and unneeded. In addition, the man-made environment can also interfere with detection or limit investigation parameters.

Fences, power lines, nearby buildings, and buried utilities are just a few of the anthropogenic sources of "noise" that can interfere with detecting the intended target. Vibrations from traffic, wind, and rain can also affect some geophysical measurements.

The penetration of a particular geophysical survey method is dependent on several factors, and the interrelationship of these factors can be very complicated. The expected penetration should be estimated prior to mobilization based on existing knowledge of the site. Penetration should be defined as the maximum depth of detection of a target in a specific environment using a specific geophysical method.

Imaging, Data, and Data Processing

In most environmental geophysics, it is the geology, not the physics, that determines the usefulness of the result. Nearly all geophysical surveys require site-specific geologic reference points and verification. The image presented by the survey is generally a representation of the subsurface, but the geology of the site must be considered when presented with the geophysical imagery. The image is sometimes heavily dependent on the data processing that is used to create it, and it is important to recognize when an image depicting the subsurface is a result of data processing and the processor's subjectivity. The imagery and data should be consistent with existing knowledge of the site.

An untrained eye may not be able to distinguish between good and bad data or imagery. If there is doubt as to the quality of the data and imagery, it is wise to check with other consultants and government agencies to verify if the data and imagery are sound or suspect. Excessively noisy data may occur, and the site will need to be re-surveyed. It is also important to be assured that the field technicians and scientists are experienced in the survey technique because the data, in some cases, is only as reliable as the technician or scientist conducting the survey. Potential problems such as these should be addressed in the scope of work and contract documents by prescribing an acceptable level of quality for the data and the imagery.

Questions to ask after the survey is completed include:

- Did the survey meet its objectives?
- Is the interpretation reasonable and consistent with the site geology?
- Is the data and imagery understandable and not too complex?
- Would additional survey work add value to the site investigation?

Table 16 on the following page is a matrix comparing the most commonly used geophysical methods discussed in this report.

Table 16. Comparison Matrix of Geophysical Survey Methods for Environmental Site Investigation.

	Terrain Conductivity (EM)	Metal Detection	Resistivity Methods	Ground Penetrating Radar (GPR)
Uses	Map contaminant plumes, locate buried conductive items, locate landfills, trenches	Locate buried ferrous metal objects	Measure bed thickness. Map contaminant plumes, location of aquifers	Locate buried objects, utilities, map lithology, fractures, locate landfills
Advantages	Fast, easy, portable, fair penetration, commonly used, relatively inexpensive	Fast, easy, portable. Works in clay rich soils, relatively low cost	Good lateral/vertical resolution, good penetration	Fast, relatively easy, portable, relatively inexpensive
Disadvantages/ Constraints	Affected by power lines, fences, utilities, other metal objects	Affected by concrete re-bar, fences, utilities, other metal objects	Labor intensive, buried pipes, metal fences, rugged topography	Not suitable in clays and wet clays, need smooth surface
Suitable for Metallic Waste	Yes	Yes	Sometimes	Usually
Suitable for Inorganic Waste	Yes	na	Yes	Sometimes
Suitable for Organic Waste	Sometimes	na	Sometimes	Sometimes
Suitable for Inorganic Plumes	Yes	na	Yes	Sometimes
Suitable for Organic Plumes	Sometimes	na	Sometimes	Sometimes
Suitable for Site Geology	Yes	na	Yes	Yes
Suitable in Clayey Soils	Usually	Yes	Yes (depends on objective)	Seldom
Penetration	Depends on coil spacing (.5 to 60 m typical)	Typically 6-20 m	Depends on spacing (typically 2-30 m)	Typically 1-10 m
Resolution	Excellent lateral resolution. Vertical good, except thin layers	Good ability to locate targets	Good vertical resolution	Excellent resolution
Cost Relative to 1 Day of Drilling*	Slightly more	Usually same or less	Usually More	Slightly More

*Geophysical survey costs are generally equivalent to drilling when considering that geophysical surveys can collect more data over a greater area, but one should weigh the relative costs and benefits of any investigative method.

Source: 1998 SAGEEP - Introduction to Environmental and Engineering Geophysics, notes by J. Greenhouse, P. Gudjurgis, and D. Slane.

SOIL AND GROUNDWATER INVESTIGATION TECHNOLOGY

Most conventional soil investigation techniques involved the use of an auger to advance the drill string and sampling tools. In the past several years, a soil investigation method commonly referred to as "direct push" has become more common in environmental site investigations. This method hydraulically "pushes" small diameter hollow steel rods and measuring devices into the ground without the use of drilling augers to remove soil or to make a path for the tool. It can be used in most materials that can be augered or sampled with a split spoon. Direct push equipment relies on a relatively small amount of static weight combined with percussion/vibration as the energy for advancement of a tool string in contrast to use of conventional rotary augers. This technique is sometimes referred to as a Geoprobe, or Enviro-Core, after the manufacturers of the most commonly used direct push devices.

Direct push can drive tools to obtain continuous soil cores, discrete soil and groundwater samples, soil vapor samples, or advance a variety of sensory probes. The maximum penetration depth is 30 m (100 ft), but in most cases, the probes used penetrate to depths of 9-18 m (30-60 ft). Penetration can be limited by hard or dense formations, boulders, gravels, or massive bedrock in the subsurface. Direct push works best in unconsolidated materials such as soils, clays, sands, and alluvial deposits.

The advantages of direct push include:

- It is accepted as a good preliminary screening tool and can collect representative soil and groundwater samples.
- Its commercial availability is widespread at a relatively low cost.
- No drill cuttings are produced during probe advancement and, therefore, waste disposal from soil investigations is minimized.
- Probing and sampling is performed as fast or faster than conventional auger drilling.
- Smaller holes are created by the probes so grouting is faster and easier.
- A variety of sampling and sensory tools are available to help analyze the subsurface conditions.

The limitations of direct push include:

- It provides one-time samples only.
- It cannot be used in very gravelly or dense consolidated formations.
- Samples must be taken 1 m (3-5 ft) below the water surface, meaning LNAPLs might be missed if floating near the surface.
- Small diameter well screens may be hard to develop and/or not representative in response to regulatory requirements.

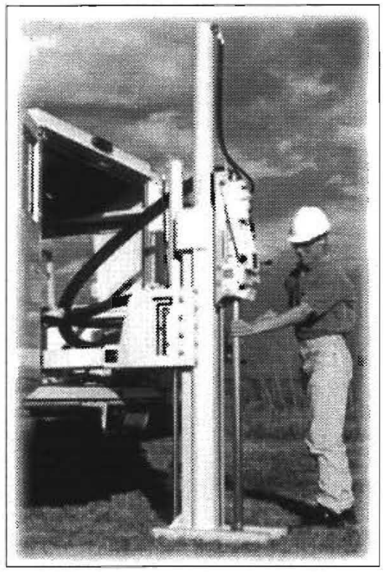


Figure 14. Truck-Mounted Geoprobe *(20)*.

There are four commonly used products in direct push technology:

- direct push soil sampling,
- direct push water sampling,
- cone penetrometer testing (CPT), and
- laser-induced fluorescence (LIF).

Soil samples are collected by driving small diameter casing with an inner sample barrel. Continuous soil samples can be collected using either plastic or steel sample liners. Water sampling can be accomplished through temporary or permanent well installation with direct push technology. The well is assembled and installed through the probe rods and constructed with prepacked screens and well riser. Conventional flush-mount or aboveground well protection can be installed, or temporary wells can be removed and the holes grouted. Temporary type wells can provide accurate water level measurements and can be used as observation wells during aquifer pump tests, in most situations. When installed properly, these small diameter wells generally meet regulatory requirements for a permanent monitoring well.

Other CPT applications include the use of EM induction, resistivity, and SP in downhole tools. These tools use the same basic principals as the surface geophysical surveys except they may enhance penetration, resolution, and ease of operation.

Cone Penetrometer Testing (CPT)

The cone penetrometer is a truck-mounted sampling device used to penetrate the ground to collect samples. Although used in geotechnical investigations for many years, CPT is relatively new in environmental applications. CPT typically consists of an enclosed 20-40 ton truck with vertical hydraulic rams used to force a sensor probe into the ground, although some CPT equipment can be mounted on lighter weight trucks. The trucks are equipped with a computer and data, and signal processing equipment. CPT works best in soft soils, whereas hard consolidated materials and gravels are problematic. Sampling cones allow for in situ sampling of liquids and gases. The operational cost is moderately expensive ($3,000 per day) depending on the array of sensors used during the investigation. Although the cost is somewhat more than conventional drilling, samples are available very quickly; real-time data is achievable, and the amount of waste generated is small compared to drilling (*21*). Similar to direct push, there are several benefits to using CPT:

- CPT is less intrusive than conventional drilling because the CPT hole is relatively small, and there are no drill cuttings to dispose of.
- Decontamination of the push rods is easier than conventional drilling.
- A grout-pumping system allows grouting of the CPT hole through a port in the cone tip as the penetrometer probe and push rods are withdrawn.

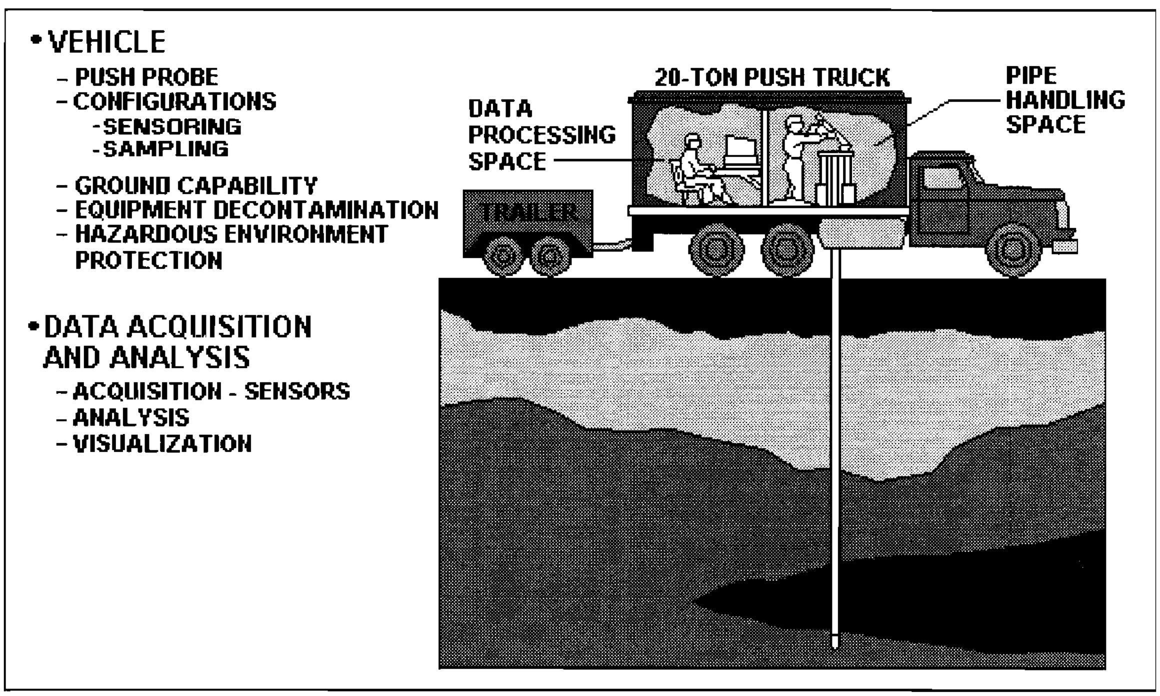


Figure 15. CPT Diagram *(16)*.

ASTM has developed, or is developing, standardized methods for the use of CPT for environmental applications. These include:

- D-3441-95, Test Methods for In Situ Penetration Tests of Soils,
- D 5778, Test Methods for Performing Electronic Friction Cone and Piezocone Penetration Testing of Soils, and
- D 6067, Guide for the Electronic Cone Penetrometer for Environmental Site Characterization.

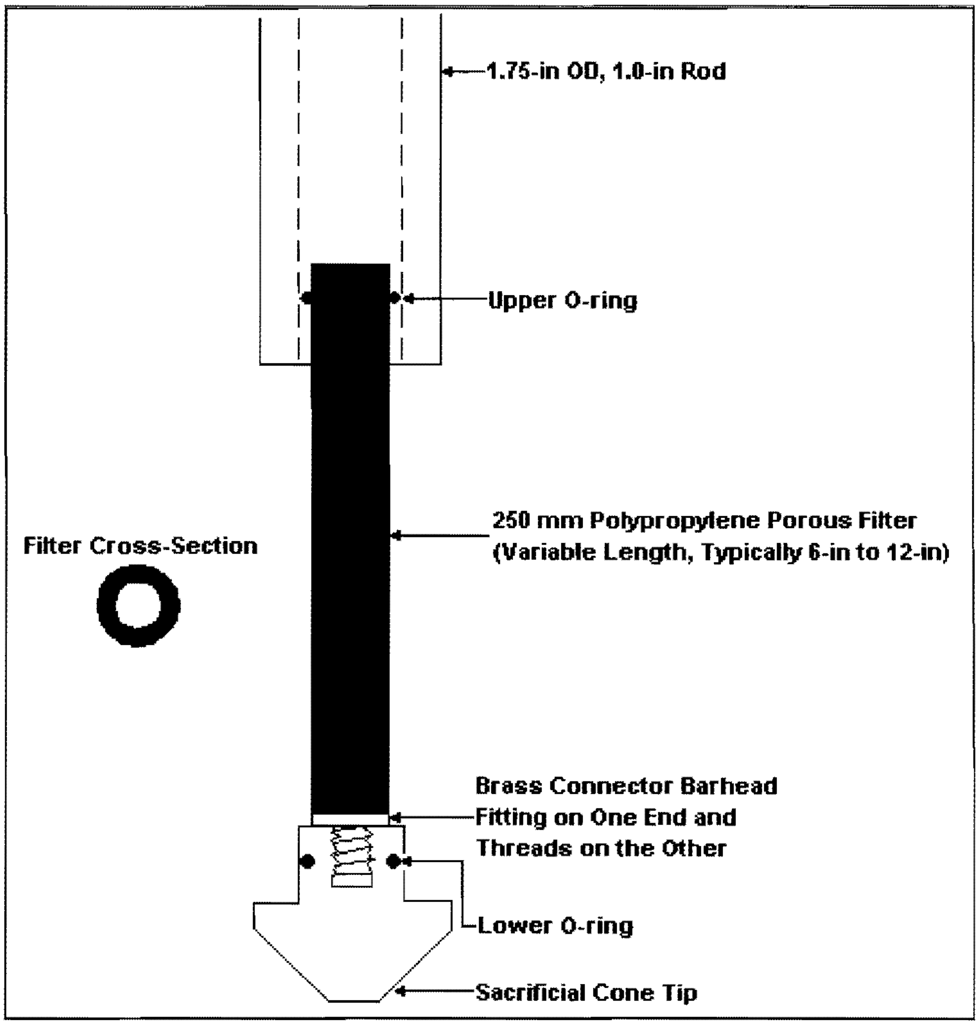


Figure 16. CPT Tool Diagram (*16*).

The CPT sensor includes the cone and sleeve which is the penetrometer portion of the tool that is used to profile the subsurface stratigraphy through strength measurements. (See ASTM D-3441-86.) Other sensor tools that may be used in conjunction with CPT include:

- laser-induced florescence (LIF) (SCAPS Probe),
- rapid optical screening tool (ROST ™) (Fugro Geosciences, Inc.),
- time domain reflectometry (TDR),
- soil resistivity/soil conductivity,
- fiber-optic RH probe, and
- radiation probes.

Laser-induced florescence (LIF) site characterization analysis penetration system (SCAPS) was developed for CPT to detect hydrocarbons (i.e., diesel fuel, gasoline, oils, etc.) by the U.S. Army under a Tri-Service agreement at the U.S. Army Waterways Experiment Station (WES) in Vicksburg, Mississippi. Another CPT tool similar to LIF is the rapid optical screening tool (ROST ™). ROST is a proprietary sensor used in conjunction with CPT to provide real-time logging of stratigraphy and delineation of hydrocarbons.

The initial development of LIF was based on the fluorometric method of detecting hydrocarbons. LIF consists of a nitrogen laser that generates bursts of UV light which are directed down an optic fiber threaded through CPT connecting rods to an optic window on the side of the probe. The UV light then passes through the window and enters the soil. If hydrocarbons are present in the soil, then a chemically induced blue-green color fluorescence is generated. This fluorescence enters back into the window, is captured by a second optic fiber and brought back to the ground surface to an optical spectrum analyzer. The color (i.e., fluorescence wavelength) defines the hydrocarbon type, and light intensity infers chemical concentration in terms parts per million (ppm). CPT and LIF combine to provide an empirical estimate of the soil stratigraphy, resistivity, and petroleum contamination.

The optimum application of CPT is at sites requiring geological, hydrological, and geochemical characterization where the subsurface can be penetrated using forces up to 40,000 pounds. Sites that typically can be characterized with CPT contain near-surface unconsolidated sediments (except those characterized as difficult to drill, i.e., where large boulders or cemented layers exist). CPT has been applied at sites as deep as 90 m (300 ft), but is generally applied to depths up to 50 m (150 ft).

CPT's best application is as a screening tool to provide initial site characterization data, which are confirmed by collecting samples that are then analyzed in the laboratory. Sites that contain petroleum hydrocarbon contamination can be screened using either the LIF or ROST™ sensors, thus providing rapid characterization of the subsurface contaminant plume. Data collected from CPT sensors can be used to reduce the number of monitoring wells required during site characterization investigations by collecting subsurface soil, soil gas, groundwater, and various chemical and geophysical readings.

CPT allows for better selection of locations for installation of monitoring wells because a greater density of characterization samples can be collected for the same or less cost. CPT can also be used to place monitoring devices in the subsurface.

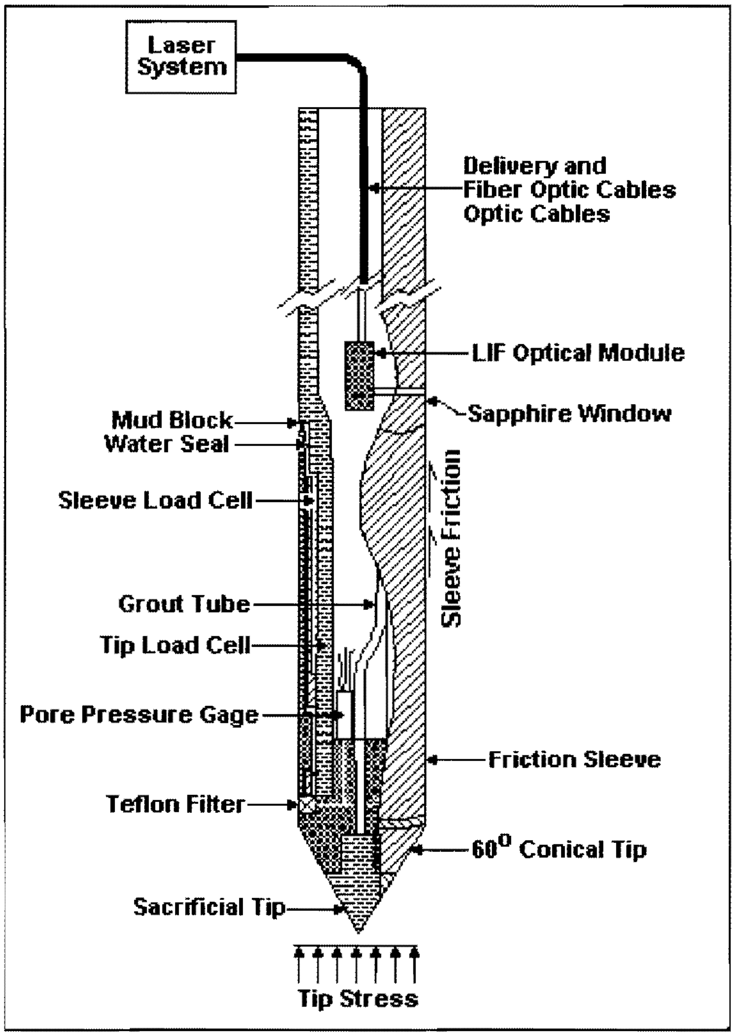


Figure 17. LIF Tool Diagram *(16)*.

Soil Gas Measurement

There are several procedures that can be used to analyze soil gas in order to detect volatile organic compounds (VOCs) in the substrate. Soil gas surveys are an effective way to screen and map the extent of VOCs, particularly low molecular weight halogenated compounds (solvents). All of the soil gas measurement techniques should be used as a screening tool. They can be used to measure relative quantification of volatile COCs but are generally not suitable for a definitive quantification, in most cases. However, in some cases, soil gas measurement is the only practical means to acquire data, such as when the size and shape or density of the soil and rock in the subsurface prevent the use of coring devices *(16)*.

On-site analysis of soil gas can be made using a field gas chromatograph (GC), photo-ionization detector (PID), flame ionization detector (FID), organic vapor analyzer (OVA), or even less sensitive combustible gas detectors. Soil gas samples can be collected in "tedlar" bags or containers for transport to a laboratory for analysis on conventional GC or mass spectrometer (MS). As with most analytical techniques, the greater the accuracy and sensitivity, the higher the cost and data quality. Field measurements do not typically yield absolute values but are useful for obtaining relative values used in the screening process, whereas, laboratory analysis yields a higher level of data quality that is defensible *(22)*.

Soil gases generally follow the path of least resistance and diffuse directly upward, and to some extent laterally from the source. VOCs exist in soils in either a gaseous phase, liquid (dissolved) phase, or solid (adsorbed) phase. The phase distribution is controlled by the VOC's physiochemical properties such as solubility (Henry's Law constant), soil properties, and environmental variables (temperature, water content, organic carbon content) *(22)*.

Soil vapor surveys can be affected by soil and atmospheric conditions at the site, so caution must be exercised when interpreting the results (see Table 18). The composition of vapor measured in any particular location may not be representative of the typical soil mass at nearby locations because of varying diffusion rates, sorption rates, soil composition, oxygen and carbon dioxide content, and other physical parameter in the soil. Atmospheric conditions, moisture content, and soil composition may not only affect soil physical properties that influence soil gas measurement, but they may also affect some of the instruments used to detect the soil gases. The use of field FID and PID instruments is a rapid and economical means for measurement but only yields a reading in relative units and is highly dependent on their calibration and, in many instances, weather conditions.

Three common soil gas measurements used in Phase II environmental site investigations are summarized in Table 17. Soil headspace measurement and soil core screening should be routinely performed on soil samples collected in the field either obtained from drilling, direct push, or hand sampling methods. The data from headspace measurements are often used to select a particular soil sample for further laboratory analysis. The same may be true for soil core screening. Soil gas measurement values are typically recorded on the drilling or sampling logs.

Soil gas survey data and headspace measurements from soil borings can be used to predict the occurrence of volatile soil gasses that may be encountered during construction and excavation. This can be a useful screening method to identify areas of concern where construction worker exposure will likely occur and estimate concentrations. However, it may not be possible to precisely predict if Occupational Safety & Health Administration (OSHA) permissible exposure limits (PELs) will be exceeded based on soil gas data from soil borings prior to construction. As previously stated, there are many factors that may affect soil gas measurement, and direct measurements at the construction site may be required to determine construction worker exposure.

Soil gas surveys, just as other investigative techniques, may require more planning and a detailed scope of work to ensure the desired outcome. When considering the use of a soil gas survey and developing a scope of work for soil gas surveys, it may be helpful to refer to ASTM D5314-92 *Standard Guide for Soil Gas Monitoring in the Vadose Zone*, ASTM D4700-91 *Standard Guide for Soil Sampling from the Vadose Zone*, or ASTM D5730-96 *Standard Guide for Site Characteristics for Environmental Purposes with Emphasis on Soil, Rock, the Vadose Zone and Groundwater (23, 24).*

Table 17. Common Soil Gas Measurement Techniques.

Application	Uses	Methods	Benefits	Limitations
Soil Vapor Surveying	Identify sources and extent of gross contamination, distinguish between soil and groundwater contamination, detect VOCs beneath paved surfaces	Sampling from soil probes into canisters, bags, or direct measurement in soil using PID, OVA, FID, GC, etc.	Rapid inexpensive screening	False positives and negatives, missed detection of small spills, disequilibrium between adsorbed and vapor phase VOC concentrations
Soil Headspace Measurement	Able to screen large numbers of samples	Measure headspace above containerized soil sample, such as plastic bag, VOA vials, using PID, OVA, GC, etc.	More representative of adsorbed solid phase concentration	Losses of vapor phase component during sampling and sample transfer
Soil Core Screening	Soil cores are screened to locate depth where highest VOC levels are located	Collect core samples and scan for vapors near core surface using portable monitor	Convenient way to collect soil from "hot spots" in cores	False negatives and positives, environmental/weather condition can influence readings

Source: Boulding, R., Ed. 1996. EPA Environmental Assessment Sourcebook, Ann Arbor Press, 1996. (p. 260).

Table 18. Factors Affecting VOC Concentrations in Soil.

VOC Chemical Property	Abbreviation	Unit	Effect on VOC Concentration	Reference
Solubility	C_W	mg/l	affects fate and transport, influences organic carbon partition coef	Roy and Griffin, 1985
Henry's Constant	K_H	atm-m^3/mole	Constant of proportionality between water and gas phase concentration, temperature and pressure dependent	Shen and Sewell, 1992
Vapor Pressure	v.p.	mm Hg	affects rate of loss from soil	Shen and Sewell, 1992
Organic Carbon Partition Coef	K_{oc}	mg VOC/g C	adsorption coefficient normalized for soil organic content	Farmer et al., 1980
Octanol/Water Partition Coef	K_{ow}	mg/VOC/mg octanol	equilibrium constant for distribution of VOC between water and an organic phase	Voice and Weber, 1983
Boiling Point	b.p.	deg C	affects co-evaporation	
Soil Property				
Total Organic Carbon	TOC	mg C/g soil	important partitioning medium for hydrophobic (high Koc) VOCs, sorption of VOCs in this medium may be irreversible	Chiou et al., 1988
Particle Size/ Texture	A	% sand, silt, clay	affects infiltration, penetration and mobility, influenced hydraulics and surface-area sorption	
Bulk Density	p_b	g/cm^3	used in estimating mobility and retention of VOCs in soils, will influence sampling device selection	Spencer, 1988
Porosity	n	%	Void volume to total volume ratio, affects volume concentration, retention, migration in voids	Farmer et al., 1980
Percent Moisture	Θ	%	affects hydraulic conductivity of soil and sorption of VOCs, determines dissolution and mobility of VOCs in soil	Farmer et al., 1980
Hydraulic Conductivity	K	m/d	affects viscous flow of VOCs in soil water, depending on degree of saturation, gradients, and other physical factors	
Environmental factors				
Relative Humidity	R.H.	%	Affects movement, diffusion, and concentration, could be site-specific and dependent on surface-air interface differential	
Temperature	T	deg C		
Barometric Pressure		mm Hg		
Wind Speed		knots	relevant to speed , movement and concentration, diffusion from soil	

From: Boulding, Russell ed. - EPA Environmental Assessment Sourcebook, Ann Arbor Press, 1996, (p. 251).

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The review of site investigation technology conducted on the Internet and World Wide Web utilized the following resources.

Web Site Name - Description	URL
ETV Site Characterization & Monitoring Technologies Pilot	http://www.epa.gov/etv/plt-02.htm
Remediation Technologies Screening Matrix and Reference Guide Table of Contents	http://www.frtr.gov/matrix2/section1/toc.html#Sec1
National Center for Environmental Assessment (NCEA)	http://www.epa.gov/ncea/
U. S. Department of Energy - Environmental Management	http://www.em.doe.gov/
Definition of Environmental Restoration Program Requirements	http://www.em.doe.gov/define/
Hazardous Waste Clean-up Information Site	http://www.clu-in.com/
Federal Remediation Technologies Roundtable Field Sampling and Analysis Technologies Matrix	http://www.frtr.gov/site/toc.html
EPA - National Center for Environmental Research and Quality Assurance	http://es.epa.gov/ncerqa/qa/index.html
Symposium on the Application of Geophysics to Engineering and Environmental Problems	http://www.sageep.com/
GeoModel, Inc.	http://www.geomodel.com/
Pacific Northwest Laboratories	http://www.pnl.gov/etd/
Georadar	http://www.georadar.com/
Colorado School of Mines, Introduction to Geophysics	http://www.mines.edu/fs_home/tboyd/GP311/jind.html?
Syracuse Research Corporation	http://esc.syrres.com/
Mount Sopris Instruments	http://www.mountsopris.com/
EPA Richland Environmental Restoration Project	http://www.bhi-erc.com/

APPENDIX A - CHECKLISTS

- **PHASE II ENVIRONMENTAL SITE INVESTIGATION PROCESS CHECKLIST**

- **ECOLOGICAL RISK ASSESSMENT CHECKLIST**
  Figure : 30 TAC §350.77(b)
  TIER 1: Exclusion Criteria Checklist

PHASE II ENVIRONMENTAL SITE INVESTIGATION PROCESS CHECKLIST

STEP 1	**EVALUATE SITE TO DETERMINE IF PHASE II IS NECESSARY**

☐ **Screening Evaluation for Phase II**

__Very Low Potential for Project Impact - No further assessment needed.
__Low Potential for Project Impact - No further assessment is needed.
__Medium Potential for Project Impact - Possible site investigation needed.
__High Potential for Project Impact - Site investigation needed.

Project Comparison Matrix

Potential for Project Impact	Alternative A Site _____	Alternative B Site_______	Alternative C Site_______
High			
Medium			
Low			
No			

STEP 2	**PLANNING A PHASE II ENVIRONMENTAL SITE INVESTIGATION**

☐ **State the Purpose and Objective:**_______________________________________

☐ **Review Existing Information, Site Conditions, and Site Limitations**

__Previous Phase I reports
__Regional/site setting and previous Phase II reports
__Other reports
__Regulatory review
__Existing site conditions & receptor survey
__Identify site limitations contaminant concentrations and distribution

STEP 3 DEVELOP A CONCEPTUAL MODEL FOR THE STUDY AREA

- ☐ **Background concentrations and PCLs**
- ☐ **Source(s) of contamination**
- ☐ **Migration pathways (groundwater, surface water, soil, biotic pathways)**
- ☐ **Factors affecting contaminant transport (including direction and rate)**
- ☐ **Potential receptors (human and ecological)**

STEP 4 DEVELOP A SCOPE OF WORK

- ☐ **Provide a general description of the proposed project**
- ☐ **Provide the type of investigation to be undertaken (subsurface, surface, multi-media)**
- ☐ **Describe the methods of investigation to be used**

  __equipment to be used (Direct push - Geoprobe, GPR, rotary auger, etc.)
  __expected size and depth for the installation of soil borings
  __size, construction, and completion of wells

- ☐ **Present a sampling plan or strategy (also see data quality objectives process)**

  __analytical methods and parameters
  __frequency and depth of samples
  __chemical analysis - analytical parameters for samples
  __allowances and contingencies for additional sampling

- ☐ **Prepare an action plan for unexpected conditions including:**

  __who makes the field decisions - name and contact of field supervisor
  __who should be notified of unexpected conditions/emergencies
  __ maximum dollar amount of additional work resulting from unexpected conditions

- ☐ **Schedule for completion of work**

  __working hours
  __access schedule

- ☐ **Baseline assumptions of expected conditions and responsibilities**

  __responsibility for regulatory notifications
  __responsibility for locating utilities
  __responsibility for disposal of wastes
  __site access
  __safety plan

STEP 4	DEVELOP A SCOPE OF WORK....(CONTINUED)

- ☐ **State the desired report format**
  __establish the information to be reported
  __establish the regulatory body or intent the report should be used for
  __state the purpose of the report, why it is being prepared
  __establish the number of copies of the report needed
  __determine who will receive the report
  __determine how many additional copies of the report are needed
  __determine the need for review or draft reports

- ☐ **On-site kick-off meeting prior to mobilization (if appropriate)**

STEP 5	CHARACTERIZE THE SITE - COLLECT SAMPLES & DATA

- ☐ **Soil Assessment**
  - ☐ Method of obtaining sample
  - ☐ Soil description and characteristics
  - ☐ Chemical constituents analyzed for the COC (e.g., benzene, toluene, etc.)
  - ☐ Geotechnical analysis (e.g., bulk density, fraction organic carbon, etc.)
  - ☐ Soil samples from the following depths:
    - 0-2 ft if affected soil is not covered
    - 2-15 ft
    - greater than 15 feet (if depth to water is less than 15 ft)
  - ☐ Percent of affected soil zone covered with impervious cover
  - ☐ Public access to the affected surface soil (0-2 ft) that is not covered
  - ☐ Affected soil zone thickness
  - ☐ Affected soil zone surface area dimensions
  - ☐ Maximum depth of contamination exceeding appropriate screening levels (PCLs)
  - ☐ Estimated volume of soil exceeding screening levels (PCLs)
  - ☐ Distance from affected soil zone to property boundary
  - ☐ Distance contaminated soil extends beyond property boundary

STEP 5 CHARACTERIZE THE SITE.....(CONTINUED)

- ☐ **Groundwater Assessment**
  - ☐ Method of sampling
  - ☐ Description of water bearing zone
  - ☐ Number of wells sampled, screened interval, well construction
  - ☐ Chemical constituents analyzed for the COC (e.g., benzene, toluene, etc.)
  - ☐ Depth, base, and thickness of water bearing zone
  - ☐ Distance from edge of plume to property boundary
  - ☐ Areal extent of water bearing zone
  - ☐ Groundwater quality/total dissolved solids
  - ☐ Groundwater classification (category 1, 2, or 3)
  - ☐ Inorganic parameters (e.g., dissolved oxygen)
  - ☐ Aquifer type (perched, confined, unconfined)
  - ☐ Water level fluctuations
  - ☐ Gradient (ft/ft)/direction
  - ☐ Saturated hydraulic conductivity (ft/day)
  - ☐ Approximate well yield (gpd)
  - ☐ Geologic formation/major/minor aquifer name

- ☐ **Surface Water Assessment**
  - ☐ Surface water samples should be collected when contaminant migration is known or suspected to affect a surface water body, especially if the project may use or impact surface waters.

- ☐ **Receptor Survey**
  - ☐ identify potential receptors and exposure pathways
  - ☐ field survey and a water well records inventory
  - ☐ migration pathways

- ☐ **Ecological Risk Assessment** (See TNRCC Checklist)
  - ☐ Provide a description of the area and the nature of the release
  - ☐ Identify environmental media known or suspected to contain COCs
  - ☐ Provide the information for the nearest surface water body
  - ☐ Identify where COCs have migrated via runoff or groundwater discharge
  - ☐ Identify the affected property
  - ☐ Identify COCs are in the soil below the first 5 ft beneath ground surface or barriers that prevent migration

STEP 6	EVALUATE DATA AND REFINE CONCEPTUAL MODEL

- ☐ Data objectives are met; screening samples are verified
- ☐ Regulatory objectives and requirements are met
- ☐ Conceptual model is complete
- ☐ Additional sampling data is **not** needed
- ☐ Additional data/sampling is needed; return to **Step Four**

STEP 7	ISSUE REPORTS

- ☐ Issue Field Report
- ☐ Issue Final Report

Note: As a general rule, more numerous sample points at a lower level of data quality can provide a better understanding of site conditions than fewer data points at a higher data quality level. As such, field screening can offer a bigger bang for the buck, especially when assessing large areas. The more quantitative the analysis, the lower the detection limit, the more accurate the results, and the more costly the analysis is to perform. Consider using the use of the Data Quality Objectives (DQO) process as a tool to select the appropriate mix of qualitative (screening) and quantitative (laboratory analysis) methods. Also consider using or incorporating aspects of the Dynamic Work Plan Process.

ECOLOGICAL RISK ASSESSMENT CHECKLIST

Figure: 30 TAC §350.77(b)

TIER 1: Exclusion Criteria Checklist

This exclusion criteria checklist is intended to aid the person and the TNRCC in determining whether or not further ecological evaluation is necessary at an affected property where a response action is being pursued under the Texas Risk Reduction Program (TRRP). Exclusion criteria refer to those conditions at an affected property which preclude the need for a formal ecological risk assessment (ERA) because there are **incomplete or insignificant ecological exposure pathways** due to the nature of the affected property setting and/or the condition of the affected property media. This checklist (and/or a Tier 2 or 3 ERA or the equivalent) must be completed by the person for all affected property subject to the TRRP. The person should be familiar with the affected property but need not be a professional scientist in order to respond, although some questions will likely require contacting a wildlife management agency (i.e., Texas Parks and Wildlife Department or U.S. Fish and Wildlife Service). The checklist is designed for general applicability to all affected property; however, there may be unusual circumstances which require professional judgment in order to determine the need for further ecological evaluation (e.g., cave-dwelling receptors). In these cases, the person is strongly encouraged to contact TNRCC before proceeding.

Besides some preliminary information, the checklist consists of three major parts, **each of which must be completed unless otherwise instructed.** PART I requests affected property identification and background information. PART II contains the actual exclusion criteria and supportive information. PART III is a qualitative summary statement and a certification of the information provided by the person. **Answers to both PARTS I and II should reflect existing conditions and should not consider future remedial actions at the affected property, although it is understood that, at a minimum, human health will always be protected.** Completion of the checklist should lead to a logical conclusion as to whether further evaluation is warranted. Definitions of terms used in the checklist have been provided, and users are strongly encouraged to familiarize themselves with these definitions before beginning the checklist.

Name of Facility: ______________________________

Affected Property Location: ______________________________

Mailing Address: ______________________________

____

____

____

TNRCC Case Tracking #s: ______________________________

Solid Waste Registration #s: ______________________________

Voluntary Cleanup Program #: ______________________________

EPA I.D. #s: ______________________________

Figure: 30 TAC §350.77(b) continued

PART I. Affected Property Identification and Background Information

1) Provide a description of the specific area of the response action and the nature of the release. Include estimated acreage of the affected property and the facility property, and a description of the type of facility and/or operation associated with the affected property. Also describe the location of the affected property with respect to the facility property boundaries and public roadways.

____

Attach available USGS topographic maps and/or aerial or other affected property photographs to this form to depict the affected property and surrounding area. Indicate attachments:

❒ Topo map ❒ Aerial photo ❒ Other ____________________

2) Identify environmental media known or suspected to contain chemicals of concern (COCs) at the present time. Check all that apply:

Known/Suspected COC Location	Based on sampling data?	
❒ Soil ≤5 ft below ground surface	❒ Yes	❒ No
❒ Soil >5 ft below ground surface	❒ Yes	❒ No
❒ Groundwater	❒ Yes	❒ No
❒ Surface Water/Sediments	❒ Yes	❒ No

Explain (previously submitted information may be referenced):

____

3) Provide the information below for the nearest surface water body which has become or has the potential to become impacted from migrating COCs via surface water runoff, air deposition, groundwater seepage, etc. Exclude wastewater treatment facilities and stormwater conveyances/impoundments authorized by permit. Also exclude conveyances, decorative ponds, and those portions of process facilities which are:

a. Not in contact with surface waters of the State or other surface waters which are ultimately in contact with surface waters of the State; and

b. Not consistently or routinely utilized as valuable habitat for natural communities including birds, mammals, reptiles, etc.

The nearest surface water body is ____________ feet/miles from the affected property and is named ____. The water body is best described as a:

❒ freshwater stream: _____ perennial (has water all year)
_____ intermittent (dries up completely for at least 1 week a year)
_____ intermittent with perennial pools
❒ freshwater swamp/marsh/wetland
❒ saltwater or brackish marsh/swamp/wetland
❒ reservoir, lake, or pond; approximate surface acres: ________________
❒ drainage ditch
❒ tidal stream ❒ bay ❒ estuary
❒ other; specify ____

Is the water body listed as a State classified segment in Appendix C of the current Texas Surface Water Quality Standards; §§307.1 - 307.10?

❒ Yes Segment # _________ Use Classification:

❒ No

If the water body is not a State classified segment, identify the first downstream classified segment.

Name:

Segment #:

Use Classification:

As necessary, provide further description of surface waters in the vicinity of the affected property:

____
____
____
____

Figure: 30 TAC §350.77(b) continued

PART II. Exclusion Criteria and Supportive Information

Subpart A. Surface Water/Sediment Exposure (Complete in all cases.)

1) Regarding the affected property where a response action is being pursued under the TRRP, have COCs migrated and resulted in an unauthorized release or imminent threat of unauthorized release to either surface waters or to their associated sediments? Exclude wastewater treatment facilities and stormwater conveyances/impoundments authorized by permit. Also exclude conveyances, decorative ponds, and those portions of process facilities which are:

   a. Not in contact with surface waters of the State or other surface waters which are ultimately in contact with surface waters of the State; and

   b. Not consistently or routinely utilized as valuable habitat for natural communities including birds, mammals, reptiles, etc.

   ❒ Yes ❒ No

   Explain: ____
   ____
   ____
   ____
   ____

If the answer is Yes to Subpart A above, the affected property does not meet the exclusion criteria. Skip Subparts B - D and complete PART III - Qualitative Summary and Certification. If the answer is No, go to Subpart B.

Subpart B. Affected Property Setting (Complete only if "No" provided in Subpart A.)

In answering "Yes" to the following question, it is understood that the affected property is not attractive to wildlife or livestock, including threatened or endangered species (i.e., the affected property does not serve as valuable habitat, foraging area, or refuge for ecological communities). (May require consultation with wildlife management agencies.)

1) Is the affected property wholly contained within contiguous land characterized by: pavement, buildings, landscaped area, functioning cap, roadways, equipment storage area, manufacturing or process area, other surface cover or structure, or otherwise disturbed ground?

   ❒ Yes ❒ No

   Explain: ____
   ____
   ____

If the answer to Subpart B above is Yes, the affected property meets the exclusion criteria. Skip Subparts C and D and complete PART III - Qualitative Summary and Certification. If the answer to Subpart B above is No, go to Subpart C.

Subpart C. Soil Exposure (Complete only if "No" provided in Subpart B.)

1) Are COCs which are in the soil of the affected property solely below the first 5 feet beneath ground surface **or** does the affected property have a physical barrier present to prevent exposure of receptors to COCs in surface soil?

❒ Yes ❒ No

Explain: ____
____
____
____
____

If the answer to Subpart C above is Yes, the affected property meets the exclusion criteria. Skip Subpart D and complete PART III - Qualitative Summary and Certification. If the answer to Subpart C above is No, proceed to Subpart D.

Subpart D. *De Minimus* Land Area (Complete only if "No" provided in Subpart C.)

In answering "Yes" to the question below, it is understood that all of the following conditions apply:

- The affected property is not known to serve as habitat, foraging area, or refuge to threatened/endangered or otherwise protected species. (Will likely require consultation with wildlife management agencies.)
- Similar but unimpacted habitat exists within a half-mile radius.
- The affected property is not known to be located within one-quarter mile of sensitive environmental areas (e.g., rookeries, wildlife management areas, preserves). (Will likely require consultation with wildlife management agencies.)
- There is no reason to suspect that the COCs associated with the affected property will migrate such that the affected property will become larger than one acre.

1) Using human health protective concentration levels as a basis to determine the extent of the COCs, does the affected property consist of one acre or less <u>and</u> does it meet all of the conditions above?

❒ Yes ❒ No

Explain how conditions are met/not met:

____
____
____
____
____

If the answer to Subpart D above is Yes, then no further ecological evaluation is needed at this affected property. Complete PART III - Qualitative Summary and Certification. If the answer to Subpart D above is No, proceed to Tier 2 or 3 or comparable ERA.

PART III. Qualitative Summary and Certification (Complete in all cases.)

Attach a brief statement (not to exceed 1 page) summarizing the information you have provided in this form. This summary should include sufficient information to verify that the affected property meets or does not meet the exclusion criteria. The person should make the initial decision regarding the need for further ecological evaluation (i.e., Tier 2 or 3) based upon the results of this checklist. After review, TNRCC will make a final determination on the need for further assessment. **Note that the person has the continuing obligation to re-enter the ERA process if changing circumstances result in the affected property not meeting the Tier 1 exclusion criteria.**

Completed by: ______________________________ *(Typed/Printed Name)*

______________________________ *(Title)*

______________________________ *(Date)*

I believe that the information submitted is true, accurate, and complete, to the best of my knowledge.

______________________________ *(Typed/Printed Name of Person)*

______________________________ *(Title of Person)*

______________________________ *(Signature of Person)*

______________________________ *(Date Signed)*

APPENDIX B - DEFINITIONS AND ACRONYMS

Affected property - The entire area (i.e., on-site and off-site; including all environmental media) which contains releases of chemicals of concern at concentrations equal to or greater than the assessment level applicable for the land use (i.e., residential or commercial/industrial).

Alternate point of exposure - A location other than the prescribed point of exposure where an individual or population will be assumed to have a reasonable potential to come into contact with chemicals of concern based on property-specific considerations.

Attenuation monitoring point - A location between the source area and the point of exposure within the migration pathway of a chemical of concern which is used to verify the adequacy of a lateral transport protective concentration level.

Background - The concentration level of a chemical of concern within an environmental medium which may either be naturally occurring (i.e., the concentration is not due to a release of chemicals of concern from human activities) or anthropogenic (i.e., the presence of a chemical of concern in the environment which is due to human activities but is not the result of site-specific use or release of waste or products, or industrial activity). Examples of anthropogenic sources include non-site specific sources such as lead from automobile emissions, arsenic from use of defoliants, and polynuclear aromatic hydrocarbons resulting from combustion of hydrocarbons. There are some commonalities regardless of the activity; specifically, the chemicals of concern are present over large areas (tens of square miles up to hundreds of square miles), and the concentration levels are generally low.

Carcinogen - A chemical of concern which causes an increased incidence of benign or malignant neoplasms, or substantially decreases the time to develop neoplasms, in animals or humans (a chemical of concern can act as both a carcinogen and a noncarcinogen).

Carcinogenic risk level - The probability of development of a neoplasm due to continuous lifetime exposure to a single carcinogen acting through an individual or combined exposure pathway.

Case narrative - The required deliverable for each sample batch that discusses any anomalies in, or problems with, the data as noted by the laboratory generating the data.

Chemicals of concern - Any substance detected at an affected property that has the potential to adversely affect ecological or human receptors due to its concentration, distribution, and mode of toxicity. Chemicals of concern include all of the following: solid waste, industrial solid waste, municipal solid waste, and hazardous waste as defined in Texas Health and Safety Code, §361.003; hazardous constituents as listed in 40 Code of Federal Regulations Part 261, Appendix VIII; constituents on the groundwater monitoring list in 40 Code of Federal Regulations Part 264, Appendix IX; constituents as listed in 40 CFR Part 258 Appendices I and II; pollutant as defined in Texas Water Code, §26.001; hazardous substance as defined in Texas Health and Safety Code, §361.003, and Texas Water Code §26.263; regulated substance as defined in Texas Water Code

§26.342 and §334.2 of this title (relating to Definitions); petroleum product as defined in Texas Water Code §26.342 and §334.122(b)(12) of this title (relating to Definitions for ASTs); other substances as defined in Texas Water Code §26.039(a); and daughter products of the aforementioned constituents.

Closure - The act of permanently taking a waste management unit or facility out of service.

Commercial/industrial land use - Any real property or portions of a property not used for human habitation or for other purposes with a similar potential for human exposure as defined for residential land. Examples of commercial/industrial land use include manufacturing; industrial research and development; utilities; commercial warehouse operations; lumber yards; retail gas stations; auto service stations; auto dealerships; equipment repair and service stations; professional offices (lawyers, architects, engineers, real estate, insurance, etc.); medical/dental offices and clinics (not including hospitals); financial institutions; office buildings; any retail business whose principal activity is the sale of food or merchandise; personal service establishments (health clubs, barber/beauty salons, mortuaries, photographic studios, etc.); churches (not including churches providing day-care or school services other than during normal worship services); motels/hotels (not including those which allow residence); agricultural lands and portions of government-owned land (local, state, or federal) that has commercial/industrial activities occurring. Land use activities consistent with this classification have the North American Industrial Classification System code numbers 11- 21 inclusive; 22 except 22131; 23 - 56 inclusive; 61 except 61111, 61121, and 61131; 62 except 62211, 62221, 62231, 62311, 62322, 623311, 623312, 62399, and 62441; 71 inclusive; 72 except 721211 and 72131; 81 inclusive; and 92 excluding 92214.

Complete exposure pathway - A source medium or lateral transport exposure pathway where a human or ecological receptor is exposed to a chemical of concern via an exposure route (e.g., incidental soil ingestion, inhalation of volatiles and particulates, consumption of prey, etc.).

Construction zone - The typical depth of construction for an affected property considering the planned or historical installation of subsurface utilities, foundations, basements, or other such subsurface structures within the vicinity of the affected property not to extend below the top of bedrock.

Control - To apply measures such as capping or reversible treatment methods and/or institutional measures such as deed notices or restrictive covenants to prevent exposure to chemicals of concern. Control measures must be combined with appropriate maintenance, monitoring, and any necessary further response action to be protective of human health and the environment.

Critical protective concentration level - The lowest protective concentration level for a chemical of concern within a source medium determined from all of the applicable human health exposure pathways as described in §350.71 of this title (relating to General Requirements) considering both carcinogenic and noncarcinogenic effects, and all applicable ecological exposure pathways as required in §350.77 (relating to Ecological Risk Assessment and Development of Ecological PCLs).

Cumulative carcinogenic risk - The aggregate risk due to exposure of an individual human receptor to multiple carcinogens originating from a single affected property and acting through an individual or combined exposure pathway.

Discrete sample - A sample of an environmental medium which is limited to a prespecified interval according to the environmental media.

Ecological benchmark - A state standard, federal guideline, or other exposure level for a chemical of concern in water, sediment, or soil that represents a protective threshold from adverse ecological effects. An ecological benchmark may also be a toxicity reference value that is established by the person based on scientific studies in the literature.

Ecological protective concentration level - The concentration of a chemical of concern at the point of exposure within an exposure medium (e.g., soil, sediment, plants, groundwater, surface water, or air) which is protective for more wide-ranging ecological receptors that may frequent the affected property and utilize less mobile receptors as a food source and determined by procedures defined in §350.77(c) or (d) of this title (relating to Ecological Risk Assessment and Development of Ecological Protective Concentration Levels).

Ecological hazard quotient - The ratio of an exposure level to a chemical of concern to a toxicity value selected for the risk assessment for that chemical of concern (e.g., a no observed adverse effects level).

Ecological risk assessment - The process that evaluates the likelihood that adverse ecological effects may occur or are occurring as a result of exposure to one or more stressors.

Environmental medium - A material found in the natural environment such as soil (including non-waste fill materials), groundwater, air, surface water, and sediments, or a mixture of such materials with liquids, sludges, gases, or solids, including hazardous waste which is inseparable by simple mechanical removal processes, and is made up primarily of natural environmental material.

Exposure area - The smallest property surface area within which it is believed that exposure to chemicals of concern by a receptor would be limited under the most conservative, reasonable current or future use scenario.

Exposure medium - The environmental medium or plants in which or by which exposure to chemicals of concern by ecological or human receptors occurs.

Exposure pathway - The course that a chemical of concern takes from a source area to ecological or human receptors and includes a source area, a point of exposure, and an exposure route (e.g., ingestion), as well as a transport mechanism if the point of exposure is different from the source area.

Facility - The installation associated with the affected property where the release of chemicals of concern occurred.

Groundwater-bearing unit - A saturated geologic formation, group of formations, or part of a formation which has a hydraulic conductivity equal to or greater than 1×10^{-6} centimeters/second.

Groundwater production zone - The groundwater-bearing unit which contributes water to a well. For example, if a well penetrates four distinct groundwater-bearing units isolated by competent aquitards, but the well is screened in only two of the units and has a competent annular seal to isolate the other two units, then the groundwater production zone consists of only the two units that contribute water to the well.

Groundwater protective concentration level exceedence zone - A protective concentration level exceedence zone within a groundwater-bearing unit as established in accordance with §350.57 of this title (relating to Determination of Critical Groundwater PCLs and Critical Groundwater Lateral Transport PCLs).

Hazard index - The sum of two or more hazard quotients for multiple noncarcinogens originating from a single affected property.

Hazard quotient - The ratio of the level of exposure of a noncarcinogen acting through an individual or combined exposure pathway over a specified time period to a reference dose for the noncarcinogen derived for a similar exposure period.

Implementation procedures - The most current version of Implementation of the Texas Natural Resource Conservation Commission Standards via Permitting.

Institutional control - A legal instrument placed in the property records in the form of a deed notice or restrictive covenant which indicates the limitations or the conditions on use of the property which ensures protection of human health and the environment.

Judgmental sample - An investigative sample of an environmental medium which is purposefully located based upon property-specific information. These samples are biased and cannot be used for statistical analysis.

Landscaped area - An area of ornamental, introduced, commercially installed, or manicured vegetation which is routinely maintained.

Long-term effectiveness - The ability of a remedy to maintain the required level of protection of human health and the environment over time.

Lower explosive limit - The lowest concentration of a vapor or gas in air that will produce a flash of fire when an ignition source (heat, arc, or flame) is present.

Method detection limit - The minimum concentration of the chemical of concern that can be measured and reported with 99% confidence that the analyte concentration is greater than zero as determined by a specific laboratory method.

Method quantitation limit - The lowest non-zero calibration standard for the chemical of concern.

Monitored natural attenuation - The use of natural attenuation within the context of a carefully controlled and monitored response action to achieve protective concentration levels at the point of exposure.

Natural attenuation - The reduction in mass or concentration of a chemical of concern over time or distance from the source of chemicals of concern due to naturally occurring physical, chemical, and biological processes, such as: biodegradation, dispersion, dilution, adsorption, and volatilization.

Off-site - All environmental media which is outside of the legal boundaries of the on-site property.

On-site - All environmental media within the legal boundaries of a property owned or leased by a person who has filed a self-implementation notice or a response action plan for that property or who has become subject to such action through one of the agency's program areas for that property.

Permanence/permanent/permanently - The property of a response action which is capable of enduring indefinitely without posing the threat of any future release of chemicals of concern above the critical protective concentration levels established for the property.

Physical barrier - Any structure or system, natural or man-made, that prevents exposure or prevents migration of chemicals of concern to the points of exposure.

Physical control - A structure or hydraulic containment action which prevents exposure to and/or migration of chemicals of concern when combined with appropriate post-response action care to protect human health and the environment. Examples of physical controls are caps, slurry walls, sheet piling, hydraulic containment wells, and interceptor trenches.

Plume management zone - The area of the groundwater protective concentration level exceedence zone at the time of response action plan submittal plus the area from the downgradient limit of the groundwater protective concentration level exceedence zone to the downgradient alternate groundwater point(s) of exposure.

Point of exposure - The location within an environmental medium where a receptor will be assumed to have a reasonable potential to come into contact with chemicals of concern. The point of exposure may be a discrete point, plane, or an area within or beyond some location.

Prescribed points of exposure - The prescribed on-site and off-site locations within an environmental medium as detailed in Subchapter D of this chapter (relating to Remedy Standards) where an individual or population will be assumed to have a reasonable potential to come into contact with chemicals of concern from an affected property.

Protective concentration level - The concentration of a chemical of concern which can remain within the source medium and not result in levels which exceed the applicable human health risk-based exposure limit or ecological risk-based exposure limit at the point of exposure for that exposure pathway. The protective concentration level may be adjusted to a lower concentration due to the presence of multiple chemicals of concern as discussed in §350.52(d) of this title (relating to Carcinogenic Risk Levels and Hazard Indices for Human Health Exposure Pathways).

Protective concentration level exceedence zone - The lateral and vertical extent of all wastes and environmental media which contain chemicals of concern at concentrations greater than the critical protective concentration level determined for that medium, as well as, hazardous waste. A protective concentration level exceedence zone can be thought of as the volume of waste and environmental media which must be removed, decontaminated, and/or controlled in some fashion to adequately protect human health and the environment.

Release - Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment, with the exception of:

(A) A release that results in an exposure to a person solely within a workplace, concerning a claim that the person may assert against the person's employer;

(B) An emission from the engine exhaust of a motor vehicle, rolling stock, aircraft vessel, or pipeline pumping station engine;

(C) A release of source, by-product, or special nuclear material from a nuclear incident, as those terms are defined by the Atomic Energy Act of 1954, as amended (42 U.S.C. §2011 et seq.), if the release is subject to requirements concerning financial protection established by the Nuclear Regulatory Commission under §170 of that Act;

(D) For the purposes of the environmental response law §104, as amended, or other response action, a release of source, by-product, or special nuclear material from a processing site designated under §§102(a)(1) or 302(a) of the Uranium Mill Tailings Radiation Control Act of 1978 (42 U.S.C. §§7912 and 7942), as amended; and

(E) The normal application of fertilizer.

Reasonably anticipated exposure pathway - A situation with a credible chance of occurrence in which an ecological or human receptor may become exposed to a chemical of concern (i.e., complete exposure pathway) without consideration of circumstances which are extreme or improbable based on property characteristics.

Remediation - The act of eliminating or reducing the concentration of chemicals of concern in environmental media.

Remove - To take waste or environmental media away from the affected property to another location for storage, processing, or disposal in accordance with all applicable requirements. Removal is an irreversible process which results in permanent risk reduction at an affected property.

Residential land use - Property used for dwellings such as single-family houses and multi-family apartments, children's homes, nursing homes, and residential portions of government-owned lands (local, state, or federal). Because of the similarity of exposure potential and the sensitive nature of the potentially exposed population, day-care facilities, educational facilities, hospitals, and parks (local, state, or federal) shall also be considered residential.

Response action - Any activity taken to comply with these regulations to remove, decontaminate, and/or control (i.e., physical controls and institutional controls) chemicals of concern in excess of critical PCLs in environmental media, including actions taken in response to releases to environmental media from a waste management unit before, during, or after closure.

Risk-based exposure limit - The concentration of a chemical of concern at the point of exposure within an exposure medium (e.g., soil, sediment, vegetables, groundwater, surface water, or air) which is protective for human health as determined by procedures defined in Subchapter C (relating to Development of Protective Concentration Levels). Risk-based exposure limits are the fundamental risk-based values which are initially determined and used in the development of protective concentration levels. Risk-based exposure limits do not account for cumulative effects from exposure to multiple chemicals of concern, combined exposure pathways, and cross-media or lateral transport of chemicals of concern within environmental media.

Sample batch - A group of samples, not to exceed 20 environmental samples, that are similar in matrix, and that are extracted, or digested, at the same time and with the same lot of laboratory reagents. This term also covers samples that do not require digestion or extraction.

Sample quantitation limit - That concentration above which a chemical of concern can be quantified with a specified degree of confidence for a particular sample and includes the effects on the sample from all procedures performed during preparation, extraction, and/or analysis which are in addition to the standard method procedures. These additional procedures may include, but are not limited to, the initial sample aliquot (volume) used in the analysis, the moisture content of the sample, any dilution or concentration steps, etc.

Sediment - Particulate material lying immediately below surface waters such as bays, the ocean, rivers, streams, lakes, ponds, or other similar surface water body (including intermittent streams). Dredged sediments which have been removed from surface water bodies and placed on land shall be considered soils.

Soil protective concentration level exceedence zone - A protective concentration level exceedence zone within the soil which may extend down to a groundwater-bearing unit.

Source area - The location of non-aqueous phase liquids and/or the location of highest concentration of chemicals of concern, or the location releasing the chemicals of concern. Generally, a source area is located in the immediate vicinity of or below primary release sources (e.g., tanks, pipelines, drums, lagoons, landfills, etc.).

Source medium - An environmental medium containing chemicals of concern which must be removed, decontaminated, and/or controlled in order to protect human health and the environment. The source medium may be the exposure medium for some source medium exposure pathways.

Stressor - Any physical, chemical, or biological entity that can induce an adverse response.

Subsurface soil - For human health exposure pathways, the portion of the soil zone between the base of surface soil and the top of the groundwater-bearing unit(s). For ecological exposure pathways, the portion of the soil zone between 0.5 ft. and 5 ft. in depth.

Surface cover - A layer of artificially placed utility material (e.g., shell, gravel, fill).

Surface soil - For human health exposure pathways, the soil zone extending from ground surface to 15 ft. in depth for residential land use and from ground surface to 5 ft. in depth for commercial/industrial land use; or to the top of the uppermost groundwater-bearing unit, whichever is less in depth. For ecological exposure pathways, the soil zone extending from ground surface to 0.5 ft. in depth.

Toxicity reference value - An exposure level from a valid scientific study that represents a conservative threshold for adverse ecological effects.

Unauthorized release - The movement of chemicals of concern into environmental media which is not allowed by state or federal law, regulation, or permit.

WASTE DEFINITIONS - (From TNRCC)

Characteristically hazardous waste (40 CFR Part 261 Subpart C) - Any waste that exhibits the characteristic of ignitability, corrosivity, reactivity, and/or toxicity as defined by the EPA in 40 CFR Part 261 Subpart C. These are often referred to as the "D" wastes.

Class 1 waste (30 TAC §335.1) - Any waste or mixture of waste which, because of its concentration or physical or chemical characteristics is toxic, corrosive, flammable, a strong sensitizer or irritant, a generator of sudden pressure by decomposition, heat or other means, and may pose a substantial present or potential danger to human health or the environment when improperly processed, stored, transported, or disposed of or otherwise managed.

Class 2 waste (30 TAC §335.1) - Any individual waste or combination of waste which cannot be described as Hazardous, Class 1, or Class 3 waste.

Class 3 waste (30 TAC §335.1) - Inert and essentially insoluble waste, usually including but not limited to, materials such as rock, brick, glass, dirt, and certain plastics and rubber, etc. that are not readily decomposable.

Waste classification code (30 TAC §335.503) - This code represents the classification of the waste stream. It is the last digit of the waste code. "H" represents hazardous wastes, "1" represents class 1 wastes, "2" represents class 2 wastes, and "3" represents class 3 wastes.

Waste control unit - A municipal or industrial solid waste landfill, including those RCRA regulated units closed as landfills, with an engineered cap and liner system which have been closed pursuant to an approved closure plan or will be implemented pursuant to an approved response action plan.

Conditionally exempt small quantity generator (30 TAC §335.6, §335.9, §335.10, §335.78, §335.323, §335.503) - Generators of less than 100 kg per month of industrial waste, or generators of less than 100 kg per month of hazardous waste or less than 1 kg per month of acutely hazardous waste.

Form code (30 TAC §335.503) - This code is associated with the description of a general type of waste stream. It consists of three (3) numeric characters. It appears in the 5th, 6th, and 7th position of the waste code. More than one form code may apply to a particular waste stream.

Hazardous substance (30 TAC §335.508) - Any substance designated as a "hazardous substance" in 40 CFR PART 302 (i.e. 40 CFR Table 302.4) including, but not limited to, RCRA hazardous waste.

Hazardous waste determination (30 TAC §335.504) - An evaluation of a waste to determine if it meets the RCRA definition of a hazardous waste.

Inert (30 TAC §335.507) - Inertness refers to the chemical inactivity of an element, compound, or waste. Ingredients added to mixtures chiefly for bulk and/or weight purposes are normally considered inert.

Listed hazardous waste (40 CFR Part 261 Subpart D) - Specific types of wastes which have been identified by the EPA as hazardous. These are often referred to as the "F" wastes (waste from non-specific sources), "K" wastes (wastes from specific sources), "P" wastes (acute hazardous off-specification species, container residues, and spill residues thereof), and "U" waste (toxic hazardous off-specification species, container residues, and spill residues thereof). A waste is considered a listed hazardous waste if it is listed or mixed with or derived from a waste listed as hazardous waste in 40 CFR Part 261 Subpart D and has not been provided a particular exclusion from the definition of hazardous as provided in 40 CFR §261.3 and §261.4.

Medical wastes (30 TAC §335.508) - Nonhazardous medical wastes which are subject to the provisions of 30 TAC Chapter 330 Subchapter Y are designated as Class 2 wastes. An example of such waste would be needle bearing syringes from plant infirmaries.

New chemical substances wastes (30 TAC §335.508) - If a nonhazardous industrial waste is generated as a result of the commercial production of a "new chemical substance" as defined by the federal Toxic Substances Control Act, 15 U.S.C.A § 2602(9), the generator shall manage that waste as a Class 1 waste, unless the generator can provide appropriate analytical data and/or process knowledge which demonstrates that the waste is Class 2 or Class 3, and the Commission concurs. If the generator has not received concurrence from the Commission within 120 days from the date of the request for review, the generator may manage the waste according to the requested classification, but not prior to giving 10 working days written notice to the Commission.

Wastes generated out-of-state (30 TAC §335.508) - All nonhazardous industrial waste generated outside the state of Texas and transported into or through Texas for processing, storage, or disposal shall be classified as Class 1 unless the waste satisfies the Class 2 or Class 3 criteria as defined in 30 TAC §335.506, §335.507 or §335.508; a request for Class 2 or Class 3 waste determination is submitted to the Commission and accompanied by all supporting process knowledge and analytical data; and the Commission approves the classification.

Petroleum hydrocarbon containing wastes (30 TAC §335.508) - Wastes resulting from the cleanup of leaking underground storage tanks (USTs) which are regulated under 30 TAC Chapter 334 Subchapter K (relating to Petroleum Substance Waste) are not subject to classification under 30 TAC Chapter 335 Subchapter R.

Petroleum substance - A crude oil or any refined or unrefined fraction or derivative of crude oil which is a liquid at standard conditions of temperature and pressure.

(A) Except as provided in subparagraph (C) of this section for the purposes of this chapter, a "petroleum substance" shall be limited to a substance in or a combination or mixture of substances within the following list (except for any listed substance regulated as a hazardous waste under the federal Solid Waste Disposal Act, Subtitle C (42 United States Code §6921, et seq.) and which is liquid at standard conditions of temperature (20 degrees Centigrade) and pressure (1 atmosphere):
(i) basic petroleum substances - i.e., crude oils, crude oil fractions, petroleum feedstocks, and petroleum fractions;
(ii) motor fuels - a petroleum substance which is typically used for the operation of internal combustion engines and/or motors (which includes but is not limited to stationary engines and engines used in transportation vehicles and marine vessels);
(iii) aviation gasolines - i.e., Grade 80, Grade 100, and Grade 100-LL;
(iv) aviation jet fuels - i.e., Jet A, Jet A-1, Jet B, JP-4, JP-5, and JP-8;
(v) distillate fuel oils - i.e., Number 1-D, Number 1, Number 2-D, and Number 2;
(vi) residual fuel oils - i.e., Number 4-D, Number 4-light, Number 4, Number 5-light, Number 5-heavy, and Number 6;
(vii) gas-turbine fuel oils - i.e., Grade O-GT, Grade 1-GT, Grade 2-GT, Grade 3-GT, and Grade 4-GT;
(viii) illuminating oils - i.e., kerosene, mineral seal oil, long-time burning oils, 300 oil, and mineral colza oil;
(ix) lubricants - i.e., automotive and industrial lubricants;
(x) building materials - i.e., liquid asphalt and dust-laying oils;
(xi) insulating and waterproofing materials - i.e., transformer oils and cable oils; and
(xii) used oils - (See definition for "used oil" in this section.).

(B) For the purposes of this chapter, a "petroleum substance" shall include solvents or a combination or mixture of solvents (except for any listed substance regulated as a hazardous waste under the federal Solid Waste Disposal Act, Subtitle C (42 United States Code §6921, et seq.) and which is liquid at standard conditions of temperature (20 degrees Centigrade) and pressure (1 atmosphere) - i.e., Stoddard solvent, petroleum spirits, mineral spirits, petroleum ether, varnish makers' and painters' naphthas, petroleum extender oils, and commercial hexane.

(C) The following materials are not considered petroleum substances:
(i) polymerized materials, i.e., plastics, synthetic rubber, polystyrene, high- and low-density polyethylene;
(ii) animal, microbial, and vegetable fats;
(iii) food grade oils;
(iv) hardened asphalt and solid asphaltic materials (i.e., roofing shingles, roofing felt, hot mix, and cold mix); and
(v) cosmetics.

Regulated asbestos containing material (RACM) (30 TAC § 335.508) - RACM includes the following materials:

> **Friable** asbestos material, any material containing more than 1 percent asbestos (*) that, when dry, can be crumbled, pulverized, or reduced to powder by hand pressure.
>
> **Nonfriable** asbestos, when dry, can not be crushed to a powder by hand pressure.
>
> - Category I nonfriable asbestos containing material that has become friable - (Category I nonfriable asbestos containing material is defined as asbestos containing packings, gaskets, resilient floor coverings, and asphalt roofing products containing more than 1 percent asbestos.).
>
> - Category I nonfriable asbestos containing material that has been subjected to sanding, grinding, cutting, or abrading - (Category I nonfriable asbestos containing material is defined as asbestos containing packings, gaskets, resilient floor coverings, and asphalt roofing products containing more than 1 percent asbestos.).

Regulated generators (30 TAC Chapter 335 Subchapters A and C) - Generators of industrial waste in quantities greater than 100 kg per month and generators of hazardous waste in quantities of greater than 100 kg of hazardous waste per month or 1 kg of acutely hazardous waste per month. (Please note: those generators of less than 100 kg of industrial waste or less than 100 kg of hazardous waste or 1 kg of acutely hazardous waste are considered Conditionally Exempt Small Quantity Generators and hence are not subject to regulation regarding notification, manifesting, and fees.)

Sequence number (30 TAC §335.503) - Appears as the first four (4) digits of the waste code. This unique number helps identify a particular waste stream and can only be used once per facility (i.e., each sequence number assigned to a waste code is site specific to that particular 5-digit Solid Waste Registration Number).

Solid waste (30 TAC §335.1 and 40 CFR §261.2) - Any discarded material such as garbage; refuse; sludge from a waste treatment plant, water supply treatment plant or air pollution control facility; or other material including solid, liquid, semisolid, or contained gaseous material resulting from industrial, municipal, commercial, mining, and agricultural operations. Solid wastes include any material that is abandoned by being disposed of, burned, or incinerated or accumulated, stored, or treated before or in lieu of these activities. Certain recycled materials are also considered wastes. Solid wastes are often referred to as "wastes." (For the complete definition of a "solid waste," please refer to 30 TAC 335.1 (Solid Waste)).

Specific industrial solid waste (30 TAC §335.508) - Nonhazardous wastes for which specific classification criteria and/or a form code has been established.

Stabilized wastes (30 TAC §335.508) - Wastes which are hazardous solely because they exhibit a hazardous characteristic, which are not considered hazardous debris, which are subsequently stabilized and no longer exhibit a hazardous characteristic, and which meet the land disposal restrictions as defined in 40 CFR Part 268 may be classified according to the Class 1 or Class 2 classification criteria as defined in §335.505, §335.506, and 335.508 of this title (relating to Class 1 Determination; Class 2 Waste Determination; and Classification of Specific Industrial Solid Wastes).

Waste code (30 TAC §335.503) - This code identifies a waste stream. It is eight (8) characters in length. The first four digits represent the sequence number, the next three digits represent the form code, and the last digit represents the waste's classification (Sequence Number + Form Code + Classification Code = Waste Code).

ACRONYMS

ACGI -American Conference of Government Industrial Hygienists

AOC - Areas of concern

APAR - Affected property assessment report

AST - Aboveground storage tank

ASTM - American Society for Testing and Materials

BTEX - Benzene, toluene, ethylbenzene, xylene compounds

C - Theoretical soil saturation limit

CAA - Clean Air Act

CAAA - Clean Air Act Amendments

CalEPA - California Environmental Protection Agency

CEQ - Council on Environmental Quality

CERCLA - Comprehensive Environmental Response, Compensation, and Liability Act

CERCLIS - Comprehensive Environmental Response, Compensation, and Liability Information System

CFR - Code of Federal Regulations

CMS - Corrective Measures Study

COC - Chemical of concern

COTR - Contracting officer's technical representative

CWA - Clean Water Act

DOD - Department of Defense

DOE - Department of Energy

DOT - Department of Transportation

DQO - Data quality objective

DF - Dilution factor

EIS - Environmental impact statement

EM - Electromagnetic

EPA - Environmental Protection Agency

ERA - Ecological risk assessment

ESL - Effects screening level

ERA - Ecological risk assessment

ESL - Effects screening level

FID - Flame ionization detector

FIFRA - Federal Insecticide, Fungicide, and Rodenticide Act

FOC - fraction organic carbon

GAO - General Accounting Office

GC - Gas chromatography

GC/MS - Gas chromatography/mass spectrometry

GIS - Geographic Information System

GPD - Gallons per day

GPR - Ground-penetration radar

GSA - General Services Administration

HI - Hazard index

HQ - Hazard quotient

HRS - Hazardous Ranking System

HSWA - Hazardous and Solid Waste Act

IDL - Instrument detection limit

K - Soil-water partition coefficient d

K (ow) - Octanol-water partition coefficient oc

LEL - Lower explosive limit

LEPC - Local Emergency Planning Committee

LLRW - Low-level radioactive waste

LIF - Laser-induced fluorescence

MCL - Maximum contaminant level

MDL - Method detection limit

MQL - Method quantitation limit

MS - Mass spectrometry

MSW - Municipal solid waste

MSWLF - Municipal solid waste landfill

NAF - Natural attenuation factor

NAPLs - Non-aqueous phase liquids

NAAQS - National Ambient Air Quality Standards

NEPA - National Environmental Policy Act

NPL - National Priorities List

NOAEL - No observable adverse effects level

OMB - Office of Management and Budget

OSC - On-scene coordinator

OSHA - Occupational Safety and Health Act

OSHA - Occupational Safety and Health Administration

OSWER - Office of Solid Waste and Emergency Response

PAH - Polycyclic aromatic hydrocarbon (sometimes referred to as PNA)

PNA - Polynuclear hydrocarbons

PCB - Polychlorinated biphenyl

PCDD - Polychlorinated dibenzodioxin

PCDF - Polychlorinated dibenzofuran

PCL - Protective concentration level

PCLE zone - Protective concentration level exceedence zone

PEF - Particulate emission factor

PEL - Permissible exposure limit

PID - Photo-ionization detector

POC - Point of compliance

POE - Point of exposure

POTW - Publicly owned treatment works

PPE - Personal protective equipment

PRP - Potentially responsible party

PRACR - Post-response action care report

RACR - Response action completion report

RAER - Response action effectiveness report

RAP - Response action plan

RBEL - Risk-based exposure limit

RCRA - Resource Conservation and Recovery Act

RFC - Reference concentration

RFA- RCRA facility assessment

RFI- RCRA facility investigation

ROD - Record of decision

RfD - Reference dose

RL - Risk level

RL - Cumulative risk level

RPF - Relative potency factor

SARA - Superfund and Reauthorization Act

SCAPS - Site Characterization Analysis and Penetrometer System

SDWA - Safe Drinking Water Act

SIN - Self implementation notice

SLERA - Screening Level Ecological Risk Assessment

SOP- Standard operating procedures

SOW - Statement of work

SPCC - Spill Prevention, control, and countermeasures

SVOC - Semi-volatile organic compound

SWMU - Solid waste management unit

SQL - Sample quantitation limit

SSAP - Sampling and statistical analysis plan

TLV - Threshold limit value

TDS - Total dissolved solids

TEF - Toxicity equivalency factor

TEQ - Toxicity equivalency quotient

TNRCC - Texas Natural Resource Conservation Commission

TPH - Total petroleum hydrocarbons

TSS - Total suspended solids

TSCA - Toxic Substance Control Act

TSD - Treatment, storage, and disposal

UCL - Upper confidence limit

URF - Unit risk factor

U.S. EPA - United States Environmental Protection Agency

USC - United States Code

USGS - U.S. Geological Survey

UST - Underground storage tank

UV - Ultraviolet light

UXO - Unexploded ordinance

VCP - Voluntary cleanup program

NOMENCLATURE FOR TRRP

Risk-based exposure limit nomenclature. A nomenclature is used in Chapter 350, Subchapter D of the TRRP (relating the Development of Protective Concentration Levels) to refer to specific RBELs. The RBEL nomenclature reflects the exposure medium and the exposure route. The exposure medium appears first in superscript text, followed by RBEL in regular text, and lastly the exposure route in subscript text. For example $^{Soil}RBEL_{Ing}$ is a RBEL where soil is the exposure medium and ingestion is the exposure route.

(1) $^{Air}RBEL_{Inh}$ - air inhalation RBEL;

(2) $^{Soil}RBEL_{Derm}$ - dermal contact with soil RBEL;

(3) $^{Soil}RBEL_{Ing}$ - ingestion of soil RBEL;

(4) $^{GW}RBEL_{Ing}$ - ingestion of groundwater RBEL;

(5) $^{GW}RBEL_{Class\ 3}$ - class 3 groundwater RBEL;

(6) $^{SW}RBEL$ - surface water RBEL;

(7) $^{AbgVeg}RBEL_{Ing}$ - ingestion of aboveground vegetables RBEL; and

(8) $^{BgVeg}RBEL_{Ing}$ - ingestion of belowground vegetables RBEL.

Protective concentration level nomenclature. A nomenclature is used in Chapter 350, Subchapter D of the TRRP (relating the Development of Protective Concentration Levels) to refer to specific PCLs. The PCL nomenclature reflects the exposure medium, source medium, and the exposure route. The exposure medium appears first in superscript text, followed by the source medium in regular text and lastly the exposure route in subscript text. For example, $^{GW}GW_{Ing}$ is a PCL where groundwater is the source medium (GW), groundwater is the exposure medium (^{GW}), and ingestion is the exposure route ($_{Ing}$). Cross-media transfer is indicated when exposure occurs in a different medium than the source medium. For example, $^{Air}Soil_{Inh-V}$ is a PCL where soil is the source medium and air is the exposure medium.

(1) $^{GW}GW_{Ing}$ - PCL for groundwater ingestion;

(2) $^{GW}GW_{Class\ 3}$ - PCL for class 3 groundwater;

(3) $^{Air}GW_{Inh\text{-}V}$ - PCL for inhalation of volatiles from groundwater;

(4) ^{SW}GW - PCL for groundwater discharge to surface water;

(5) $^{Tot}Soil_{Comb}$ - surface soil PCL for combined soil ingestion, dermal contact, inhalation of volatiles and particulates, and for residential land use, ingestion of aboveground and belowground vegetables;

(6) $^{Air}Soil_{Ing\text{-}VP}$ - PCL for inhalation of volatiles and particulates from surface soil;

(7) $^{Soil}Soil_{Derm}$ - PCL for dermal contact with surface soil;

(8) $^{Soil}Soil_{Ing}$ - PCL for ingestion of surface soil;

(9) $^{Veg}Soil_{Ing\text{-}Inorg}$ - surface soil PCL for ingestion of inorganic COCs in vegetables;

(10) $^{Veg}Soil_{Ing\text{-}Org}$ - surface soil PCL for ingestion of organic COCs in vegetables;

(11) $^{GW}Soil$ - PCL for surface and subsurface soil to protect groundwater;

(12) $^{Air}Soil_{Inh\text{-}V}$ - PCL for inhalation of volatiles from subsurface soil;

(13) $^{Air}Air_{Inh}$ - air PCL for inhalation; and

(14) ^{SW}SW - surface water PCL