PRINCIPLES

OF

ENVIRONMENTAL

RESTORATION

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U. S. Army Environmental Center
Aberdeen Proving Ground
Edgewood Area

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1. INTRODUCTION

Background

This manual is provided to assist Installation and Base Realignment and Closure (BRAC) Cleanup Teams, USAEC restoration oversight managers (ROMs), and other personnel responsible for environmental restoration activities in performing related duties in an expeditious and cost-effective manner. The guidance provided herein is drawn from the collective experience of environmental restoration managers working on both public and private lead sites since the inception of environmental restoration programs in the United States. Those programs were formally promulgated with the development of the National Multi-Agency Oil and Hazardous Materials Pollution Contingency Plan (later to become the National Contingency Plan or NCP) in 1968. Over the years, the plan has evolved in response to lessons learned and Congressional mandates included in legislation such as the Federal Water Pollution Control Act (FWPCA) Amendments, the Resource Conservation and Recovery Act (RCRA), the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), and the Superfund Amendments and Reauthorization Act (SARA).

Concentrated efforts in environmental restoration began in the 1980s with passage and implementation of CERCLA. With time, it became apparent that Congress had underestimated the size of the undertaking both in terms of the number of sites that would have to be addressed and in the cost for addressing a typical site. In part, the funding shortfall was believed to arise from inefficient allocation of resources in program execution. Consequently, funding was increased and pressure was applied to improve performance. Both private and public entities began to study ways to reduce the cost and improve the outcome of restoration activities. The U. S. Environmental Protection Agency (EPA) developed and launched the Superfund Accelerated Cleanup Model (SACM), an approach that utilized the flexibility inherent in the NCP to eliminate nonessential investigation costs. This was followed by the development of the Streamlined Approach for Environmental Restoration (SAFER) by the U. S. Department of Energy (DOE). In the private sector, the American Society for Testing and Materials (ASTM) initiated the Risk-Based Corrective Action (RBCA) Program.

In 1997, the Army Environmental Center (AEC) launched a peer review process and subsequently the Independent Technical Review (ITR) Program as a means of validating the approaches being taken to environmental restoration at BRAC and, more recently, active sites as well as to identify opportunities for streamlining. With implementation of the reviews, it was observed that a number of issues were repeatedly encountered at sites regardless of the regulatory program under which the work was being conducted. Many of the more significant findings were summarized in a recent review of 27 ITR recommendation reports. These findings include:

- There is a need to better document and communicate decisions.
- There is a need to focus activities on core problems.
  - ✓ In 9/27 cases, risk was calculated for scenarios inconsistent with the site use plan.
  - ✓ In 10/27 cases, the conceptual site model was developed as a by-product, not used as a tool to scope studies.
  - ✓ In 8/27 reported risk resulted from contaminants present in background samples.
  - ✓ There was a common misconception that if an applicable or relevant and appropriate requirement (ARAR) is exceeded, a response is required.
- Data collection is often performed ineffectively and inadvisably.
  - ✓ In 13/27 cases, the Data Quality Objectives process was not employed.
  - ✓ There was confusion between data gaps and data needs.
  - ✓ Efforts were being expended to characterize incomplete pathways.
- There is no early focus on likely response actions and the subsequent impact on data needs.
  - ✓ In 6/27 cases, the remedy cost more than the value of the resource being restored.
  - ✓ In 9/27 cases, monitored natural attenuation was not considered even though conditions appeared to meet EPA policy guidelines for selection.
  - ✓ In 12/27 cases, remedies were implemented with no exit strategy articulated.
- There is a tendency to default to more data collection in an ill-fated attempt to resolve all site uncertainties.

As a result of these findings and their consistency with observations made with the previous streamlining initiatives, key concepts for resolution of these problems have been identified and distilled into the Principles that are the core of this manual. Additionally, tools have been developed to assist in implementing the four principles.

The four Principles of Environmental Restoration are:

- **Developing effective communication and cooperation with a Project Management Team (PMT) is essential;**

- **Clear, concise, and accurate problem identification and definition are critical;**

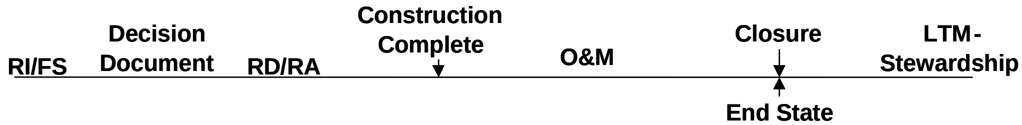
- **Early identification of likely response actions is possible, prudent, and necessary; and**

- **Uncertainties are inherent and will always need to be managed.**

Applicability of the Principles in the Restoration Process

The Principles presented in this manual are not new concepts in and of themselves. Rather, they are implicit in both the NCP and RCRA corrective action policies. They can be applied at any point in the remediation process, and to any remediation or investigation, regardless of the type or magnitude of the problem being addressed. In order to understand and embrace these Principles, the reader must first recognize that both CERCLA and RCRA explicitly provide for flexibility in what can be done, assuming certain basic steps are followed. Historically, however, this regulatory and policy flexibility has not been well implemented. For example, the emphasis of both programs is to decide whether to take action to solve problems. The traditional approach to reaching this decision has been to conduct extensive site investigations and studies to collect as much data as possible about the site, and to then make a decision as to whether or not to move forward. Under this approach, data collection and investigation become the focus of the process rather than a means to achieving an end. However, as will be illustrated throughout this manual, activities such as collecting data should be done when it fills clearly defined data needs that can support the decision-making process (i.e., not all data gaps will be filled). If embraced, application of the Principles can save resources in terms of both time and dollars, while at the same time promote a better, more strategic decision-making process. Figure 1-1 illustrates the parallel elements of the RCRA and CERCLA processes, and Figure 1-2 illustrates how the four Principles can be applied throughout the remediation process.

Figure 1-1: The Parallel Elements of RCRA and CERCLA Processes



RCRA	CERCLA	Common Requirements
RFA	PA/SI	Identify releases and need for further investigation
RFI	RI	Characterizes the nature and extent of contaminant releases (uncertainty reduction). Determines potential human and environmental risk.
CMS	FS	Identification, evaluation, and screening of remedial alternatives (uncertainty mitigation)
Statement of Basis	Proposed Plan	Identification and public notice of the preferred alternative
Permit Modification	ROD	REMEDY SELECTION
CMD	RD	Development of detailed plans for selected remedy
CMI	RA	Construction, testing, and implementation of selected remedy
Closure/Post-Closure	Completion	Construction completed and post-construction plans in place
Closure/Post-Closure	Closure	Specific cleanup levels reached and remedial activities complete.

Figure 1-2: The Principles Apply to All Phases of Environmental Restoration

	Pre-Decision Document		Post-Decision Document	
Principle	Scoping	RI/FS/RFI/CMS	RD/RA	Post Completion
Develop effective communication and cooperation within a PMT is essential	Articulate problem to stakeholders	Approve uncertainty management strategy and select preferred remedy	Develop common interpretation of decision document	Approve contingency implementation and conduct 5-year reviews
Clear, concise and accurate identification of problem is critical	Define the problem	Identify decisions that address the problem and focus efforts to determine needed information	Define remedial action objectives	Define end-states measure performance
Early identification of likely means of achieving objectives is possible, prudent, and necessary	Identify hierarchy of preferred alternatives	Focus investigations on fatal flaws and selection/design criteria	Select design basis and use to determine significance of uncertainties	Prepare performance expectations to evaluate progress and provide early warning of failure
Uncertainty is inherent and must be managed	Distinguish data needs from data gaps	Balance uncertainty reduction with countermeasures to impacts that effect remedy selection	Determine uncertainties with sufficient impact to require contingencies	Monitor conditions as a means of determining when contingencies must be implemented

Organization

The manual begins with a discussion of each of the four Principles and their interrelationships during conduct of environmental restoration activities. Chapter 2 describes the critical need for communication and cooperation among stakeholders (Principle 1) to advance the environmental restoration effort and, where appropriate, facilitate property transfer. The third chapter introduces the concept of identifying problems (Principle 2) and formulating problem statements to focus subsequent efforts. Chapter 4 addresses the utility of early identification of likely response actions (Principle 3) as a means of focusing investigations once a problem has been defined. Finally, the concept of uncertainty management (Principle 4) is introduced in Chapter 5. Each Principle is discussed in detail along with examples of tools for implementation and output illustrating its use and utility.

The concluding four chapters deal with the application of the Principles during conduct of environmental restoration activities. Chapter 6 addresses the formulation and use of conceptual site models as a means of retaining internal consistency and focus. Chapter 7 introduces methods such as the Data Quality Objectives (DQO) process and dynamic decision making as means of reducing uncertainty through data collection. Uncertainty management through mitigation of residual uncertainties is described in Chapter 8. Chapter 9 concludes with a discussion of the need for exit strategies and long-term care implications of common remedies.

Supplemental materials appended to the manual include design basis and fatal flaw listings for common remedial actions, references, and additional decision logic diagrams to assist in planning investigations.

Assumptions

This manual was developed with the assumption that the user is an Army project manager, decision maker, design engineer, or line manager; lead regulator; or otherwise responsible party with the authority to determine the direction and content of environmental restoration activities at active or BRAC Army installations. The reader is expected to be conversant in environmental restoration program fundamentals such as regulatory framework and programmatic mission. In general, the reader is assumed to be a "reviewer" rather than a "doer" (i.e., responsible for planning and reviewing work products such as investigation reports and designs, not in actually performing the technical work required during the investigation, design and implementation).

It is assumed that the environmental restoration activity is being conducted under CERCLA or the corrective action aspects of RCRA. While issues such as lead-based paint and asbestos removal may benefit from application of the Principles, these activities are not contemplated in the examples provided or the accompanying text. No assumptions are made with respect to the stage of restoration that has been reached. Information is provided relative to all phases of activities including pre-decision document (preliminary assessment, scoping, investigation and remedy selection) and post-decision document (design, implementation, and stewardship) activities.

Objectives

This manual is a companion to the Principles of Environmental Restoration Workshop organized and sponsored by the Army Environmental Center. It is designed to supplement materials presented during the course, and to act as a stand-alone guidance for those unable to attend a course delivery. It is designed to help the reader understand the Principles and learn how to apply them in practical ways throughout restoration activities. The Principles presented in this manual do not provide a recipe for conducting studies.   Rather, they provide a framework and an approach to work plan development and review, and decision making in which different methodologies can be embedded. Each user is encouraged to select methodologies consistent with the Principles and assemble them in a manner that is best suited to the site and the stakeholders in a given situation. It is far more important at this juncture for the reader to understand why certain actions are recommended rather than how they are to be implemented.

After reading this manual, it is expected that the user will:

- Understand the Principles of Environmental Restoration and their applicability to all phases of restoration activities;
- Recognize the flexibility available in the NCP and site-specific decision documents that facilitate streamlining; and
- Appreciate why specific elements of environmental restoration are necessary rather than feel committed to a specific process for how those elements can be conducted.

Success in implementing this approach is directly related to the degree to which each stakeholder embraces the Principles and their application. One of the objectives of the Workshop is demonstration of the efficacy of this approach from the perspectives of the regulators, the Army, and other stakeholders. A corollary objective is to explain the utility of the Principles in:

- Encouraging strategic thinking, team building, and problem solving;
- Seizing opportunities for cost and schedule streamlining; and
- Improving communication with all stakeholders.

2. COMMUNICATION AND COOPERATION

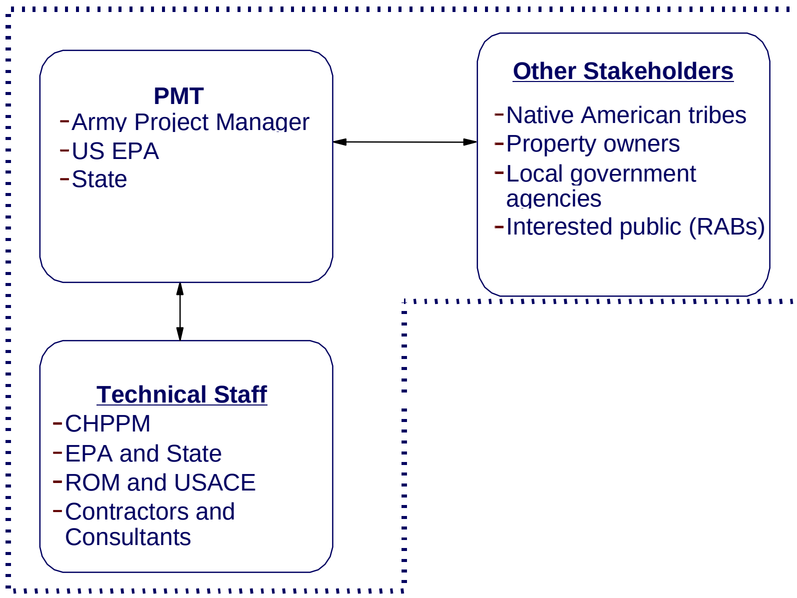
Introduction

At Army installations, all major stakeholders represent public assets of one kind or another. The dollars being spent are public funds. The resources being restored or protected are public lands and facilities. Moreover, it is public health and the environment that is being protected through environmental response actions. As a result, all parties should have the same goal: to restore the environment to a level that poses no unacceptable risk at reasonable cost. However, differences traditionally arise in defining the level of acceptability, and in determining the level of comfort in alternative approaches to achieving acceptable levels of risk. Historic antagonism between and among the parties arises from different perceptions about uncertainties and different levels of comfort in dealing with risk management. Traditional "barriers" to streamlining can be overcome through teamwork and early agreement.

<u>Principle 1: Developing effective communication and cooperation with a Project Management Team (PMT) is essential.</u>

The stakeholders are represented in the decision-making process by the Project Management Team (PMT). In general, the PMT is comprised of a representative of any entity that has the ability to say no to a decision. Under most Federal Facility Agreements (FFA) that means at a minimum, the PMT will include the Army (as lead agency), EPA, and the appropriate State and local regulators (Figure 2-1). In rare circumstances, there may be other parties such as Indian nations, the proposed new site owners, or co-occupants that have sufficient standing to be included in the PMT, but generally speaking, these parties do not have primary decision-making authority. Technical staff and contractors are never a part of the PMT. While these parties play a major role in providing input to the decision-making process and implementing decisions, they are not decision makers and have no legal standing with respect to required actions by the PMT.

Figure 2-1: Project Management Team Approach

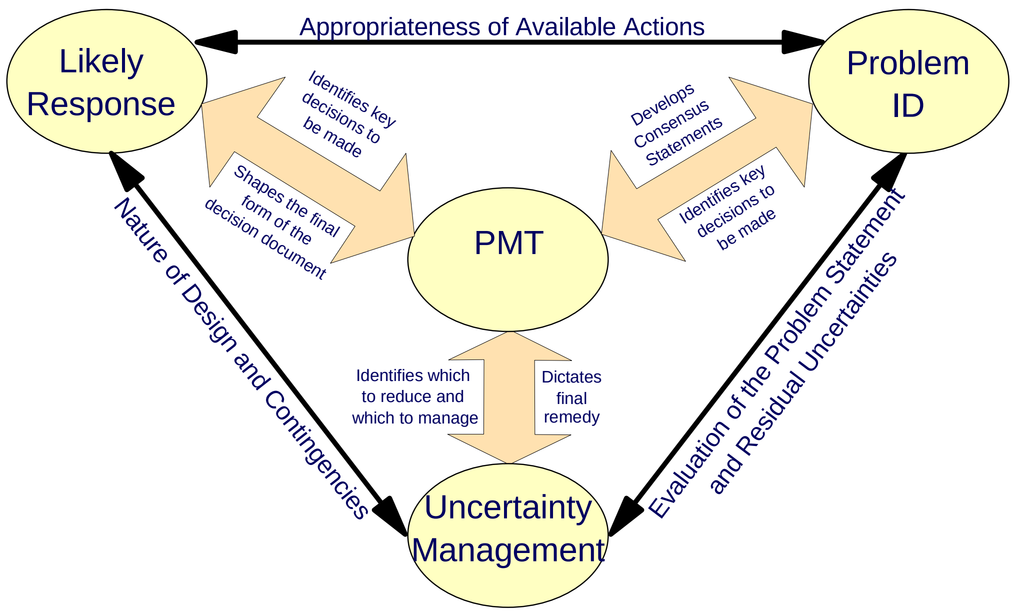


One of the keys to bringing perceptions closer together so that the PMT functions as a team is to foster frequent, early, and open communication. All parties need to know the facts so that they can participate in the decision-making process in a meaningful way. Without open communication, one or more of the parties become fearful that they have been denied critical information and, therefore, are reluctant to accept the defined problems and preferred solutions.

Better communication and a team approach engenders the cooperation needed to move forward expeditiously. Ultimately, the objective is for the PMT to own the process and the product. As a consequence, all members of the PMT need to be fully engaged in the planning, evaluation, and decision-making activities so that when plans and decisions are taken to the public they can be endorsed by the PMT as a whole. This section discusses the organization and operational mode a PMT may want to adopt to facilitate communication and cooperation throughout the program.

Critical to the success of the Principles at any Army installation is the successful cooperation and communication, both internally and externally, of the PMT. As illustrated in Figure 2-2, the level of success in implementing the other three Principles is directly related to the effectiveness of early communication and cooperative planning efforts. How the PMT applies the Principles will vary from site to site and from project to project, and is a process that will evolve over time.

Figure 2-2: PMT Implements the Other Three Principles



Organization

Each member of the PMT represents the public's best interests, albeit from different perspectives. Moving ahead requires proper alignment to assure that all perspectives are adequately addressed. This approach does not limit in any way a regulatory enforcement authority or sovereign immunity, but provides an opportunity for regulatory agencies to use their authorities to move the project forward. Issues that could potentially slow or stop progress are known early in the process, rather than later during document review. Key decision makers on the PMT need to constantly strive to reach consensus on the major aspects of the project. This begins with sharing information, planning, identifying decisions to be made, and setting decision criteria at the outset of a project, ensuring all decision-making authorities are aware of factors that will impact the project moving forward and seeking the opportunity to develop early consensus. Every member of the PMT must be fully engaged and responsible for the project's scope, direction, objectives, and results. To make this process work, all members of the PMT need to own the product as well as the process.

A key example of the value in reaching early and continuing consensus is the need to develop an exit strategy. The goal of any remediation project is ultimately to reach completion by bringing the site to an acceptable, selected end state. However, often times it is difficult, unless agreed to in advance, to know that the end state has been reached and, therefore, at what point the project is complete. An important element of all PMT discussions should be the development of an exit strategy designed to achieve project closeout quickly. The earlier the parameters defining closeout can be defined and agreed upon, the more streamlined and efficient the activities will be that are required to achieve closeout. Conversely, closeout will be costly and delayed if members of the PMT have differing perceptions about basic closure requirements.

Operation

The PMT operates through continuous communication and by holding meetings and conference calls in which decisions are identified, discussed, and made. This means that each member is informed of all planning, results, and other issues throughout the project. For example, all members of the PMT should be aware of major uncertainties (e.g., unknown conditions or parameter values) that could jeopardize project objectives. The PMT also understands and agrees on those contingencies that will be implemented in the case that negative impacts of uncertainties are encountered.   When there are surprises, they should be surprises to all parties. Presumably, if everyone agrees to the methods being applied and the use of the data to support making identified decisions (and this agreement is clearly communicated and documented), there will be little controversy about results after the fact. Therefore, there will be few instances where work needs to be redone, or members of the PMT (or other stakeholders) second guess the efficacy of methods after their application.

Key activities of the PMT can be categorized into three main areas:

- Planning - What is the problem (Problem Definition)?
  - What are the decisions that address the problem?
  - What are the decision criteria?
  - What data support making the decisions?
  - What confidence level does each decision require?
  - What are the consequences of a decision error?

- Communicating
  - Internally to technical support
  - Upward to management
  - Outward to other stakeholders

- Documenting
  - Formalize agreements
  - Ensure permanence of knowledge and decisions (knowledge management)

Planning activities focus on identification of the decision logic to be followed. For example, the PMT needs to identify what decisions will be made, what criteria will be used to make the decisions, and what actions will be taken if criteria are exceeded or not exceeded. The PMT is responsible for communicating this information "up the chain" and outward to other stakeholders. Communication does not mean that reports of completed work are merely distributed to interested parties. Communication should include briefings on the scope of planned activities, the alternative courses of action for which decisions need to be made, the criteria and rationale for those decisions, and the consequences of making a decision error (an incorrect decision). Furthermore, the PMT must document the decisions that are made. This will ensure programmatic progress survives personnel changes and ensures that knowledge will be passed on to future stakeholders and those ultimately responsible for stewardship if constituents are left in place for extended periods of time.

It is key to remember that while documentation must be produced to communicate and memorialize the process and results, documentation in and of itself is neither an objective nor an end point. Documents should never be set as milestones. Milestones should be completion of defined tasks. Documents can then be used to memorialize the completion and archive supporting information. These documents may represent defined points in a project schedule.

The PMT functions through the life of the environmental restoration program, applying the other three Principles as appropriate. The means by which those Principles are applied evolves with the stage of restoration activities being conducted as follows:

- Pre-Decision Document - PMT
  - Prepares problem statement
  - Selects candidate response actions for consideration
  - Recommends preferred alternative
  - Approves uncertainty management strategy

- Response Design and Implementation - PMT
  - Develops consensus interpretation of decision document
  - Defines/agrees on remedial action objectives
  - Interprets performance measurements and monitoring data
  - Approves designs
  - Determines need to implement contingency plans

- Post-Construction Completion or Closure - PMT
  - Conducts 5-year reviews
  - Reviews monitoring data
  - Directs implementation of contingencies when necessary

Implementation

Although the Principles themselves are not new, effectively applying the concepts into restoration projects is an evolving process. The level of success in implementing the Principles is directly related to the effectiveness of the PMT. However, there are significant challenges that the PMT will face throughout of the project:

- Lack of empowerment;
- Budget constraints;
- Fear of sharing (and taking) responsibility; and
- Existing relationships.

Empowerment is a common problem for members of the PMT. Project managers are often not authorized to make agreements. When consensus is reached by the PMT only to have higher authorities withhold approval, future cooperation is jeopardized. Understandably, participants are reluctant to expend time and effort in decisions that they have no confidence will survive. If PMT representatives cannot be delegated decision authority, they should increase the frequency of their communication with their management to better identify those decisions that will sustain management support.

Budget constraints are particularly challenging. The Army representative on the PMT has no ability to make budget decisions. Moreover, budget cycles are not well suited to timely response to new information as it is developed. As a consequence, it is common for consensus decisions to be thwarted on the basis of a lack of available funds for implementation. The impact of this dilemma on cooperation within the PMT can be minimized by open discussion of budget constraints on an ongoing basis, and prioritization of activities within individual budget categories. In addition, there needs to be concerted efforts by the PMT Army representative to fairly articulate the PMT decisions in requests for funding submitted to management. At the same time, EPA and State representatives need to recognize the funding constraints are not superimposed by installation staff and should not create barriers to a smooth working relationship at the PMT level.

There is a natural tendency for installations to not want to share all information. This is particularly true of information that might make contamination seem worse than it is, or lead to more extensive cleanup requirements. Similarly, regulators may be reluctant to share responsibility for decisions that may not be popular with some stakeholders or that appear to imply too close a working relationship with the Army. These attitudes are counterproductive. As indicated previously, open communication of all data is essential to increasing the likelihood of making the right decision. While all significant information will ultimately come out, sharing the information early can minimize the potential for damaging relationships and maximizes the chances of finding mutually agreeable interpretations. (This is not to say that all data should be shared prior to validation. If all parties are comfortable with the context and uses of unvalidated data, it may be possible to disseminate it within the PMT; but unvalidated data can be taken out of context and lead to unnecessary expenditures associated with subsequently having to lay invalid data to rest.)

Existing relationships can create barriers to cooperation. If members of the PMT have had an adversarial relationship in the past, it may be difficult to put that aside and work cooperatively in the future. This is particularly true if there are basic trust issues involved. In these circumstances, there may be merit in changing one or more of the members of the PMT to facilitate getting a fresh start.

In the end, the best approach to meeting these challenges is to develop a working team and jointly make decisions from the start. Some attributes of a successful team include the following:

- ***A common goal***, mission or purpose which is accepted by all members (it may help to articulate this in writing at the outset).
- ***Interdependence*** within the team -- members understand how they need each other in order to be successful.
- ***Shared decision making*** in working toward the common goal.
- ***Mutual accountability*** for team performance.
- A sense of ***"sink or swim" together*** as a group.
- ***Competition is external*** to the team; a group with internal competition is not a team.

Every member of a successful team is focused on the common goal. The team is goal-oriented, rather than a group of people focused on personal tasks.

Summary

Early, frequent, and open communication within the PMT and externally to management and other stakeholders along with cooperation amongst team members allows the PMT to function as a single entity focused on execution of their responsibilities. Time and effort lost as a result of poorly functioning teams and miscommunication drain valuable resources and create additional barriers to streamlining. Only when the PMT functions as a team can it apply the other Principles of Environmental Restoration effectively.

3. PROBLEM IDENTIFICATION AND DEFINITION

Introduction

More than any of the other three Principles, clear and concise problem definition appears to be a simple statement of the obvious; and in many respects it is. Unfortunately, as environmental restoration has become more common, it has become process oriented and has drifted away from this focus. Practitioners can be observed performing activities prescribed in general guidance irrespective of the presence of a connection between those activities and the objective of the immediate work (i.e., select the appropriate response alternative). As an example, many data collection efforts are justified on the basis that they are needed to characterize the nature and extent of contamination as discussed in the NCP, even though available data are sufficient to provide the core information needed to move forward with a response decision and implementation. In these cases, characterization is being conducted for its own sake with no identified rationale about using the additional data to select between response alternatives. This has led to the seemingly endless phases of investigation with no real progress made with respect to actual cleanup. Similarly, reports identified in the NCP are declared milestones and used to demonstrate progress rather than document completion of specific tasks that entail true progress. The Principles constitute an approach to enhance the environmental restoration process that focuses on objectives and real end points rather than the process itself.

Environmental restoration is driven by two key questions:

- Does a problem exist?
- If one does, what should be done about it?

<u>Principle 2: "Clear, concise, and accurate problem identification and definition are critical"</u> and provide the focus necessary to answer the first of these questions.

Through clear, concise, and accurate problem identification and definition, the PMT creates a standard for evaluating the merits of proposed response actions. The result of applying this Principle is embodied in a problem statement that, when used properly, is a valuable tool for communicating site issues with the public at a level they can understand. The problem as defined in the problem statement is what is scoped, characterized, and ultimately remediated. Hence, it plays the central role in determining what needs to be done and why.

In practice, problem identification is integrated with the other Principles - identifying response actions, managing uncertainty, and creating an effective

PMT. The PMT is ultimately responsible and accountable for problem definition at all levels on which environmental restoration activities occur:

- Installation wide: What is the focus of the overall installation strategy and how should resources be organized to investigate and remediate areas of concern (AOCs)?

- At an operable unit (OU) or group of OUs that share common problems: What are those problems? What is the problem statement for each problem that is identified?

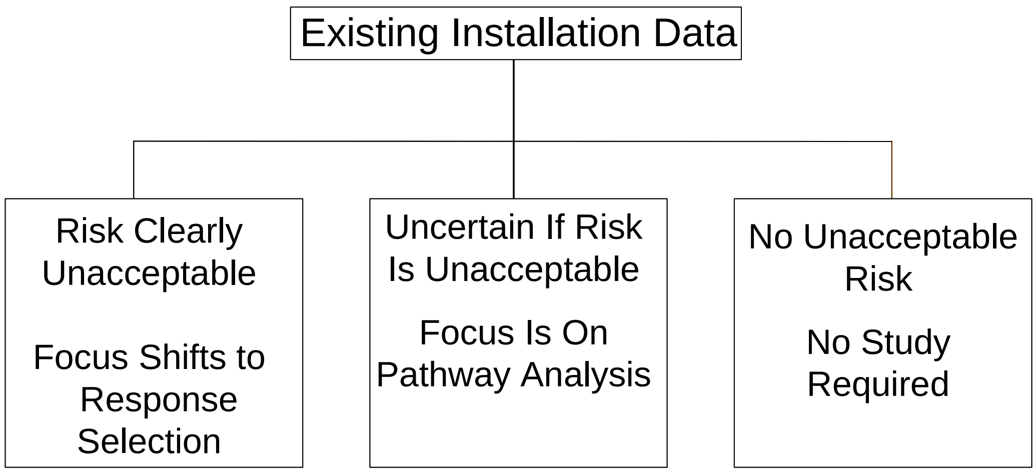
- At an individual release site: What is the condition that requires a response?

This chapter discusses the need to identify the potential problem early, document it in a problem statement consistent with the conceptualization of the site, and structure subsequent activities on the basis of what constitutes necessary and sufficient data to substantiate or refute its existence.

Problem Definition

As mentioned in the previous chapter, it is the responsibility of the PMT to identify and define problems at the installation. As employed herein, a problem is defined as *a situation posing real or potential unacceptable risk, or a condition that requires a response.* A problem may be an unacceptable potential risk to human health or the environment (e.g., evaluations may indicate that a health-based standard has been exceeded at the point of exposure), or a perceived risk (e.g., dioxin observed in soil even if no chance of exposure exists). There are thresholds that define whether a current or potential exposure pathway poses unacceptable risk. However, there are also conditions that regulations, agreements, or public perceptions delineate as unacceptable, regardless of the actual degree of risk posed. For example, underground storage tank regulations require removal or closure in-place of tanks that are not properly protected from corrosion or leakage regardless of whether they pose a risk. As shown in Figure 3-1, this determination should initially start with existing installation data.

Figure 3-1: Focus of Risk-Based Studies



Where remediation is driven by chemical releases that may pose potential or perceived unacceptable risks, there are three categories of releases that should be identified for purposes of focusing data collection:

<u>Category 1: Unacceptable Risk</u>

> This category includes releases that clearly exceed risk-based criteria to the extent that remedial action is required in the near term. The first key question has been answered: a problem exists. Any efforts expended to determine nature and extent of contamination should be scoped to address the aspects of nature and extent that will impact selection and design of the remedy. Therefore, data collection should be focused on gathering the information required to answer the second key question on what to do about the problem. These sites are candidates for removal actions if there are limited choices for a response, ongoing exposures, or the potential for substantial cost growth if left unremediated.

<u>Category 2: Uncertain Risk</u>

> This category includes AOCs where it is uncertain if releases have occurred at levels that pose unacceptable risk. More data may be required to substantiate a problem. In these cases, the primary objective for data collection will be to identify complete pathways and quantify the source and releases to determine if resultant risk exceeds the threshold of acceptability.

Category 3: No Unacceptable Risk

> This category includes AOCs where it is known that no action is required. This determination should be documented and the site removed from further consideration.

It is Category 2 that poses the greatest challenge to the PMT. Consensus as to whether a response is required often is not reached easily. There may exist situations where there is sufficient uncertainty with respect to the applicability of requirements or the estimated level of risk involved that the PMT cannot determine or agree on whether or not an unacceptable risk exists.   The inability to agree on whether a response is warranted does not in itself represent a problem; rather, this represents a data need. Because determining whether an unacceptable risk exists is a critical initial activity for the PMT, investigation activities may be required to fill the data need.   However, these activities (i.e., data collection) are not defined as a response action and, until the PMT can reach agreement on a path forward, no problem exists within the meaning of this Principle.   **A data need does not equate to a problem.**

Not all uncertainties need to be resolved. Uncertainties with respect to site characteristics, regulatory issues or technology performance are data gaps, but become data needs only when their resolution is fundamental to being able to answer one of the two key questions of environmental restoration. Information needs include data to establish with sufficient certainty that a condition poses a problem (i.e., requires a response), and data necessary to focus on what response action to take. Data gaps not relevant to these fundamental decisions are generally not significant and need not be resolved. Hence, if filling a data gap does not affect how the PMT would respond to the two key environmental restoration questions, the data gap is not likely to be a data need.

Once identified and agreed upon by the PMT, problems consist of one of three types, characterized as follows:

1. Contamination is present above concentrations associated with an unacceptable level of risk;
2. Response is required because of legal requirements or other commitments; or
3. Response can be demonstrated to be less costly than efforts required to determine if a response is required because of risk.

At Army sites, the majority of problems arise from releases of contaminants that pose a potential risk to human health or the environment (i.e., the first type of problem). This is particularly true of restoration efforts being conducted under

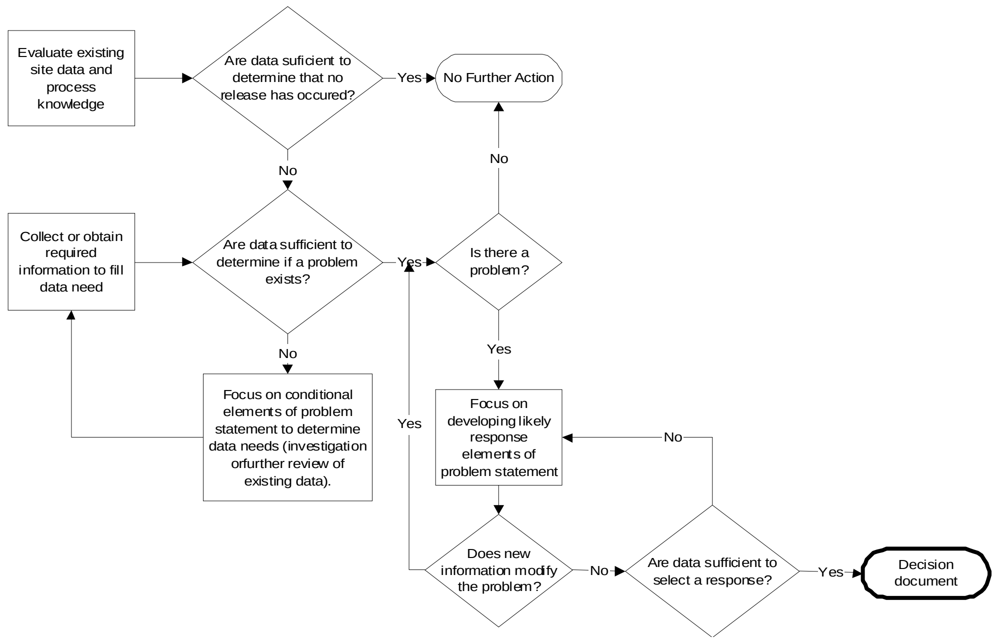
CERCLA. These problems must be characterized only to the degree sufficient to substantiate a potential unacceptable risk (i.e., demonstrate a problem exists) and evaluate response alternatives.

Other situations requiring response arise because of specific requirements in a permit (e.g., clean closure of a regulated unit, removal of related equipment) or other legal requirements that have not been met (e.g., tank removal, State requirement not based on site-specific risk consideration). This second type of problem is most often encountered when restoration is performed under RCRA or when a State program applies. Often, these requirements are clearly identified and can be accomplished without collecting data to justify no action or alternative actions. Because these responses are not risk-based, there may be no utility in conducting a risk assessment. As such this type of problem should be identified up front so that unnecessary studies are avoided.

Finally, there may be conditions that are not legally required (e.g., owner/operator internal policy) and/or will be more difficult to assess than resolve (e.g., small volume fuel release to surface soil). These situations are characterized as the third type of problem. When these situations are encountered, they should be flagged and addressed before resources are committed to unnecessary studies. Due to fiduciary responsibilities borne by Army staff, taking a response on sites where assessment is being by-passed can not be considered lightly. The PMT must carefully document the cost savings and justification to avoid the perception of having pursued an action arbitrarily.

Sorting through the three types of problems can be addressed most efficiently by sequencing the relevant decisions (Figure 3-2). Once specific legal requirement(s) beyond CERCLA are found to exist, all subsequent work should be focused on meeting the legal requirements, not on assessing risk. Remaining actions should be risk driven unless it is less costly to remove potential risk than to assess it. For these types of problems, the Army addresses its requirement to protect human health and the environment by conducting an evaluation of residual risk after the removal is performed.

Figure 3-2: Decision Logic



Problem Scope

A problem is seldom equal to an OU or an AOC. Multiple problems may exist within these unit definitions, or problems may exist across unit boundaries. For example, OUs may contain multiple types of waste disposal units, contaminants, media, receptors, and potential exposure pathways. Individual problems must be evaluated within the unit under investigation. Likewise, if soil contaminated with a particular contaminant is found throughout several AOCs, a problem can be defined once, then can be applied to all occurrences of the contaminant in the soil (barring any additional receptors or other factors).

Problem definition is the focus because poor problem definition results in poor PMT performance as evidenced by:

- Poor project focus
  - Overly extensive or ineffective investigation (e.g., trying to remove insignificant uncertainties)
  - Extended remedy selection process

- Poor project execution
  - Not fixing the problem

  - Fixing a non-problem
  - Fixing the problem at greater cost than needed

- Poor project closeout
  - Inappropriate exit strategy
  - Prolonged site closeout
  - Inappropriate or inadequate contingency plans

Problem Statement

Having defined the problem, the PMT must document/communicate the basis for response. A problem statement structured as a decision rule can be an effective tool for communication because it describes the basis for planning the decision-making process. The problem statement is a clear, concise description of the condition that may need a response. It provides linkage to the key decisions that need to be made at any point in time by specifying the condition requiring response, reflecting the current conceptual site model, and evolving as knowledge is gained.

The following are example problem statements.

- Lead is found in excess of the preliminary remediation goal, 400 mg/kg, in the top 2 feet of soil over an area greater than one-quarter acre that is anticipated to be developed for residential use.

- Groundwater quality data confirm contamination beneath the installation above the MCL for TCE while historic practices indicate a strong likelihood that a portion of the contamination is present as DNAPL. Off-site migration is indicated, but not confirmed, and the nature of residual source material in the vadose zone is unknown.

Problem statements define the circumstances that require a response. Key components of a problem statement include media, contaminants and concentrations, volumes, and regulatory or other drivers. Problem definition becomes the "if" part of an "if…then" decision rule. A decision rule includes:

- A statement of the unacceptable risk or condition (i.e., problem definition);

- The action that will be taken;

- When necessary, the data required (or sufficient) to support the decision;

- Decision criterion (action level); and

- Data statistic to be used to make the decision.

The “then” portion of the problem statement cast in a decision rule format addresses the response actions that will be taken as described in Chapter 4.

Decision rules are an accepted manner of linking together problem statements, likely response actions, and data required to support the decision. They clearly communicate how the PMT intends to respond to a given set of circumstances and what thresholds or key factors will lead to taking a specific action (i.e., they summarize the decision logic).

Decision rules are used to document what constitutes sufficient information to make a decision. The initial focus is on the decision of whether to take action (i.e., whether a problem exists). The data required to support this decision may vary widely -- from characterization information, to identification of the concentrations that pose a problem, to input on stakeholder concerns. If adequate information does not exist, it is collected only to the extent necessary and sufficient to allow for a decision to be made.

Necessary and Sufficient Data

In the context of writing the problem statement (the first key question in environmental restoration), necessary data are data that, when obtained, could substantially change the content of the problem statement. Data are not necessary if regardless of their value, the problem statement will not change (i.e., data must have the potential to change a decision about the content of the problem statement before they are necessary). Sufficiency can be defined as the amount of data needed to support the decision to the necessary (agreed upon) level of confidence.

A continuing challenge at AOCs is the identification of the point at which the investigation is sufficient to declare there has been no release (i.e., when to stop collecting data in search of a problem). By definition, there is no investigation of AOCs for which there is no history of release or any reason to believe a release may have occurred. However, there are many examples of PMTs attempting to prove the negative when poor records or anecdotes leave the issue of release in question.

For AOCs where a release may have occurred, samples are collected and analyzed to determine if chemical residues are present. Since there may be residues that do not pose a risk, soil screening levels (SSL) or preliminary remediation goals (PRG) are usually identified as thresholds. If contaminant concentrations do not exceed the threshold, there is no problem. The PMT needs to be able to make that decision without requiring extensive random sampling. Because the initial samples are usually biased (i.e., taken from the likely point of greatest contamination) these samples may generate sufficient information to make the required decision.

By preparing a good problem statement, there is a means of testing to see if proposed activities are necessary and sufficient to get to the point where the best means of resolving the problem can be selected. Once a problem statement can be written, the focus of decisions and, therefore data collection, shifts to what response is appropriate (Figure 3-2).

This Principle applies throughout the environmental restoration program, but is manifested differently depending on the phase of activity being conducted:

- Pre-Decision Document
  - Clear, concise statement of the problem

- Post-Decision Document
  - Clear, concise statement of restoration objective
  - Clear definition of performance measurements that demonstrate response completion

- Post-Construction Completion or Closure
  - Document construction is complete and/or desired end state has been reached

Summary

A problem is a condition that requires a response. Problems are what are scoped, characterized, and ultimately remediated at release sites. For Army installations, most problems are associated with chemical residues from releases that pose unacceptable risk under current or reasonably anticipated future use scenarios. Therefore, it is essential to quickly identify all relevant problems at a site and document them in problem statements as a means of communicating with stakeholders and keeping subsequent efforts focused.   Problem statements should be reviewed continually to ensure that proposed actions are consistent with the identified or expected problem and revised as appropriate when new information is obtained.

With transition to the post-decision document phases, the focus on problem evolves to a clear statement of remedial action objectives, performance monitoring goals, and the desired end state.

4. EARLY IDENTIFICATION OF LIKELY RESPONSE ACTIONS

Introduction

Principle 3: Early identification of likely response actions is possible, prudent, and necessary.

Early identification of likely response actions is possible because of the lessons learned from over 20 years of conducting environmental restoration efforts in this country. It is prudent because it can help focus subsequent activities, and it is necessary because resource limitations dictate against expenditures that do not directly support attainment of the PMT's objective. The third Principle assists in addressing the second key environmental restoration question (i.e., what should be done in response to a problem?). Hence, while the second Principle (problem identification) is directed toward identifying *what* needs to be accomplished, the third Principle is focused on *how* it is to be accomplished.

Early versions of the environmental restoration program established a process that utilized sequential activities. Initial efforts involved data collection to characterize a site, followed by analysis of all possible technologies to select the best response for resolving the problem. Two decades of experience, however, indicate that for many common scenarios, there are only a few (and often only one) technologies that will survive the selection process as the preferred choice. Indeed, recognizing circumstances when a single technology is inevitably the best selection, the EPA has developed presumptive remedies that can be selected without extensive analysis when site characteristics so warrant. The third Principle is an acknowledgement of the accumulated experience from previous efforts (i.e., it is possible to focus efforts early, and in so doing, reduce time and cost associated with evaluating alternatives that will never be selected).

This chapter discusses the merits of early identification of likely response actions through development of a hierarchy of preferred technologies, and the use of that short list of candidate responses to identify data needed to select and design the final remedy.

Shifting the Focus of Investigations

Problems, by definition, require a response. Therefore, once it is determined that a problem exists, the focus of investigations should shift from problem definition, to identifying the most likely response, or set of response actions, to address the problem. Identifying the likely response early allows the PMT to begin to focus on a remediation strategy and data needs to evaluate the suite of technologies identified as possible candidates. It helps ensure that investigation and data collection activities only take place to the extent they support the selection and design of likely response actions. This approach does not preclude a broad technology evaluation, or consideration of innovative approaches. Rather, because it seeks to eliminate those technologies with obvious fatal flaws from the range of options, it allows the PMT to seek early consensus on the likely range of potential solutions to the problem identified, including innovative possibilities.

There is no obligation under either RCRA or CERCLA to evaluate a fully comprehensive suite of alternative actions. Under CERCLA, the only remedy that must always be evaluated is no further action (NFA). Similarly, under RCRA, project managers are only required to bring forward one remedy that will meet the remediation objectives. Eliminating less viable response options early eliminates unnecessary analyses and documentation and, therefore, saves time and resources. Time is a yardstick of PMT performance; public confidence can decline and risk to project success can increase over time with inaction. Although the PMT may in fact be busy evaluating a multitude of options, in public perception, because no decisions have been made, confidence declines. A bias toward reducing the timeframe over which a given level of risk persists increases public confidence and decreases cost by eliminating unnecessary activities such as unnecessary data collection and investigation for a remedy that will clearly not meet the remediation objectives.

In addition to evaluating technical approaches, regulatory requirements must be evaluated to determine which authorities are most likely to drive decisions. As noted in the previous chapter, if a response is required regardless of risk implications, there is no utility in conducting a risk assessment. Conversely, if there is no legal driver, there may be no justification for expenditures on any kind of response (tantamount to saying there is no problem). Hence, identification of legal drivers is an important aspect of verifying the need for a response, as well as sorting through viable alternatives.

Benefits of Early Identification

Early identification of likely response actions allows:

- Early focus on appropriate remedial action objectives and key elements of an exit strategy.

- Early consideration of the implications of potential response actions and the data needs associated with ultimate selection and design of a remedy.

- Development of a hierarchy of probable technologies for a defined problem such that data collection targets only those data that are critical to evaluation of only those options that are likely to be viable.

- Early consideration of presumptive remedies, generic approaches, and a phased response.

- Implementation of removal and/or interim actions that restore the environment in lieu of studies and may minimize some unproductive activities such as redundant characterization and risk assessments of conditions obviously in need of a response.

Early identification and communication of response actions can streamline:

- Workplan development;
- Sampling and analysis needs;
- Technology evaluation;
- Documentation; and
- Design.

In essence, by focusing on a limited number of technologies early in the investigation, it is possible to address most data needs in a single or limited data collection campaign, thereby reducing mobilization and demobilization costs and time requirements to get to a decision point. Moreover, costs associated with data for the sole purpose of evaluating technologies that will never be selected are minimized. While the optimum would be to focus on the single preferred technology, the reality is that it may not be possible to eliminate all alternatives until much of the characterization work is complete. Therefore, early identification efforts target development of a short list of likely responses. This list is modified as new information is developed.

Hierarchy of Preferred Technologies

Categorizing problems includes considering likely responses. Ideally, the PMT identifies likely response actions for high priority concerns as early in the process as possible. However, there is a balance that must be struck. If identification is too early, it may well address the wrong problem, thereby leading to unnecessary activities. In general, identification of likely response actions begins when a potential problem is identified. In fact, it may be possible to identify a very limited number of response actions with only the identity of the contaminant and affected media known.

The Army has over 20 years of experience in selecting, implementing, and evaluating long-term performance of remedies at contaminated installations. The knowledge of what has and has not worked that can be distilled from that experience often allows the identification of a very limited number of technologies that comprise the hierarchy of preferred technologies. It is a hierarchy because technologies are listed in order of preference. The technologies are preferred because they have a history of being the most cost-effective, most often selected, and most successful. By focusing on this hierarchy, it is possible to anticipate data needs for the selection of one technology. Moreover, by narrowing the field of technologies early in the process, it is easier to commit resources to looking at innovative technologies with the potential to address weaknesses in more common candidates.

An example hierarchy of preferred remedies for groundwater remediation under two scenarios follows:

Scenario 1: High Permeability

1. Monitored Natural Attenuation
2. Recirculating Wells
3. In Situ Air Sparging
4. Enhanced Bioremediation
5. Pump and Treat

Scenario 2: Low Permeability

1. Monitored Natural Attenuation
2. Treatment Barriers
3. Enhanced Permeability Pump and Treat
4. Electrokinetics

If presumptive remedies exist, they should be at the top of the list of likely response actions. Presumptive remedy guidance introduces significant information on the data needs and methods to evaluate the efficiency of presumptive technologies. Moreover, presumptive remedies for specific sources, such as SVOC from wood treating, are applicable to SVOC from other sources as well. Presumptive remedy documents are available at http://www.epa.gov/ superfund/resources/presump.

Based on current presumptive remedy guidance from the EPA, there is a hierarchy of preferred technologies for every major category of contaminant in soil:

Volatile Organic Compounds

1. Soil vapor extraction (SVE)
2. Excavation with thermal desorption
3. Excavation with incineration

Semivolatile Organic Compounds

1. Biological degradation (either in situ or ex situ)
2. Excavation with thermal desorption (not recommended for explosive contamination above detonation thresholds)
3. Excavation with incineration

Metals and Inorganic Contaminants

1. Reclamation/recovery
2. Solidification/Stabilization
3. Containment e.g., capping

For solid waste landfills, the presumptive remedy is capping after identification and removal of large deposits of drummed liquid wastes.

For ground water, the default remedy has been extraction with wells or trenches followed by treatment. Innovative technologies such as permeable treatment barriers and in situ oxidation are demonstrating sufficient promise that they may soon be recognized as presumptive for sites with specific characteristics.

Removal and interim actions eliminate unnecessary characterization efforts and can reduce the likelihood of extensive, low value requirements in the future while facilitating more rapid closeout.

Technology-Driven Data Needs

As mentioned earlier in this chapter, once a problem has been substantiated, the focus of investigations should turn to identification of likely response actions. When likely response actions have been identified, data needs include the information required to assess fatal flaws and characterize selection parameters to assist the PMT in choosing among remedies. *Fatal flaws* are site conditions or parameter values that would make a remedy impossible to implement effectively or render it much less desirable relative to other remedies. Examples of fatal flaws for possible remedies include the following:

- Caps - waste buried below water table so that dissolution will continue even if infiltration is eliminated.
- Excavation - contaminant lies below buildings in active use whose structural integrity and utilities cannot be safely jeopardized.
- Permeable Treatment Wall - absence of an impermeable layer to key the wall into so that plume underflow is likely.

Selection and design parameters are conditions or characteristics the nature/value of which will affect whether one remedy would be preferred over another, and how the selected remedy would be designed. Examples of selection and design parameters include:

- Caps - nature of release mechanism of concern (i.e., volatilization such that gas migration or extraction controls are required; direct contact such that armoring or a buffer of clean soil and access restrictions are required; infiltration/percolation to groundwater such that an impermeable layer and/or net positive evapotranspiration balance are required).
- Excavation - depth of contamination with respect to selection among various options for equipment with different depth capabilities.
- Permeable Treatment Wall - aquifer permeability from which wall thickness and/or continuous vs. funnel and gate decisions are made.

Design basis questions are a tool that can be applied to identify fatal flaws and selection parameters for most common remedies. The design bases for 16 common remedial action technologies are provided in supplemental materials appended to this manual

Completion of the Problem Statement

The remedy selection process utilizes the DQO process to ensure that only necessary and sufficient data are obtained. *Necessary* data include any information, the nature/value of which would change the selection of a remedy to an alternative. Data are *sufficient* when the AOC is characterized relative to the fatal flaws and key design parameters of the selected remedy.

When a limited number of likely responses can be identified, the problem statement can be expanded into an "if...then" decision rule. If a single response is not indicated, the "then" portion of the statement can be tiered with an indication of the criteria that would be used to select among the hierarchy of preferred technologies. For example: If lead is found in the top 2 feet of soil in excess of the PRG, 400 mg/kg, across one-quarter acre or more, then a phytoremediation pilot study will be conducted. If the pilot study results indicate the lead PRG can be achieved in less than 3 years, then phytoremediation will be selected as the final remedy. If phytoremediation is not selected, then the soil will be removed and treated for reclamation and/or immobilization of the lead.

Use of the decision rule form for the problem statement furthers its value as a tool for effective communication by clearly identifying the likely responses and the conditions under which each would be selected. Advantages of writing a decision rule statement are that it:

- Provides a clear path forward;
- Reduces potential for unnecessary work; and
- Highlights identity of remaining issues.

To the extent possible, it is good to advise stakeholders of the criteria that will be used to select among alternatives or alert them to a single technology being considered so they can voice concerns early in the process. Ideally, when the final recommendation is made for a remedy, stakeholders will have been prepared and understand how the selection was made.

The third Principle, early identification of likely response actions, applies through all phases of the environmental restoration project. In the pre-decision document phase, it calls for early identification of likely response technologies. In the post-decision document phase it evolves to early identification of the design basis.

For stewardship, the third Principle focuses on early identification of long-term care requirements and the contingencies that should be implemented if performance monitoring suggests objectives are not being met.

Summary

When a problem has been substantiated, the primary purpose of remaining investigatory activities shifts to selection and design of an appropriate response. Hence, there is much to be gained by narrowing the field of probable responses early in the program and using the identity of reasonable alternatives to focus data collection activities. Many times, the field of candidate technologies can be narrowed early enough in the project to accommodate integration of data collection activities needed to substantiate a problem with those used to support selection of the preferred remedy. To the extent that there is a strong likelihood a problem does exist and there are economies with combining the efforts, the early identification of likely responses facilitates streamlining.

EPA guidance on presumptive remedies and prior experience from similar sites are good sources of information from which to select a hierarchy of preferred technologies. Design bases for selected technologies can then be used to identify key data that are required for selection and design activities. Likely response actions are documented as the "then" portion of a decision rule formulation of the problem statement. Criteria for selection among alternative responses should be articulated early and communicated with stakeholders.

5. MANAGING UNCERTAINTIES

Introduction

Since much of the contamination at sites occurs in groundwater and subsurface rock and soil, it is difficult to characterize the nature and extent of residual contamination and migration pathways. Similarly, the multiplicity of contaminant-matrix combinations and related factors make it difficult to predict how effective a remedy will be in advance. Furthermore, it is impossible now to determine what all future site uses and potential exposure scenarios are likely to be. Site characterization, design, and implementation efforts can quickly become complex
and time consuming if one seeks to remove all unknown or uncertain conditions and parameter values. Therefore, it becomes necessary to manage uncertainty by weighing the costs and impacts of reducing unknowns through data collection now, against the costs of having to implement contingency plans to address potential issues if the unknown conditions prove to be problematic in the future.

The consequences of residual uncertainties can vary greatly. If a response action is sufficiently robust, it may be unaffected by deviations in the site conditions, thus removing the need to narrow the uncertainty surrounding those conditions. In other cases, alternate conditions may prove fatal to a design and necessitate formulation of contingency plans so that a response action need not be halted when and if those conditions are encountered. The optimum balance point between reduction and mitigation of uncertainties will be site-specific and can be identified by reasoned application of uncertainty management concepts.

This chapter discusses the need to determine the significance of unknowns (uncertainties) and describes the two alternatives for managing those uncertainties that are significant to the decisions being made. An uncertainty matrix is introduced as a tool to facilitate evaluation of the optimum management strategy for a site, balancing uncertainty reduction through data collection and uncertainty mitigation through application of robust technologies and contingency plans.

Unknown=Uncertainty=Data Gap Significant Uncertainty=Data Need

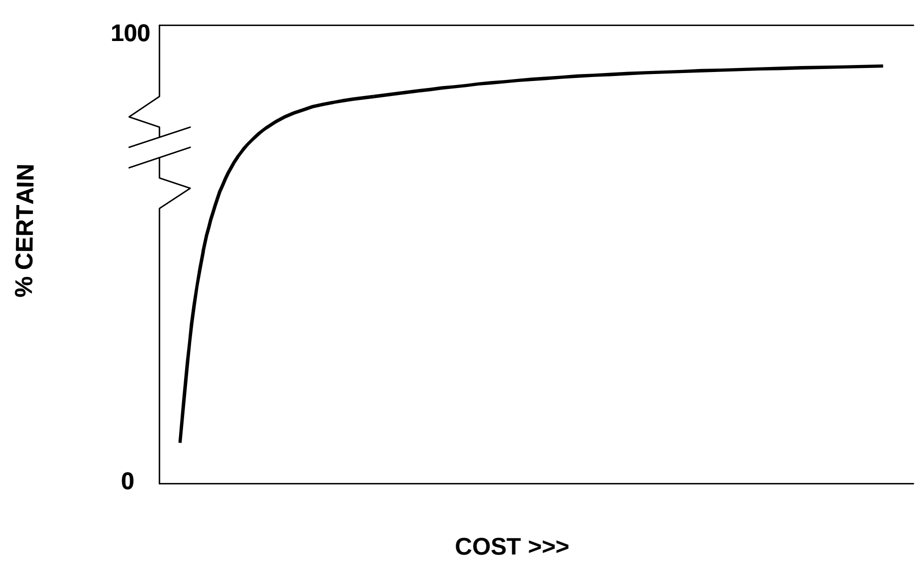
Inevitability of Uncertainty

Principle 4: Uncertainties are inherent in environmental restoration and must always be managed.

Uncertainty management is essential for accelerated progress in site restoration because it helps PMTs make decisions when complete information is not available. Since resolution of all uncertainties or unknown conditions is not possible, the PMT must be able to distinguish between significant and insignificant uncertainties, make decisions when uncertainty exists, and effectively communicate how uncertainties are addressed.

It is important to note that, for decisions based on environmental measurement, no amount of resources can eliminate uncertainty and no management plan can guarantee that some degree of uncertainty does not remain. Figure 5-1 illustrates the relationship between investigative cost and uncertainty reduction. Theoretically, there is no limit to cost. Theoretically and pragmatically, 100 percent certainty cannot be achieved.

Figure 5-1: Data Utility Curve



Historically, it was assumed that uncertainty was resolved once site characterization was complete. If conditions were not well characterized, default values were assigned and presumed to be correct. The probability that assumed values were not correct, and the impact of uncertainties related to technology performance and future site use, were not formally addressed. However, the inevitability of uncertainty is clear in the universal use of monitoring with any remedy that leaves chemical residues in place. If there were absolute certainty in the effectiveness of a proposed remedy, no monitoring would be required. The imposition of monitoring requirements is a clear acknowledgement that uncertainties in technology performance persist.

This Principle focuses on an opposing approach wherein uncertainties are clearly identified and a formal strategy for their management is developed by the PMT. Uncertainties of many types must be understood and managed to generate effective restoration strategies. Page one of the CERCLA guidance for RI/FS says:

> *"A significant challenge . . . is the inherent uncertainties . . . ranging from potential unknowns regarding site hydrogeology and the actual extent of contamination . . . . While these uncertainties foster a natural desire to want to know more, this desire competes with the Superfund program's mandate to perform cleanups within designated schedules. The objective of the RI/FS process is not the unobtainable goal of removing all uncertainty, but rather to gather information sufficient to support an informed risk management decision . . . . As hypotheses are tested and either rejected or confirmed, adjustments or choices as to the appropriate course [of action] are required. These choices . . . involve the balancing of a wide variety of factors and the exercise of best professional judgment."*

Key Concepts in Uncertainty Management

In order to develop an effective uncertainty management strategy, it is important to be able to perform three tasks:

1) Determine the significance of the uncertain parameter and the consequence of assuming an incorrect value;
2) Evaluate tradeoffs between cost of data collection and "decisional benefits" obtained compared to the cost of mitigation through adoption of contingency plans; and
3) Achieve PMT consensus to optimally balance data collection and contingency planning.

These tasks are best performed when the following are understood:

- The impact of uncertainties on project objectives (i.e., knowing whether the PMT can "afford" to be wrong (and how wrong), or whether the PMT must be right). If the value for a parameter is not known, but any probable value will not change the decision being made, the data gap is not a data need and, by definition, the uncertainty is not significant.

- Tradeoffs between the benefits gained from additional information (e.g., ability to use less expensive response) versus the cost (funding and schedule) to obtain it. The tradeoffs illustrate the central concept of determining when uncertainties can be managed in an effective and efficient manner.

- A strategy for managing uncertainty should be defined that will provide the balance between reducing and counteracting uncertainty at the least cost. In some cases, the uncertainty must be reduced to acceptable levels through investigation (e.g., review existing data, site characterization, treatability studies). In other cases, the residual uncertainty is counteracted by contingency planning (If X happens, then do Y).

- The approach to managing uncertainty must be a PMT consensus. The history of a site may make it important to have a wider level of comfort (less uncertainty) than would be acceptable to just the PMT or technical project team staff. The process for establishing acceptable levels of uncertainty may include the general public (e.g., a restoration advisory board).

- Consideration of uncertainty starts in scoping and continues through implementation.

For any given installation, there is a balance of uncertainty reduction and uncertainty mitigation that is optimum with respect to cost, time, or risk objectives. At some sites (e.g., an area with surface soil contaminated by dioxin), strenuous efforts to reduce uncertainty in advance may pay off in a much more efficient cleanup because of the high cost associated with any efforts to remove and destroy this contaminant. At other sites (e.g., a heterogeneous landfill), prior characterization may have little benefit, because of the impracticability of identifying representative samples, and the challenge is to manage uncertainty during remediation. At most installations, both approaches are used to some degree. Optimization means striking the right balance between the two.

Significant Uncertainty

The significance of an uncertainty arises from the degree to which the value of an unknown parameter or condition impacts a decision that must be made. If the same decision will be made regardless of the value, the value has no benefit to that decision and the uncertainty is insignificant. On the other hand, if the range of probable values for an unknown parameter or condition includes those that could change the outcome of the decision, the uncertainty is significant. When addressing decisions as to whether a problem exists, significant uncertainties include contaminant concentrations, the presence of pathways and receptors, and the nature of future site uses. When addressing decisions related to selection of a response, significant uncertainties include those associated with fatal flaws (i.e., ability to meet remedial action objectives) and selection parameters (i.e., characteristics that make one alternative preferable over all others) for the hierarchy of preferred technologies.

For an uncertainty to be significant, there must be the potential for at least two conditions or values, one of which would change the pending decision. This implies that within the range of probable values for any significant uncertainty there lies a decision criterion (threshold value) at which the decision would change. For example, a PMT is considering selecting soil vapor extraction for removal of solvents from contaminated soil and the permeability of the soil is not known. The uncertainty is significant for the remedy selection decision if the range of probable values spans a threshold value of 10-5 cm/sec at which point extraction becomes infeasible.

There are two types of insignificant uncertainties (i.e., do not represent a data need): 1) Those that are insignificant due to the nature of the uncertainty; and 2) Those that are insignificant because the range of probable or likely values falls completely below (or above) the threshold at which a decision would be changed. Insignificant uncertainties for a given problem (i.e., those that do not affect the overall direction of the project) are not necessarily trivial. For example, if a storage area has a capacity of 100,000 cubic yards and a response will only generate between 3,000 and 10,000 cubic yards, the volume of material to be generated is insignificant to the action. However, using up to 10 percent of available capacity for one response may create other installation-wide issues. Therefore, the PMT must review uncertainties in all relevant contexts before dismissing them.

Alternatives for Managing Uncertainty

Uncertainty can be managed through reduction or mitigation. *Reduction* is accomplished by collecting sufficient data to narrow the range of probable values until it no longer spans the relevant threshold for the decision being made. In the example from the preceding section, soil vapor extraction tests could be conducted in hopes that better data would indicate soil permeability was characterized as being greater than or less than 10-5 cm/sec. *Mitigation* is accomplished by making the decision in a way that is insensitive to the uncertainty (e.g., has a higher or lower threshold so that the range of probable parameter values no longer spans the threshold). The latter may be achieved by identifying a contingency that would be invoked if the true value were found to lie on the other side of the threshold than assumed when the decision was made.

The remedy being contemplated can affect both the significance of specific uncertainties and the identity of the optimal means of management. For example, at a landfill where exhumation is being considered, volume to be

excavated can be important with respect to capacity of the proposed disposal site. Volume would not be important if capping were contemplated. In the former case, the volume uncertainty is best mitigated by having a contingency plan for dealing with extra volume and proceeding with implementation, since the exact volume can not be known until excavation is complete. (There are numerous examples of extensive characterization efforts underestimating volumes to be excavated because of soil heterogeneities and the cost of sampling on a fine-scale grid.)

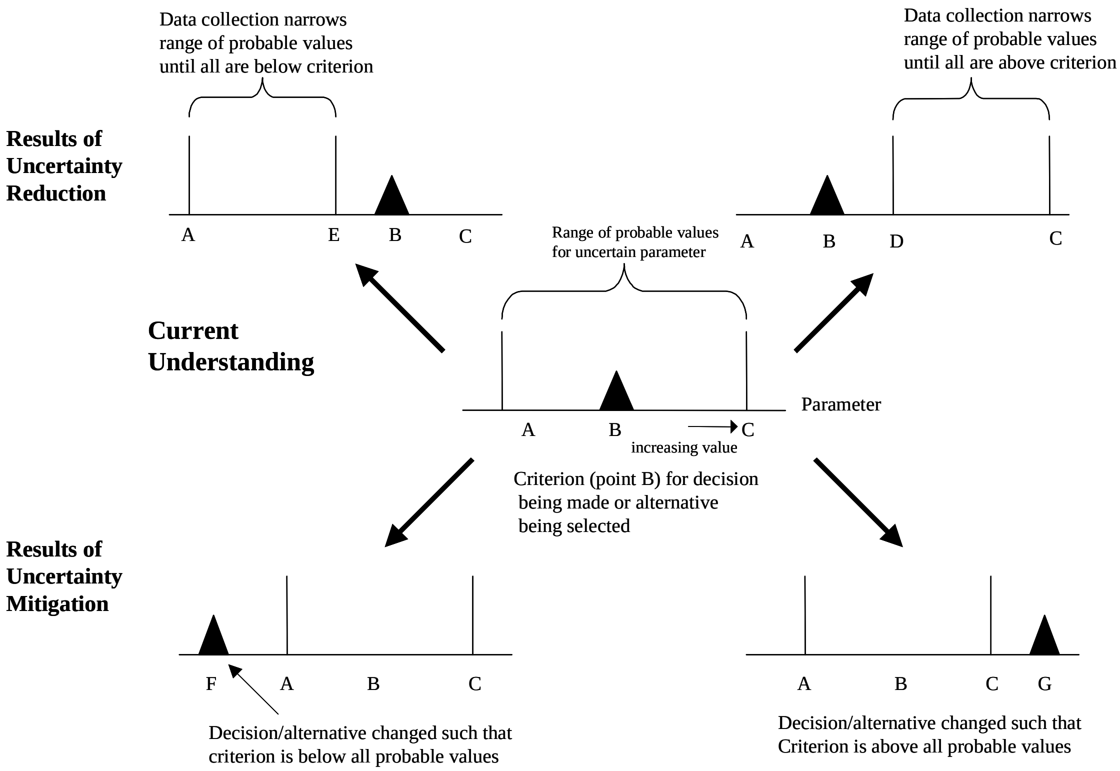
Alternatively, if capping to preclude leaching is contemplated, the presence of waste below the water table is a fatal flaw. Implementation will not lead to discovery of the flaw and will frustrate attempts to mitigate the problem. Therefore, this is an uncertainty that must be reduced. The presence of submerged waste may not be all that significant for the exhumation option unless depths are sufficient to necessitate dewatering or shoring.

Uncertainties must be understood in order to be managed effectively. Organization, documentation, and planning of environmental restoration projects must be performed with the uncertainties and their consequences in mind. There are numerous ways in which the PMT can be "wrong" or uncertain about an installation and its problems. Categorizing uncertainties by source helps to focus on the type of data needed to manage or reduce the uncertainties identified. Sources of uncertainty include site characterization, technology selection, regulatory requirements, and future land use. These sources of uncertainty are interrelated. For example, uncertainties in site characterization lead to uncertainties in whether a technology will work and what regulations apply. Uncertainties in technology performance can lead to uncertainties in regulatory compliance.

Significant uncertainties that must be reduced prior to an action represent data needs. The data may be obtained prior to implementation of a remedy (e.g., site characterization, pilot-scale treatability study), or it may be possible to collect the data during implementation. Significant uncertainties that can be managed effectively are those that can be addressed through a contingency plan. Such contingency plans are included in decision documents, or subsequent design documents.

The approach to managing uncertainty will include both reducing and mitigating uncertainty (Figure 5-2). The challenge is to reach PMT consensus in establishing the balance between the two components.

Figure 5-2: Options for Uncertainty Management



Characterizing Uncertainty

Uncertainty management allows the PMT to change emphasis from assessment to implementation where appropriate (Figure 5-3). Uncertainties can be characterized by the following information:

- Likely or expected condition - this is the assumed value for the unknown parameter or condition given all available data (e.g., permeability is 5x10-4 cm/sec).

- Range of probable values including all reasonable deviations from the expected condition - this is the full range of probable values for the unknown parameter or condition estimated from the available data and any bounding calculations that can be made (e.g., soil size characterization is categorized in literature as having a potential permeability range of 10-3 to 10-6 cm/sec).

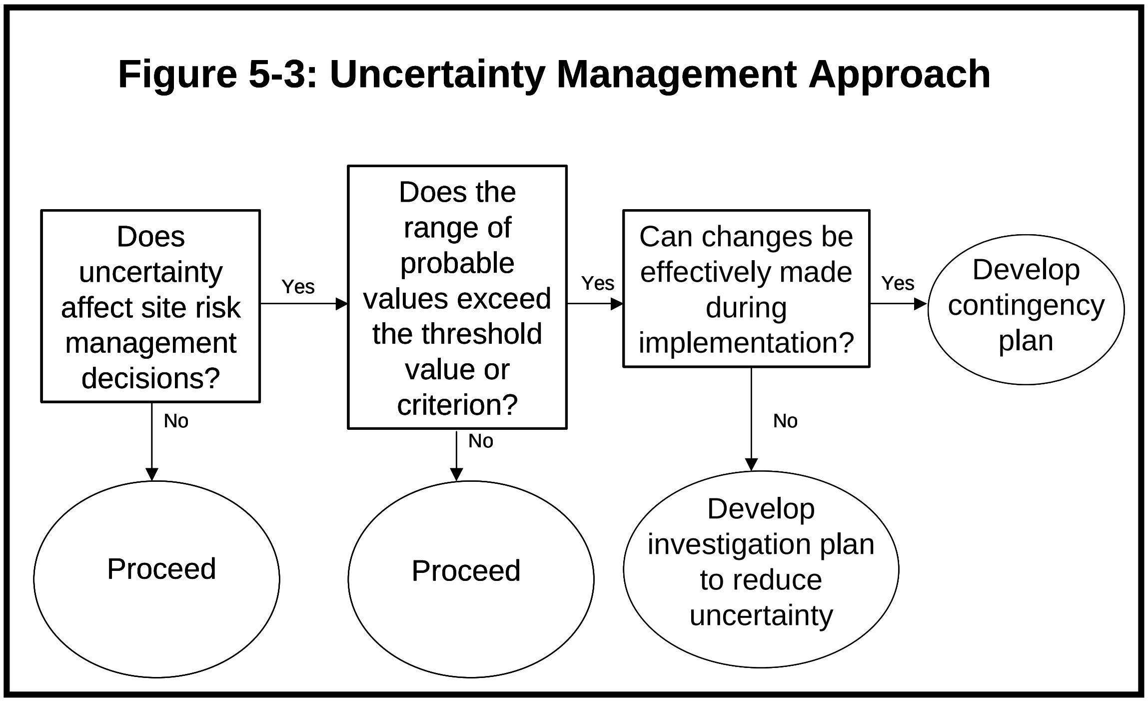
- Probability of occurrence - this is a qualitative statement of the likelihood that the assumed value is significantly wrong (e.g., high, medium, or low).

- Time to respond - this is an estimate of how long the PMT would have to correct for a deviation once the true value was observed (e.g., years -- since low permeability would minimize potential impact of soil contamination on ground water, delays in implementation would not add significantly to immediate risk).

- Potential impact on problem response/resolution - this is an indication of how the deviation would impact response effectiveness or attainment of remedial action objectives and should identify any threshold value that may be relevant (e.g., if permeability is less than 10-5 cm/sec, extraction will not be effective and time to cleanup will be extended decades).

- Monitoring plan - this identifies the means by which the uncertain parameter or condition could be monitored during implementation to detect deviations from the assumed value (e.g., measure pressure drop between extraction and observation wells and calculate indicated permeability).

- Contingency plan - this identifies the course of action to be taken if monitoring indicates that a significant deviation does exist (e.g., pneumatic fracturing will be performed throughout the contaminated zone).



All factors are assessed to determine how an uncertainty will be managed - either by reducing it or developing a contingency plan. The example uncertainty management matrix provided in Figure 5-4 focuses on uncertainties associated with the implementation of a likely response action, and illustrates how this tool can be used to help organize information needed to classify identified uncertainties into the following categories and document the management strategy:

- Uncertainty insignificant to ultimate objective - probable values do not span decision criteria.
- Uncertainty must be reduced with more data - uncertainty is significant and cannot be mitigated at less cost than that required for data collection to reduce it.
- Uncertainty significant, but can be managed by contingency plan at lower

cost than data collection required to reduce it.

Figure 5-4: Categorizing Impact of Uncertainties

Consider a landfill which is to be exhumed to meet regulatory requirements for closure.

Probable Condition	Reasonable Deviation	Probability of Occurrence	Time to Respond	Potential Impact	Monitoring/ Investigation	Contingency Plan
Saturated soil conductivity expected to be 10E(-4) cm/s	Conductivity likely to range from 10E(-2) to 10E(-7) cm/s	High (based on existing hydrogeologic data)	Long	Low - May impact the drainage of rainwater if <10E(-4) cm/s	N/A	Insignificant - No impact on likely response action.
Soil is expected to be stable (i.e., greater than Class C)	Soil may be unstable (i.e., <50% or soil is less stable than Class C)	Low (based on results of previous slump tests)	Short (excavation face may sluff or cave in)	High - Threat to worker safety - Could increase cost or delay schedule	Conduct visual inspections an additional slump tests	Significant - Shore walls - Lay back excavation
Contents are expected to be solid waste only	Hazardous waste may be encoun-tered	Medium (based on process knowledge	Short (to prevent excavation from being delayed)	High - May delay excavation - May increase disposal costs and change handling requirements - May pose worker safety problems	Sample and analyze excavated materials; compare results to regulatory criteria	Significant - Develop contingency plans for excavation, storage, and disposal of hazardous waste; analyze cost impacts to ensure available funding

Uncertainty management is appropriate for both individual projects and larger installation-wide programs. In both cases, it starts with the initial assessment of existing data and the initial construction of the conceptual site model (CSM). With an initial CSM, uncertainty management assists in defining the data needs and/or other strategies for addressing uncertainty with respect to the existence or nature of a problem. Once a problem has been substantiated, its focus is on whether the technology can meet the desired cleanup objectives. The uncertainty management strategy should be addressed formally in the documentation of the investigation results, technology evaluation, and remedy selection. Finally, it is evaluated throughout remedy implementation to determine if any uncertain conditions are realized.

The consideration of uncertainties and their impact does not occur at any one discrete point in time. Rather uncertainties are continually evaluated throughout the investigation, design, and implementation phases. The iterative nature of the feedback is particularly evident during implementation. For instance, the nature of residual uncertainties may influence the type of contract vehicle being considered. Once a contract type is selected, contingencies must be scoped into the statement of work. If contingency costs are too high, an alternate design basis may be appropriate. Ultimately, the alternate design may best be implemented through a different contract vehicle.

Uncertainty management occurs in all phases of environmental restoration. In the pre-decision document phase, the emphasis is on determining the viability of potential risk pathways or other essential elements needed to substantiate the existence of a problem. In the post-decision phase, uncertainty management is used to decide among designs and contingencies that are robust enough to ensure protectiveness in the event that assumed values were in error. During post-construction or closure, the emphasis is placed on conduct of long-term monitoring and interpretation of results to indicate if the remedy is performing in a manner that will meet objectives or if contingency plans must be implemented.

In summary, categorizing uncertainties:

- Forces explicit statements and consensus on uncertainties that may exist.

- Establishes agreed to approaches to manage uncertainties: Lack of explicit recognition of uncertainties, lack of consensus, and lack of planning on how to proceed will create substantial project management and project performance issues.

- Makes explicit the needs for data collection and/or contingency planning: Once problems are defined, data collection, studies, investigations, and analyses should be focused on identifying and planning how to manage uncertainties by balancing the means of reducing or mitigating.

- Helps document how the response will proceed: Uncertainty management strategy needs to be explicitly agreed to among PMT members and communicated with other stakeholders.

- Facilitates closeout by minimizing pursuit of unneeded data.

Not defining and discussing acceptable uncertainty is the source of most differences in opinion. The more explicit the PMT is in what uncertainties exist, what their impacts are, and how they will be addressed, the more likely it is that a consensus can be reached.

Summary

Uncertainty is inherent in environmental restoration. If the uncertain parameter or condition has an impact on a decision that must be made, it is significant and must be addressed specifically in the uncertainty management strategy. Uncertainties can be reduced through data collection or mitigated through use of robust technologies or contingency plans. The selection between the two options should be driven by the cost associated with each and the potential impacts of making a wrong decision. In general, most practitioners default to reduction even though that often involves higher costs. Moreover, many insignificant uncertainties are similarly reduced with no net benefit to the project.

Uncertainty management should be undertaken formally with a documented strategy that clearly outlines the residual uncertainties and the basis for selecting the management technique applied. An uncertainty matrix is a useful means of organizing the required analysis and communicating the resulting strategy.

6. CONCEPTUAL SITE MODELS

Introduction

The four Principles of environmental restoration presented in chapters 1 – 5 provide a philosophy and framework for conducting site investigations, remedial design and implementation and, when necessary, long-term care of sites. Chapters 6 – 9 present tools and methodologies for conducting site work that embrace and embellish upon the Principles.

A conceptual site model (CSM) is a depiction of key elements and interfaces that describes the fate and transport of contaminants from source to receptor at a given AOC. It is a means of organizing data, identifying decisions to be made, identifying significant uncertainties, and communicating the overall understanding of the site amongst the PMT and technical support as well externally to stakeholders. It facilitates development of the problem statement, and to the extent that viable responses must control sources, interrupt pathways, or isolate receptors, it assists in identifying the hierarchy of preferred technologies. Finally, it serves to identify data needs and provides a means of determining their significance relative to whether a problem exists.

This chapter describes the uses of the CSM and provides guidance on form and content that maximize its utility as a means of communicating with stakeholders. The linkage between the CSM and the problem statement are explored with particular emphasis on considerations relative to future site use.

The CSM as a Management Tool

Any model is a cartoon or abstract of reality. It is intended to convey relationships and interfaces between component parts in a form that enhances one's ability to understand those interrelationships and use them in a diagnostic and/or predictive mode. There are many formats for models depending on the intended use and the complexity of data available to put in them. A CSM can be a simple drawing or diagram, a narrative description, or a sophisticated numerical construct depicting the spatial relationship of key elements that determine the fate and transport of contaminants such as location of source materials, the direction of transport, presence and nature of media affecting transport, and extent of contamination.

Initially, a CSM is used to organize information on how contaminants have potentially been released and transported. Ultimately, it helps to conduct evaluations of complete chemical transport pathways and focus on appropriate response actions. For a potential risk to be associated with a release, there must be a complete pathway from the source to a receptor and the receptor must be there when the contamination arrives or is still present. As a consequence, risk-based concerns only exist when transport by complete pathways is sufficient to exceed acceptable risk levels in the time frame in which exposure, human or ecological, will occur. The data needed to characterize chemical transport pathways are identified (to an appropriate degree) through use of the CSM. The presence of receptors and the degree of exposure are most often determined by the likely land/resource use patterns present at the time of arrival (based on EPA directives on land use determinations).

For maximum benefit, the PMT can use the CSM to assist in identifying critical decisions, and then communicating those decisions effectively. This is contrasted with a common approach wherein the CSM is simply a product of the remedial investigation. The PMT can also use the CSM to show how the understanding of site conditions changes as additional data are collected, or to illustrate why data collection activities are not needed to proceed. As such, there are three key concepts regarding CSMs:

1. The CSM is used to organize and communicate information about site characteristics.

The CSM should reflect the best interpretation of available information at any point in time (i.e., the model should be considered a reflection of current understanding rather than a single point in time). If new data are found to be inconsistent with the model, either the data are in error, or the model needs to be revised. Similarly, any hypothesis posed for the site and any remedy evaluated must be consistent with the CSM. Evaluating a remedy that relies on mechanisms inconsistent with the CSM is wasted effort. The CSM represents the location and the interrelationships of site features that affect fate and transport of contaminants from source to receptor. As such, it can be used as a tool to determine if all current or potential future receptor exposures associated with a contaminant release have been identified. Moreover, since responses can remove sources, intercept pathways, or isolate receptors, the CSM can help to identify and evaluate candidate responses.

2. The CSM helps identify data needs.

To the extent that the CSM reflects the best understanding of the site, uncertainties (data gaps) become clearly visible. Moreover, since pathways must be complete before a receptor is exposed to source chemicals, the CSM can also indicate when an uncertainty is not significant (e.g., relates to an incomplete pathway).

3. The CSM is a primary vehicle for communicating complete chemical transport
and exposure pathways.

It provides a good summary of how and where contaminants are expected to move and what impacts such movement may have. Hence, it supplies additional information to explain why a problem is a problem, why it is inconsistent with desired results and, therefore, why a response is anticipated. By highlighting complete pathways, the CSM facilitates identification and communication of environmental concerns. Ultimately, the data needed are those that assist in making the important identified decisions in a consistent manner. One way to identify the right decisions and, therefore, collect the right data is to have a complete and accurate CSM.

CSM Form and Content

While there are many different forms of a CSM that the PMT may elect, a good CSM accomplishes the following five objectives:

- Identifies and locates contaminants, sources, release and transport mechanisms, transport pathways, intake routes, and receptors;
- Delineates contaminant, concentrations in media, and flux rates by pathway in narrative and graphical forms;
- Quantifies background concentrations for each formation or unit;
- Explicitly recognizes and highlights uncertainties (known and unknown conditions); and
- Evolves with data and other information (new site-use history information).

A CSM benefits from use of multiple formats to best portray available information.
A good narrative summary is the best means of describing the AOC, its history, the nature of sources, quantitative aspects of migration pathways, and the identity of ecological and human receptors as well as the circumstances under which exposure is anticipated. Examples of such narratives are included in Appendix D and materials available from the American Society for Testing and Materials (ASTM) [Reference numbers PS85-96, E1689-95, http://www.astm.org]. As with the initial CSM, the narrative should be simple and concise. When data are presented, they should be synoptic, but representative of key findings relative to the problem statement and potential risks. The CSM will be a major part of any communications with stakeholders and, therefore, should be written without a lot of technical jargon or misleading information. Major components include:

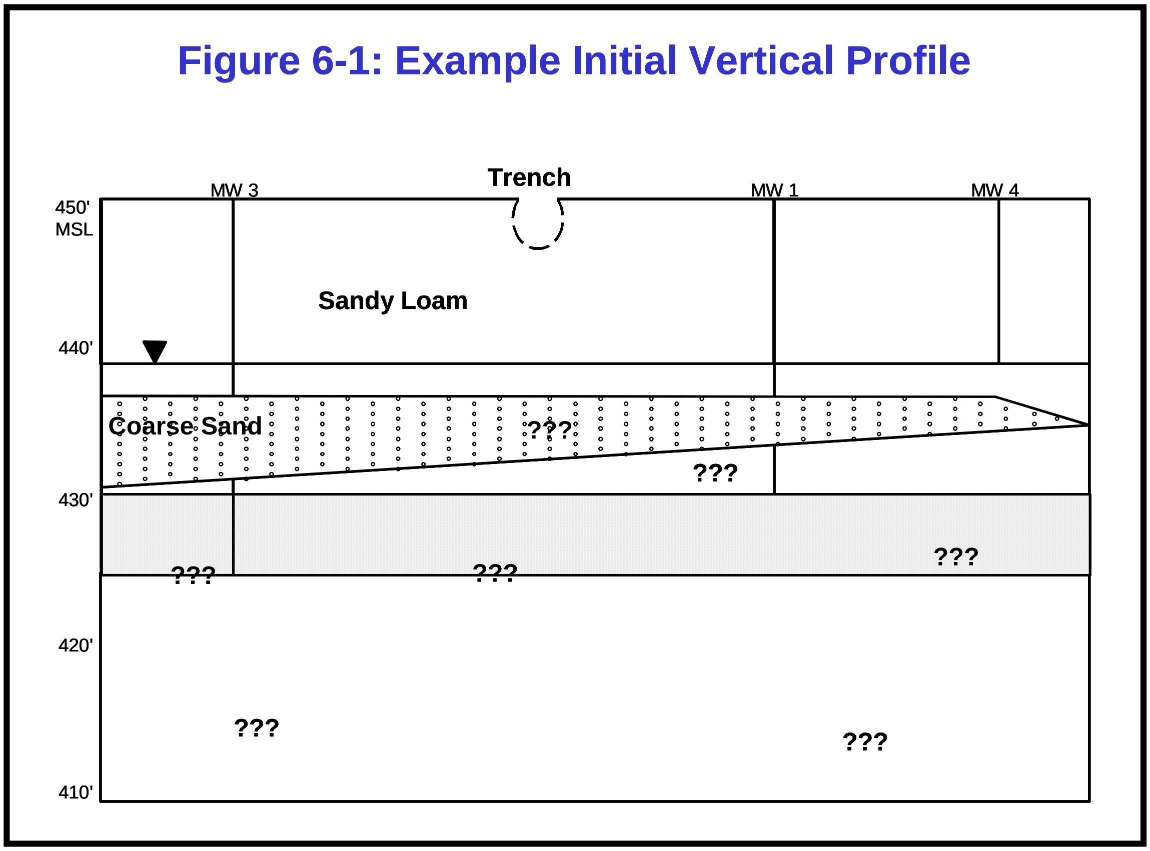
- AOC summary;
- AOC description;
- Source description;
- Pathway descriptions; and
- Receptor identifications and descriptions.

Maps should always be included in a CSM. At a minimum, maps should include relative position of sources, pathway determinants and near-field boundary constraints, surface water features, prevailing wind pattern, and plume contours. When multiple contaminants are present, it may be necessary to produce separate maps of each contaminant group to keep from obscuring data through multiple overlays. If subsurface contamination is present, a vertical profile of the site should be included. Fence diagrams or representative boring logs may suffice, but simplified forms focused on the most important features are best in order to facilitate communication with stakeholders. Tabular data may be included, but tables should be keyed to map features and should contain representative data only, not an exhaustive display of all data.

A standardized summary wire diagram format has been developed for use in EPA documents. These depictions show at a glance the identity of completed pathways, including their source, release mechanisms, transport mechanisms, intake routes and receptors. The stylized graphic is a handy summary, but not a substitute for the entire CSM package. Quantitative aspects, spatial relations, and unique features that impact on the true nature of resultant exposure are not to be found in the wire diagram. Moreover, it serves more to summarize the findings of investigations than to focus remaining activities.

One means of producing flow diagrams is the application of the Site Conceptual Exposure Model (SCEM) Builder. An advantage of using this software is that it can easily evaluate several alternative CSMs and can be used to quickly evaluate whether an agreement can be reached on a CSM produced by a technical support contractor. The SCEM Builder is available (at no cost) at http://www.eh.doe.gov/oepa. When you pull up the web site, click on “Tools,” then “Site Conceptual Exposure Model (SCEM) Builder,” and follow the directions for downloading.

Initially, the CSM is used both to organize the discussion of available data and to identify data needs. In the mapped form, uncertainties can be highlighted by question marks (see Figure 6-1). In the narrative form, unknowns should be specifically called out and critical data needs identified where appropriate. Whenever groundwater pathways are involved, a vertical profile should be included to help interpret data and visualize potential pathways. All pathways should be discussed including those not judged complete. In that way, the CSM serves as a checklist indicating that all pathways have been considered and why specific pathways have been excluded.



To identify releases and distinguish those originating from site activities as opposed to off-site sources, it may be important to establish background concentrations. Background may arise from naturally occurring substances (minerals, plant residues), deposition from regional or global transport (fallout), or plumes from up-gradient sources. Because geochemistry can change with the nature of the host geology, background levels may be different for different soil types and aquifer units. Guidance on establishing background concentrations and using them to identify site-related releases is available from sources such as the California Department of Toxic Substances (*Selecting Inorganic Constituents as Chemicals of Potential Concern for Risk Assessments at Hazardous Waste Sites and Permitted Facilities, February 1997*, downloadable at http://www.dtsc.ca.gov/sppt/opptd/pollprvn/p2sb14gm.pdf).

With data collection, some of the uncertainties at an AOC are likely to be reduced or removed. That reduction should be reflected in the CSM. The PMT can revise the CSM by removing question marks and replacing statements about uncertainty with descriptions of sources, pathways, and receptors. This ensures that the CSM accurately reflects the current understanding of site conditions and remaining uncertainties.

The CSM should contain only features and data that are important to the risk manager. As such, the focus is on the problem statement as currently written and the viable pathways for which unacceptable risk has been identified. Hence, the problem statement and CSM should always be consistent and evolve with new data as acquired.

Land Use and the CSM

As is apparent from guidelines for risk assessment, the nature of land and resource use dictates the identity of the receptor populations, exposure or intake route, and the circumstances under which the exposure will occur. Exposure scenarios differ significantly with land use. While current use is easily identified, future use is always an uncertainty that must be dealt with for persistent contaminants. A simple approach to managing this uncertainty has been to constrain future use through institutional controls. Such responses must be made compatible with prevailing land use policies. In a recent review of risk-based decision making, the National Research Council noted that the common deferral to containment remedies with risk-based decision making increases the need for realistic and comprehensive evaluation of long-term use potential.

Current and *reasonably anticipated* future land uses and corresponding exposure scenarios should be considered in the selection and timing of corrective actions. If land use changes can be predicted, they can serve as a basis for phased responses. As the uncertainty with respect to future use increases, there are more incentives to select robust remedies and well-defined contingencies. Reasonable land use assumptions should be assessed when developing goals for any given facility and used to focus all aspects of the remediation process. When major structural changes are anticipated (e.g., changes in industrial base, closure of large activities, resource depletion), the uncertainty can be bounded or the reasonable alternatives expanded. In any event, change is inevitable and should be managed as an uncertainty. It is not sufficient to assume current use will remain indefinitely or that zoning restrictions will withstand economic pressures in the future if there are no compelling reasons to corroborate that assumption (e.g., presence of wetlands that would preclude development of residences). However, it is also not fiscally responsible to assume that the least restrictive land use (i.e., residential), if in fact there are factors that suggest that residential use is not a reasonable alternative in the future.

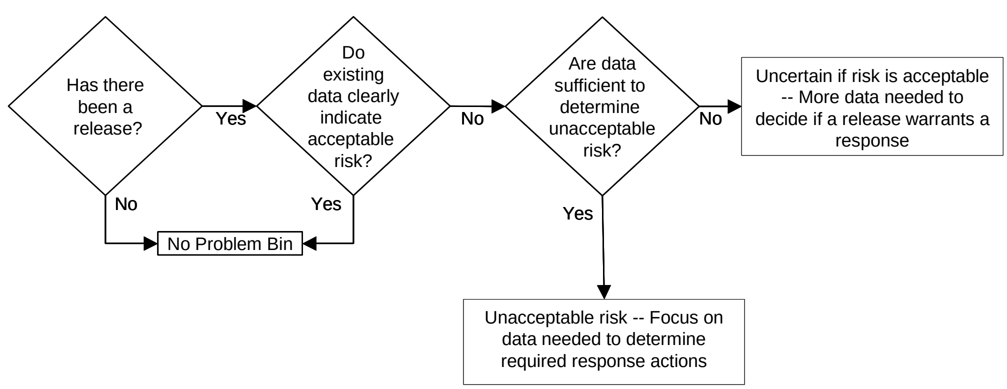
The CSM and Data Collection

The thought process applied to focus data collection efforts draws on the CSM to answer questions at the core of each fundamental decision and from which priorities are established. Once enough information is available to write a problem statement, a problem exists. Therefore, by definition it requires a response to solve the problem. At this point, attention needs to shift from the first question - Does a problem exist? - to the second question - What and when will something be done to address it?

Further data collection relative to nature and extent of contamination is important only to the degree that nature and extent may change the acceptability of the risk and the approach to remediation (Figure 6-2). This does not mean data needs no longer exist. It means that the data needed are those associated with evaluating and selecting the response. If data will not change the decision being made, they are not necessary for selection or completion of a response. For example, if groundwater data confirm the presence of contamination posing unacceptable risk within a defined plume boundary, further sampling within that boundary will not change the decision that a problem exists. Therefore, additional testing must be justified on the basis of how results can alter the selection or design of a remedy.

Recognizing that the focus is now on responses, the PMT's efforts will be most productive if they can identify a limited number or a single response that is most likely to result in an acceptable risk. For many installations, narrowing the list of candidate technologies is readily accomplished using past history as discussed under the third Principle.

Figure 6-2: Data Collection Decision Logic for Risk-Based Problems



7. UNCERTAINTY REDUCTION: PLANNING AND IMPLEMENTING DATA COLLECTION

Introduction

As noted in the previous section, uncertainty can be managed through reduction or mitigation. Traditionally, reduction through data collection has been the default approach. Indeed, over time, the investigation phase of environmental restoration has become a dominant element of every project. This in turn has led to the proliferation of sequential data collection activities including:

- Preliminary Assessment;
- Site Inspection;
- Expanded Site Inspection;
- Remedial Investigation (Often divided between operable units, broken into phases, and/or subdivided by soil, groundwater, background, and ecological surveys);
- Feasibility Study investigation;
- Treatability Study; and
- Remedial Design investigation.

While each of these activities may be necessary for any individual site, rarely are all required. There is no mandate to conduct specific activities beyond those needed to answer the two basic environmental restoration questions:

Is there a problem?
If there is a problem, what should be done about it?

As a consequence, streamlining efforts such as SACM and SAFER included initiatives to combine data collection elements and focus them in a manner that would reduce the generation of unnecessary information.

This chapter discusses approaches to focus and streamline data collection such as the DQO process and dynamic decision making. These techniques have proven valuable both in assuring the utility of data that are collected and in minimizing the collection of data for which there are no uses relative to the primary mission of environmental restoration.

Data Needs Vs Data Gaps

The saying, "If a little is good, a lot is better," does not necessarily hold for data collection. Although more data may help better articulate a problem or may improve the ability to select a course of action, the additional data collection activity requires time and, therefore, delays implementation of the response.

Hence, data must materially affect the quality of the decision being made if they are to justify the added delays inherent in collecting them. It follows that it is prudent to make maximum use of available data, thus preventing what might otherwise be redundant efforts. One means of facilitating use of existing data is the Data Quality Assurance (DQA) process, which is applied to determine what decisions a data set can be used to support.

Where there are data gaps, it is important to first determine if they constitute data needs (i.e., do they resolve significant uncertainties). In order to accomplish that, it is best to determine how the data will be used and then what amount, kind, and quality of data are needed for that use. Typically, the utility curve for data (Figure 5-1) starts out on a steep upward slope and then rapidly levels off. Collecting additional data in the area of the horizontal asymptote is usually not productive. The mandate to determine the nature and extent of contamination is often over-interpreted. The intent is to require determination of the nature and extent of contamination to the degree necessary to write the problem statement and select the best response.

The CSM serves as a tool to help identify unnecessary or unproductive data collection efforts. Data associated with incomplete or nonviable pathways are unnecessary and can be eliminated from plans. Conversely, data to complete knowledge of viable pathways is important.

There are high priority data needs when a problem is uncertain, but likely to exist, which involve potential ongoing human and/or ecological exposure to unacceptable risk. Proposed data should be able to demonstrably improve the ability to write the problem statement. In other words, the investigation should target those areas of uncertainty that currently prevent completion of the problem statement.

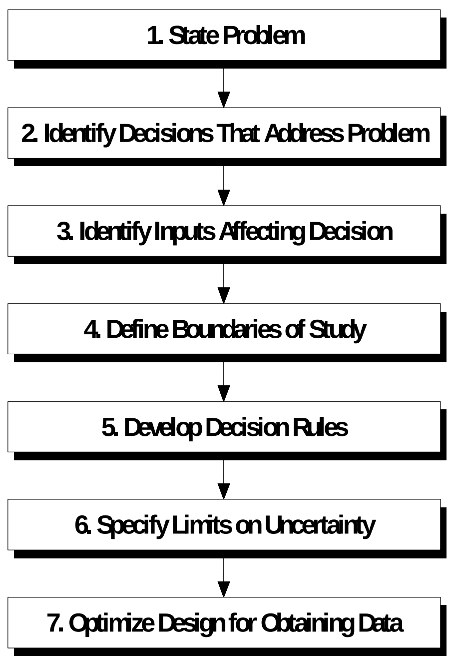
There are also data needs where there is a known problem, but there is uncertainty as to the response that should be made. In this case, data needs are associated with information required to finalize selection and design of the preferred corrective action. This is a very targeted effort. Each proposed data point should be challenged to see how or why it would affect the decision to select a preferred remedy or its design. If it will not, it is not required. For example, if a pump and treat or permeable treatment barrier remedy is the likely strategy and the perimeter of the plume has been mapped, additional wells inside the plume will not likely change the selection or design unless a condition that would be a fatal flaw for pump and treat is suspected (e.g., presence of DNAPL). Since the permeable treatment barrier can contain DNAPL and the pump and treat remedy cannot, the uncertainty over the presence of DNAPL may be managed by selection of the more robust alternative without having to reduce the uncertainty further. In this case, the bias towards uncertainty mitigation (as opposed to reduction) reflects the cost and limited effectiveness of technologies capable of locating or confirming the presence of DNAPL.

Similarly, there is often a desire to better map soil slated for exhumation, but if there are no capacity concerns, the data will not change the decision to excavate. In essence, data needs arise from fatal flaws or key design parameters specific to the technologies being evaluated.

Planning Data Collection

Identifying and defining the decisions to be made is an essential part of the planning process and is performed through application of the DQO process. The DQO process is comprised of seven steps that are shown schematically in Figure7-1. Each of these steps and their application to planning and implementing data collection is discussed below.

Figure 7-1: Steps in the DQO Process



1. <u>State the Problem</u>. Stating the problem should be a simple description of the issues at the site that are cause for concern. The problem statement should be brief and should identify the source, and the potential to result in unacceptable human health or ecological risk as discussed in Chapter 3.

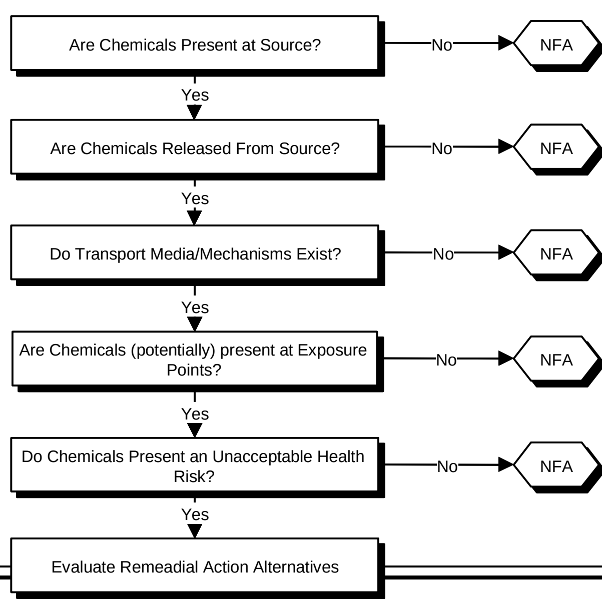
2. <u>Identify Decisions that Address the Problem</u>. A significant part of identifying decisions is accomplished by using a CSM as discussed in Chapter 6. Many

forms of the CSM are appropriate to identify the pathways by which human or ecological receptors can be exposed to chemicals released from the AOC. CSMs are used to identify decisions to be made about the potential chemical transport pathways. When a transport pathway is incomplete, there is no exposure or risk to human or environmental receptors that can result in an adverse effect.

The next step is to identify and define the decisions that are related to the CSM that will support resolution of the problem statement. These decisions can be specific or generic. The approach to defining the decisions should make more use of the CSM and the decisions should be related to the problem statement and site-specific conditions. Site-specific conditions may include current and future land use.

Generic decisions can be identified for each chemical transport pathway, as shown schematically in Figure 7-2 for a landfill. A typical decision for a landfill source may be, “Is a landfill present at the exact identified location?” Note that the exact location of the landfill does not need to be known to evaluate releases from the landfill. Decisions for determining whether or not a specific release mechanism exists can be identified. A basic decision to be made may be stated as, “Are contaminants being released in amounts that are potentially harmful to human health or the environment?” The need to evaluate a specific release mechanism depends on many factors, including the condition of the landfill cover and the specific contaminants potentially present in the source. For example, the suspension (wind erosion) release mechanism pathway would not be evaluated if the actual waste materials were covered with soil. In addition, the volatilization pathway would not be evaluated if it were known that the source contained only non-volatile components (construction debris).

Figure 7-2: Generic Landfill Decisions

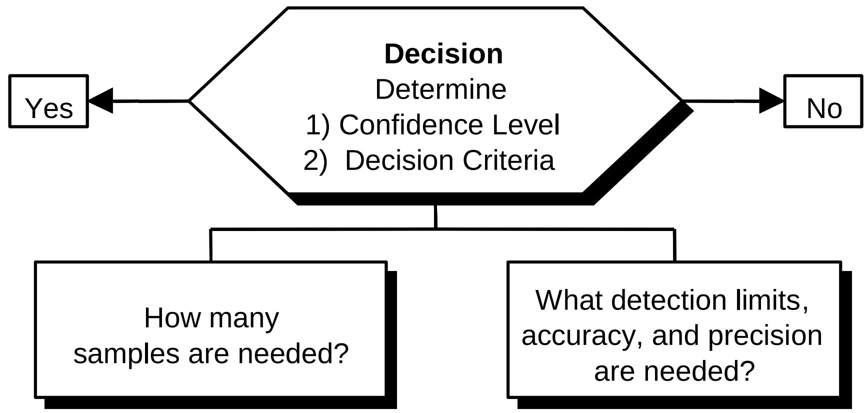


Pathway-specific decisions are also identified for transport media in each chemical transport pathway. This type of decision can be expressed as, "Are chemicals being transported in concentrations that are potentially harmful to human health or the environment?" A final decision to be made relates to the potential exposure of receptors, and may be stated as, "Are contaminant concentrations at identified exposure points harmful to human health or the environment?" If the answer is yes, the PMT proceeds to select the remedial alternative.

It is important that each decision is stated so that it can be satisfied with a yes or no answer. In fact, the PMT should formulate decisions that can be answered yes or no as a step in identifying data needs. The potential action that will be taken when the decision is answered must also be explained in the diagram and text. For example, if the decision is made that there is a source, the next step is to collect data to evaluate the presence of a release mechanism. The data for these two decisions can be collected in a single field mobilization effort. If the data support the decision that there is not a source, there is no further action, i.e., evaluation of a release mechanism, even though the data are collected, would not be done. When a no further action decision is made, there is no additional data collection or data evaluation for the specific pathway being evaluated.

The input to be considered in defining a decision is shown schematically in Figure 7-3. The decision in Figure 7-3 could represent any of the generic decisions illustrated in Figure 7-2 related to source, release mechanism, transport, exposure, risk or remedy selection (e.g., Are chemicals being leached from soil?). It is necessary to specify the confidence level for the decision so the number of samples, accuracy, and precision can be determined. The decision criteria must also be identified to assure proper selection of methods to support the required detection limits. When an answer can be given for the decision that is not a yes or no, the decision is not adequately defined to plan data collection. Poorly defined or undefined decisions most often lead to the need for additional data collection regardless of the outcome of the data collected. When decisions are identified that cannot be clearly answered yes or no, the DQO process must continue until an appropriate decision (one that can be answered only yes or no using data that could be collected) is defined. Defined decisions that cannot be answered only yes or no should be modified or separated into more than one decision. This will ensure that any additional data needed to meet project objectives will be identified in the Sampling and Analysis Plan (SAP).

Figure 7-3: Typical Decision Process



3. Identify Inputs that Affect Decisions. This step in the process identifies the specific data needed to support decisions. For example, to identify inputs for the "are there chemical releases?" decision (Figure 7-2) and the pathway being considered is infiltration or percolation of chemicals from a landfill site, a likely input would be chemical concentrations in subsurface soil beneath (or adjacent to) and "down gradient" of the landfill source. The data input is chemical concentration in subsurface soil and the location of the sample both horizontally and vertically. The resulting input would be, for example, to collect data for samples adjacent to the source at a depth of five feet below the disposed wastes.

4. Define Study Boundaries. There are many study boundaries to be considered. The primary example of a study boundary given in EPA's DQO guidance is the level of funding. Other boundary conditions include; physical limitations of sampling, time constraints (agency schedule), materials migrating on site from off-site sources, agency policy, public opinion, Army policy, and permission to sample off-site locations not owned by the Army. All potential boundary conditions should be evaluated when the SAP is being prepared and it is best if the evaluations are actually included in the SAP.

5. Develop Decision Rules. Decision rules are developed from the decisions identified in Step 2. The decision rule can be considered a statement of the hypothesis to be tested. Data are collected to confirm or reject the hypothesis. For example, a decision in Figure 7-2 is, "are chemicals released from the source?" This decision can be changed to the form of a decision rule, which is an "If...then" statement. An example decision rule would be; "If a chemical is released from the source in concentrations greater than the decision criterion,

then the transport media for this pathway will be investigated to determine if there is transport of chemicals. The decision criteria are generally numerical values related to the decision being made. Often the decision criteria are related to concentrations that are protective of human health or the environment. Numerical decision criteria determine the quality of data that are needed to make the decision. These criteria can be health based screening levels (e.g., PRGs), MCLs, regulatory criteria for various media, negotiated criteria, or remedial design criteria for remedial design-related decisions. The decision criteria determine the accuracy and precision of the analytical measurement needed for each defined decision

When the decision rule is stated in a chemical- and sample-specific manner, the decision rule would be, “If the concentration of chloroform in subsurface soil samples collected at five feet below the source is greater than 20 mg/kg, then additional investigation will be performed to assess potential transport of chloroform by the shallow aquifer.” The decision criterion (20 mg/kg in this example) would be a value that is protective of human health and the environment.

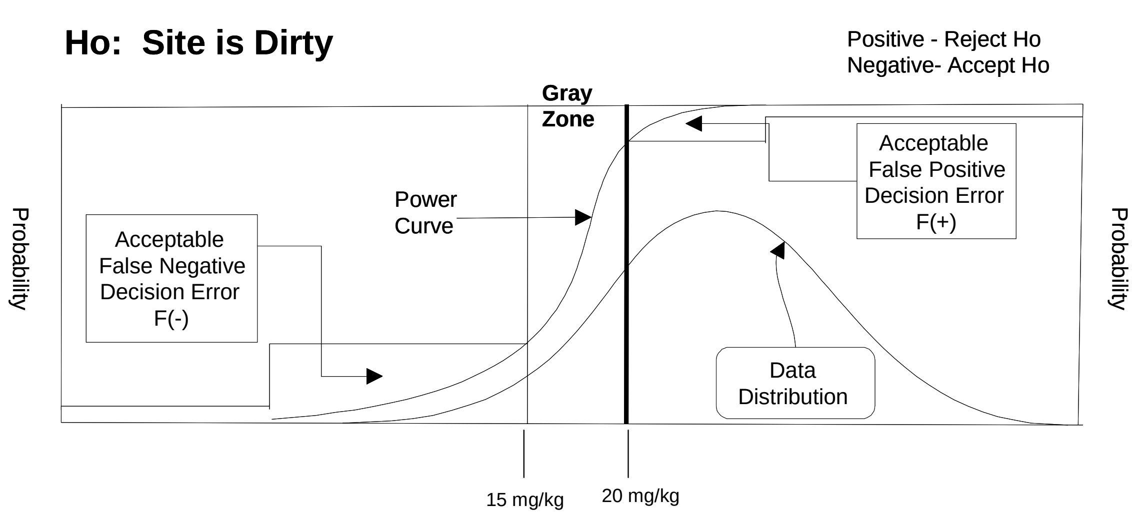
6. <u>Specify Limits on Uncertainty</u>. Initially, the PMT may not be comfortable acknowledging there is uncertainty in making decisions for an investigation. However, EPA’s RI/FS guidance states that it is not an investigative objective to eliminate uncertainty, but to make defensible decisions. The confidence level needed for the defined decision is the “acceptable uncertainty” identified in EPA’s DQO guidance. (Note. This use of the term uncertainty refers to the ability to make confident decisions i.e., the level of certainty that a decision is correct. This differs from the broader definition of uncertainty addressed by the fourth Principle.) The reality of an investigation is that it is not possible to collect enough data to be one hundred percent confident that the measured data statistic is identical to that of the true population. When the PMT defines acceptable uncertainty, it is important to understand that there is always uncertainty in measured data and decision making. In addition, the level of acceptable uncertainty is established for the <u>decision</u> being made, not for the collected data. The PMT must note that the entire population must be sampled when attempting to eliminate uncertainty, and even with that effort, measurement error and uncertainty still exist.

After the decision rule has been defined, the confidence level or acceptable uncertainty in each decision must be identified. Acceptable uncertainty is equivalent to feeling comfortable about a decision when it is based on collected or available data. Generally, less uncertainty (more comfort) is needed to support a no action alternative than an active remedial action. Two kinds of uncertainty are considered in planning data collection and making decisions. The most important uncertainty is called a *decision error* (probability of making an incorrect decision). The second uncertainty is that the collected data will not be within the concentration range needed for confident decision making and is related to the *Gray Zone*. The Gray Zone is the range of concentrations where decision errors <u>are</u> acceptable.

Figure 7-4 is a power curve diagram that illustrates the acceptable decision errors and the Gray Zone acceptable error for an investigation when the null hypothesis is that the site is contaminated. This hypothesis assumes the data distribution is at concentrations generally greater than the decision criterion (shown by the data distribution curve). A decision error for a truly contaminated site is to reject the null hypothesis and declare the site clean (this is a False Positive [F(+)] decision error). The consequences of an F(+) decision error are that an area would not be investigated further or remediated when it is potentially harmful to human health or the environment. A decision error for a truly uncontaminated or clean site is to accept the null hypothesis and declare the site contaminated (this is a False Negative [F(-)] decision error). The consequences of an F(-) decision error are that resources would be used to investigate and/or remediate a clean site and there would be no health-related benefits for human or ecological receptors.

The acceptable decision error and Gray Zone uncertainties are directly related to the question of "How many samples are needed?" Lower acceptable uncertainty requires more samples. The uncertainty in a decision is related to the quantity and quality of the data and to the magnitude of difference between the collected data and the decision criterion. For example, data sets with high variability (low quality) can be used to make very confident decisions, as will be explained later in this section.

Figure 7-4: Power Curve Ho: Site is Dirty



When identifying acceptable uncertainties the PMT must consider EPA's goal to protect health, which is to protect 95 percent of the exposed population. This results in an acceptable F(+) decision error probability of 0.05, which is appropriate when the site concentration is near the decision criterion. However, when the site concentration is much larger than the decision criterion, the consequences of an F(+) decision error are less acceptable. Therefore, as shown in Figure 7-4, the acceptable F(+) decision error is reduced to one percent at the higher concentrations. The PMT must document these consequences as part of the planning task.

Establishing a Gray Zone for the H_o = the site is "dirty," assumes for data collection planning, that it is acceptable to clean up areas that may have concentrations less than the decision criterion (20 mg/kg). The gray zone shown in Figure 7-4 means that for planning purposes, those areas with subsurface soil concentrations greater than 15 and less than 20 mg/kg would be remediated. The acceptability of decision error within the Gray Zone acknowledges that substantial numbers of samples would be required to conclude that data within this zone are confidently less that the decision criterion.

The width of the Gray Zone is not based on technical or scientific merit. It is derived by PMT consensus. For example, it is unlikely that the PMT would feel comfortable collecting as few as three or as many as 1,000 samples to support a single decision in a remedial investigation of a single source. However, because of their experience, PMT members may feel comfortable within the range of 15 to 30 samples. There is a similar comfort range for decision errors. F(+) errors may range from 0.10 to 0.01 probability and F(-) errors may range from 0.10 to 0.50 probability. These comfort ranges are difficult to document. However, it is necessary to reach agreement on the number of samples. This agreement can be documented in terms of acceptable decision error and Gray Zone width by using EPA's Decision Error Feasibility Trials (DEFT) software (http://www.epa.gov/crdlvweb/databases/datahome.htm). This software relates acceptable decision errors and Gray Zone width to the number of samples needed. This approach allows the PMT to communicate their SAP in terms of decisions being made and acceptable uncertainty.

As stated earlier, high quantity and quality data are not always required to make confident decisions. For example, one can have a minimal data set with a relatively large variance and still make a confident decision as shown in Figure 7-5. Because the mean of the data is very small compared to the decision criterion, one can be more than 95 percent confident that the site concentrations do not exceed the decision criterion. This highly confident decision can be made although one does not have a high confidence that 4.8 mg/kg represents the true average concentration in subsurface soil. The PMT's objective is to make confident decisions, not to be confident that the collected data are "truly" representative of the population being sampled.

Figure 7-5: Compare Data To Decision Criterion

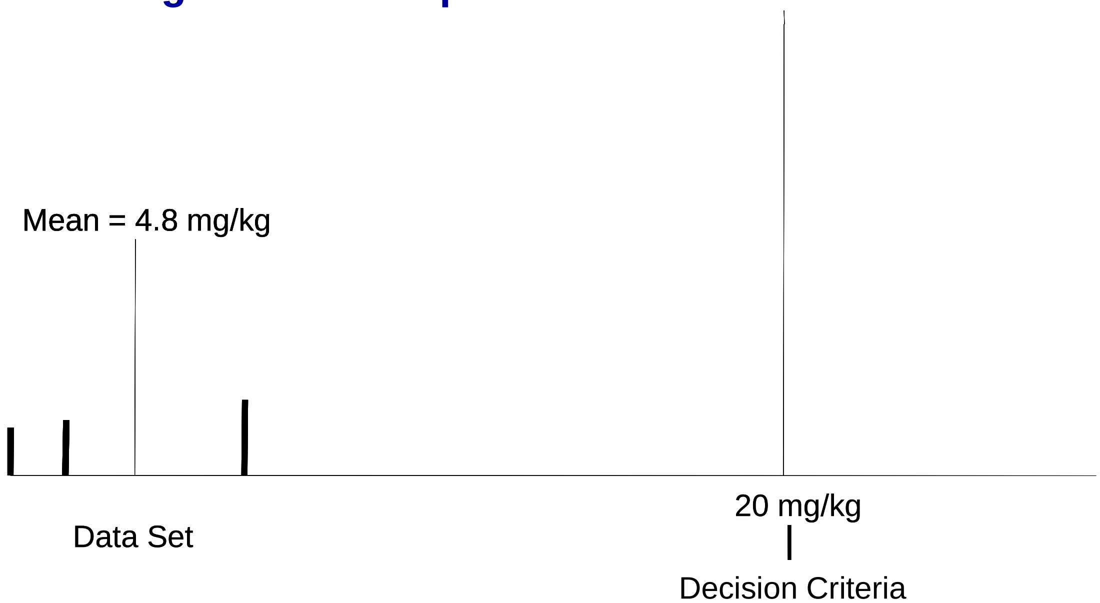
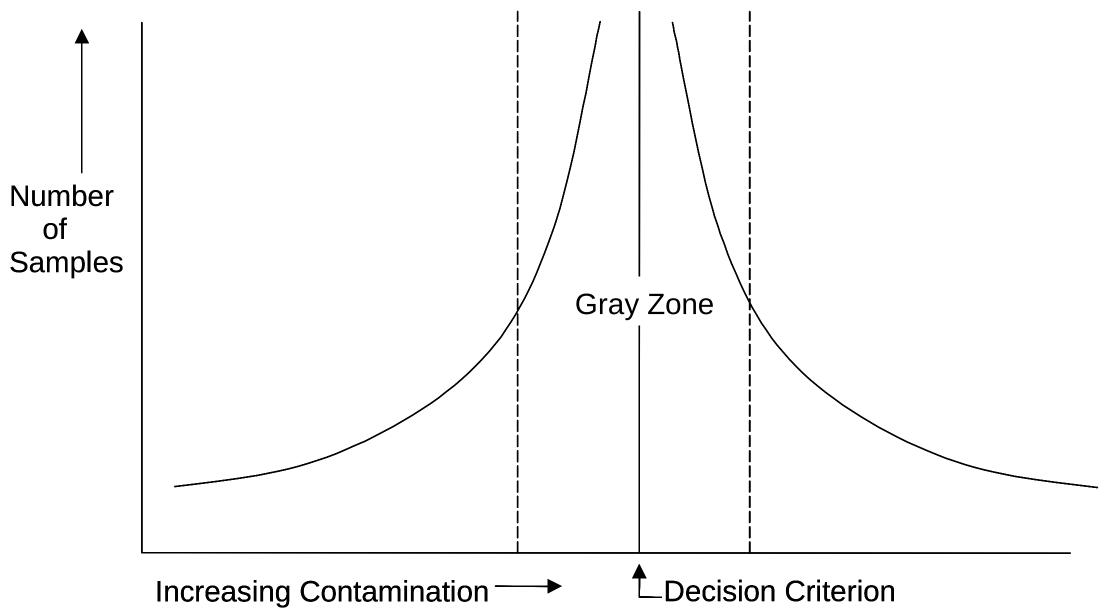
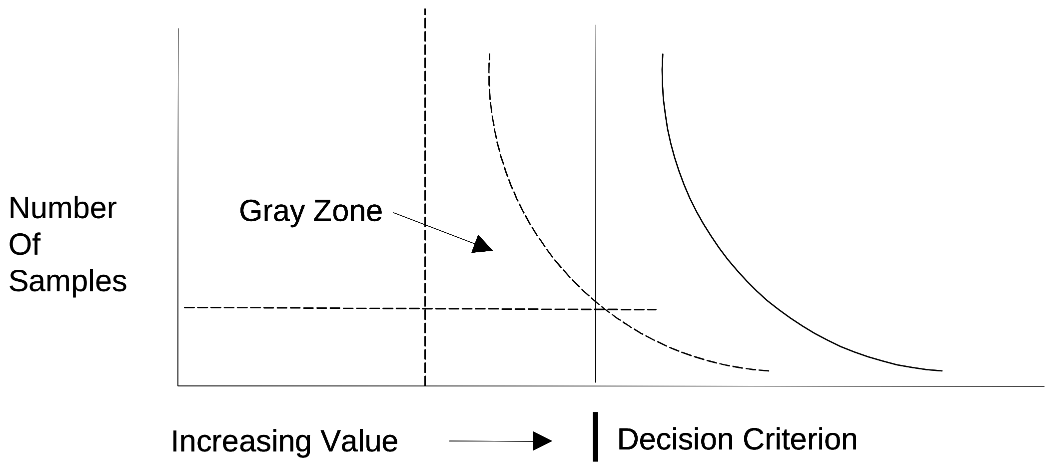


Figure 7-6: Number of Samples



When the mean of the data set and the decision criterion become close to the same value, additional data are needed to keep the same level of confidence that the mean of the data set is greater or less than the decision criterion. The solid curve and decision criterion lines in Figure 7-6 show schematically how the number of samples increases as the mean (or other data statistic) approaches the decision criterion. The Gray Zone concept can also be explained using the dotted lines in Figure 7-7. The lower Gray Zone line becomes a pseudo decision criterion, which is used only for planning purposes (not decision-making). The intersection of the decision criterion, and the dotted curve shows the number of samples required (horizontal dotted line). Note that a wider Gray Zone results in fewer samples.

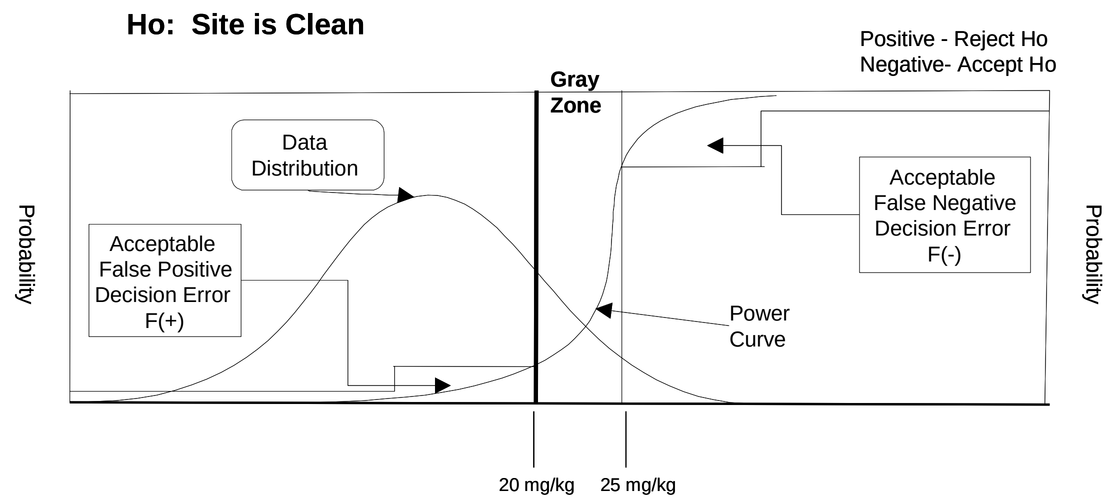
Figure 7-7: Number of Samples - Gray Zone



There are occasions when the PMT cannot reach consensus that past activities do or do not warrant investigation of an AOC. In these situations, if an investigation is planned, it is recommended that the null hypothesis used for the SAP is that the site is "clean." The power curve for this hypothesis is shown in Figure 7-8. For this hypothesis, the Gray Zone is to the right of the decision criteria because the consequences of remediating a clean site are more severe than potential human or ecological risk at a clean site. The data distribution is on the lower concentration side of the decision criterion with few concentrations greater than the decision criterion. This strategy acknowledges that a few modest exceedences of the decision criterion at a clean site will not result in an unacceptable risk. The upper Gray Zone concentration becomes the value for decision-making. Within the Gray Zone concentration range, decision errors are acceptable.

For the example shown in Figure 7-8, the consequences of missing subsurface soil at concentrations up to 25 mg/kg is acceptable, because there is no reason to believe that the site is contaminated and the data distribution is generally less than the decision criterion. For planning purposes this Gray Zone means that soil containing greater than 20 but less than 25 mg/kg would not be investigated further or remediated.

Figure 7-8: Power Curve Ho: Site is Clean



7. Optimize Design for Obtaining Data. After identifying the decisions, decision criteria, the input to support the decisions (data) and acceptable uncertainty, the approach to obtain the data can be optimized. Optimization examines the sampling strategy, sample location needs, sample number, analytical data for samples, etc., for each data use. The optimization process identifies potentially co-located samples and samples that can be used to obtain data that support more than one decision. The data set statistic used to compare to the decision criterion has a significant influence on the sampling strategy that is appropriate to collect the data. For example:

- A judgmental approach is appropriate if the maximum or minimum value detected are compared to the decision criterion;
- A random approach is appropriate if the mean (or a statistic representing the mean, e.g., 95 UCL) is compared to the decision criterion;
- A systematic approach is appropriate if the decision criterion is representative of a spatial characteristic of the area (exposure area); and
- A combination of the strategies can be used for specific decisions, for example a randomly located systematic approach is appropriate to compare the mean of an area with a decision criterion.

As plans are developed to collect the data necessary to resolve uncertainties selected for management through reduction, they are merged into a SAP. The

SAP attempts to integrate the activities such that mobilization for field efforts can be minimized. As plans and protocol are merged, there may be opportunity to optimize through combination of samples, co-location of samples, and selection of more robust methods. The SAP provides an opportunity to take a systems view of the data reduction effort and eliminate redundancies or leverage synergies. With today's technologies there is no reason for characterization plans that require years to complete. By recognizing what is technically achievable, the PMT can identify viable alternatives to excessively lengthy investigation plans, thus meeting the objective to accelerate schedules.

Dynamic Decision Making

Dynamic decision making and related approaches that employ a dynamic work plan identify data needs and methods, but leave specific quantities and samples open to selection as a result of interpretation of data as they are collected. This approach is enabled by field analytical and screening methods that provide real-time output. The EPA Technology Innovation Office has prepared the document: "Field Analytical and Site Characterization Technologies," EPA-542-R-97-012, which summarizes observations from 204 applications of new techniques at installations across the country. Methods are available for soil, water, air and soil gas samples containing a variety of contaminant types or specific chemicals (Figure 7-9). These methods can be applied in support of dynamic work plans.

Figure 7-9: Dynamic Decision Making

Technology	VOC	SVOC	Fuels	Inorganics	Explosives	Pesticides
Biosensor					S, W	
Colorimetric Strip				S, W	S, W	
CP Mounted Sensor	S, W	S, W	S, W			
Fiber Optic Sensor	SG, W	W	W			
GC/Soil Gas	S, W, SG, A	S, W	S, W, SG			S, W
Immunoassay	S, W	S, W	S, W	S, W		S, W
Hg Vapor Analyzer				A		
XRF				S,W		

S--Soil
W--Water
A--Air
SG--Soil Gas

*Adopted from EPA 542-R-97-012

Dynamic decision making allows implementation of phased or conditional investigations that minimize mobilization activities and eliminate delays for sample turnaround, interpretation, and re-planning. It allows defined data values or relationships to serve as end points rather than a defined number of samples. This approach facilitates resolution of apparent contradictions in CSM or apparently anomalous data and minimizes problems with temporal equivalence.

For example, to determine the depth of chromium contamination prior to selecting an excavation alternative with a full laboratory sampling and analysis approach, the PMT would elect to prescribe a maximum sampling depth and analyze samples at 5-foot intervals. If the predetermined maximum depth were not sufficient, another mobilization for a subsequent, deeper boring(s) would be necessary. With a dynamic decision-making approach, the PMT could apply field x-ray fluorescence (XRF) for total chromium. The PMT would set a threshold value and continue downward until an agreed to number of successive depth samples below the threshold were obtained. In this way, the depth could be defined in a single campaign.

Field methods can expedite uncertainty reduction only if they are sensitive enough to answer the pending question at the level of significance relative to any operative thresholds. As such, they must have detection limits below the threshold value. For example, XRF may be helpful in addressing pathways associated with total chromium, but is not sensitive enough to address hexavalent chromium thresholds even when it is assumed that all chromium is hexavalent chromium.

The threshold value for a parameter varies with the use to which the data are being put. When quantification is the goal, the threshold may be a risk-based concentration, which can be very low. When the objective is delineation or targeting for subsequent, more sensitive analyses, the threshold may be higher. In the depth of chromium example, XRF screening would provide a good indication of distribution prior to excavation, while higher resolution laboratory analyses would be required for confirmation after excavation.

Laboratory confirmation may be advisable for some methods depending on use of the data and the reliability of the method. For instance, field XRF data should be calibrated with periodic samples sent off for atomic adsorption or inductively coupled argon plasma analysis in the laboratory to avoid misinterpretations due to matrix interference. Conversely, field gas chromatography on soil vapor samples may not need any further confirmation, especially if soil vapor extraction is the preferred remedy.

The PMT must determine the nature and frequency of confirmatory sampling. Frequency may be reduced if early results indicate close correlation between laboratory and field results. Conversely, the greater the variability and or deviation between the two data sets, the more important it will be to maintain a frequent cross check. In general, confirmation at the 10 percent level is a good starting point.

Pre-determined, documented decision rules provide the necessary basis to manage field-based characterization approaches, such as those applied with dynamic decision making. Decision rules specify (as necessary):

- Technique to be used;
- Procedures to implement the techniques;
- General areas and depths of characterization;
- Threshold values above which a decision is determined or additional considerations are triggered; and
- Contingencies or extended activities (as appropriate).

For example, "Samples will be taken in four compass directions at 100 feet spacing moving outward from the source area and vertically at 20 foot intervals. If concentrations display a downward trend and the last sample had less than 5 mg/kg TCE, then characterization on that vector can be terminated."

It is important to understand the logic behind an approach to identify minimum requirements and devise a plan that will fill those gaps at the desired level of confidence.

Summary

Uncertainty reduction is accomplished by collecting data to fill specified data needs. Data needs are determined on the basis of consistency with the CSM and related problem statement (if one has been formulated). The DQO process provides a logical thought sequence to identify the minimum data required to proceed in answering relevant site questions fundamental to the environmental restoration project. The DQO process involves seven discrete steps:

1. State the Problem;
2. Identify Decisions that Address the Problem;
3. Identify Inputs Affecting those Decisions;
4. Define Study Boundaries;
5. Develop Decision Rules;
6. Specify Limits on Uncertainty; and
7. Optimize Design for Obtaining Data.

The availability of field analytical methods enables some data collection efforts to be accomplished with dynamic decision making wherein real-time results are obtained and utilized to direct subsequent efforts on the basis of pre-determined decision logic. The latter approach reduces cost and time requirements associated with sampling and analysis activities.

8. UNCERTAINTY MITIGATION: MANAGING UNCERTAINTY WITH CONTINGENCIES AND TOLERANT DESIGNS

Introduction

The second means for managing uncertainty is mitigation through use of robust designs and contingency plans. All uncertainties that cannot be or are not reduced to a level of insignificance must be mitigated. Whereas reduction efforts are focused on decreasing the range of probable values for an unknown parameter or condition in hopes of rendering it too narrow to span the decision threshold; mitigation is directed towards moving the threshold to a point outside of the range of possible values for the unknown parameter or condition (as shown in Figure 5-2).

This chapter discusses the options available for uncertainty mitigation. It describes the nature of residual uncertainties commonly found at sites and the degree to which they lend themselves to tolerant (robust) technologies or contingency plans to counteract the effects of deviations from conditions assumed, in order to proceed with remedial action design and implementation. Variations of the uncertainty matrix are provided to illustrate its use in both pre-decision document and post-decision document phases of work. In order to design responses and select effective contingencies, the PMT must be able to reach consensus on the intent of the decision document and the breadth of flexibility it allows. The factors relevant to determining the degree to which contingencies must be developed are also discussed.

Nature of Residual Uncertainties

Ultimately, the PMT will arrive at the point where a decision must be made with no further data collection to support that decision. There are many uncertainties that can arise that defy uncertainty reduction or are so difficult to reduce that they are best managed through mitigation with contingencies. An example of the latter uncertainties arises when there is a need to prove the negative (i.e., prove that a given condition or problem does not exist anywhere on an installation). In other cases, the geologic complexity is such that the tools are not available to definitively characterize all regions of interest (e.g., karst or fractured rock systems). The PMT must recognize and deal with those uncertainties early in the process.

Common examples of uncertainties that may remain regardless of site characterization approaches include:

- Existence and location of DNAPLs;

- Nature and interconnectivity of fracture flow or faulting;
- Presence of drums or “hot spots” in landfills;
- Presence of discrete waste container, object or agent alluded to in anecdotal records;
- Effectiveness of proposed response;
- Time required for response to meet remedial action objectives; and
- Probable future land uses over time.

Remaining uncertainties can arise because of the inability to reduce them through data collection, or a conscious decision by the PMT not to collect data, because it is more cost-effective to mitigate the uncertainty. Of those uncertainties remaining after site characterization, some may be reducible as a result of information gathered during implementation of the response or performance monitoring of the remedy (e.g., volume of contaminated soil to be excavated), and some may never be resolved (e.g., presence of a hot spot in a landfill that is to be capped). In either case, the PMT must plan for, and counteract, any adverse effects that could arise from conditions or values for those uncertainties different than the assumed values (most likely values) on which the decisions were based. This is accomplished through use of contingencies or technologies that are sufficiently robust as to have higher or no thresholds (situations in which they do not meet performance expectations) of significance.

On rare occasions, significant uncertainties impact the ability to completely define an unacceptable risk. More frequently, however, remaining uncertainties will impact selection and design of a response. In either case, these are uncertainties for which contingency planning or use of new investigation techniques is warranted.

The management strategy for uncertainty in problem definition (i.e., determine if risk is unacceptable) focuses on the tradeoffs between:

- Ongoing investigation (traditional techniques);
- Use of new investigation techniques;
- Implementation of a remedy as a safeguard against potential exposures; and

- Long-term monitoring as a compromise data collection effort.

For residual uncertainties associated with remedy selection and design, the PMT may select a conservative remedy that assumes worse case conditions, or identify monitoring and contingency plans capable of identifying deviations from assumed conditions soon enough to implement the required contingency.

Alternatives for Uncertainty Mitigation

Uncertainty mitigation focuses on changing the decision criteria for which the unknown data are required. Changes may result from using an alternate assumed value or condition that results in a more robust response for which the residual uncertainty is insignificant, or from identifying a contingency that can be implemented to counteract the impact of deviations from the assumed value. The nature of the preferred approach is a function of the type of residual uncertainty, the capability of available technologies, and the degree to which data bound the range of reasonable deviations from the assumed parameter value.

Consider the case of an uncertain exposure or risk. An area is known to have been used for escort training. Glass ampoules of chemical agent may have been buried after the exercises were complete. There is no cost-effective method to quickly determine the existence or location of these ampoules. If the site is assumed clean and released for unrestricted use, there is a potential for damages if ampoules are subsequently encountered. One means of mitigating this uncertainty is to assume the ampoules do exist, recognize the technical impracticability of clean closure, and opt for institutional controls through restricted access and retained ownership. In this case, the decision criterion has been eliminated because the course of action is protective regardless of whether or not the ampoules exist. In essence, the uncertainty has been rendered insignificant.

An example of uncertainty over the performance of a response would be the long-term stability of geochemical conditions required to support attenuation mechanisms central to a monitored natural attenuation remedy. In this case, no one can accurately predict if there will be future changes in background chemistry that could impact attenuation. Hence, the PMT may decide to monitor the geochemistry until attenuation has brought conditions to a state that meets the remedial action objectives (RAOs). Decision criteria are set to indicate when geochemical changes are sufficient to trigger implementation of an active remedy as a contingency that counteracts the loss of attenuation at the levels required to meet the RAOs. In this case, the decision criterion has been augmented by a second criterion (the decision threshold for the contingency action) that becomes operable if monitoring data signal the need.

Another example would be the case where the saturated zone is thought to contain conduits that are preferential pathways for plume migration. If a reasonable level of field investigation has failed to locate such conduits, the preferred remedy can be implemented utilizing sentinel wells in front of the potential receptor wells. This should be accompanied by a plan for well-head treatment or supplemental capture wells should contaminants reach the sentinel points at levels above response objectives. In this example, the presence of the conduits would be identified only if they threaten the receptor wells. Other conduits could exist, but if they do not threaten the receptor wells, the PMT can accept the uncertainty of their existence since their presence poses no risk and, therefore, constitutes an insignificant uncertainty.

Selecting Between Mitigation Alternatives

In selecting the likely response technology for environmental restoration, it is necessary to apply and integrate the Principles. Just as the overall activity begins with development of a problem statement, response selection begins with development of the performance objective. Typically, PMTs begin with the need to protect human health and the environment and then translate that into much greater detail, as it is refined to a site-specific application.

Similar to use of the CSM to bound and target site characterization activities, technology selection is bounded and focused by a subset of the CSM that quantitatively defines those parameters and conditions that will impact applicability and performance of the selected response. For those parameters or conditions that are uncertain, the PMT must assume a most probable value or state, based on the best available information. The uncertainties are characterized with respect to whether or not they are best resolved during implementation.

When the uncertainty is likely to be resolved during implementation, having a monitoring plan to alert the PMT that a deviation is likely, and contingency plans in place for any activation necessary can minimize impacts. This strategy is known as the Observational Approach. For example, an area of contaminated soil is thought to contain only trivalent chromium and is being exhumed and treated to immobilize the chromium with a solidification process that will not be effective on hexavalent chromium. The contingency plan for discovery of hexavalent chromium could be preprocessing with reducing agents to convert all chromium to the trivalent form prior to solidification. In this case, some means of chromium speciation would be used to monitor the soil as it is exhumed and detect the presence of hexavalent chromium.

When the uncertainty is not likely to be resolved during implementation, the contingency needs to be built into the response (i.e., the response technology needs to be tolerant of all the possible values or states for the uncertainty such that there are no adverse impacts regardless of what the true value is). This can be viewed as a special case of the Observational Approach, wherein the contingency is pre-mobilized. Alternately, this approach can be viewed as one based on assumptions of the most restrictive conditions for the design basis.

There is less flexibility inherent in this approach and a greater commitment of resources.

An example of a tolerant technology approach would be a treatment train for groundwater that may have iron precipitation problems that would affect air stripping. An iron removal process could be added to the train or air stripping could be replaced with activated carbon, a process that is less likely to suffer iron impacts.

Contingency plans and/or tolerant technologies are selected and developed to the degree required to ensure meeting performance objectives in a timely manner. The key is to identify and evaluate each uncertainty and then select the appropriate management strategy rather than not think through the potential consequences and have the decision made by default.

Alternative Uncertainty Matrices

Variations of the uncertainty matrix are a useful way to systematically address uncertainties. The preferred format is a modification of the matrix provided previously in Figure 5-4 to determine the significance of uncertainties. In one form (Figure 8-1), technologies are compared to determine their relative sensitivities to uncertainties. In a second (Figure 8-2), the selected technology is evaluated to select contingencies.

Figure 8-1: Uncertainty Matrix – Response Selection

Uncertainty	Assumed Value	Response	Threshold	Probability of Exceedance	Impact
Permeability 10^{-5} to 10^{-2} cm/s	10^{-3}	Pump and treat	$\leq 10^{-4}$	Low	Incomplete capture, excessive drawdown
		Permeable treatment wall	$\geq 10^{-3}$	Moderate	Insufficient contact time
		In situ bioremediation	$\leq 10^{-3}$	Moderate	Incomplete treatment due to poor mixing of nutrients
Preferential Conduits – Present or Absent	Absent	Pump and treat	Present	Moderate	Insufficient containment, risk to receptor wells
		Permeable treatment wall	None if have aquiclude to key in to	Low	
		In situ bioremediation	Present	Moderate	Incomplete treatment

Figure 8-2: Uncertainty Matrix– Response Design

Response	Parameter	Design Basis	Range of Values	Impact	Threshold for Impact (Probability)	Monitoring	Contingency	Time to Implement
Monitored Natural Attenuation	Long-term geochemical stability	Stable	Stable/ Unstable	Arsenic becomes mobile	ph > 8 ph < -3 (low)	Eh-ph, As in sentinel wells	Pump and treat	6 months
	Irreversibility of adsorption	Irreversible	Reversible/ Irreversible	Release of arsenic in future	>10% release (low)	As in sentinel wells	Pump and treat	6 months
	Presence of preferential pathways	None	Several	Arsenic escapes may be transported to well	>10% of flow (moderate)	Monitor receptor wells for As	Well had treatment	3 months
	Current perimeter is static	Static	Retreating to growing	No immediate effect due to buffer zone	Flux exceeds buffer zone > ¼ mile growth (moderate)	As in sentinel wells	Pump and treat	6 months
	Permanence of institutional controls	Non-residential	Through residential	Potential for on-site wells to result in ingestion	First potable well (low)	Five year reviews	Buy out water rights	1 month

Each uncertainty is entered on its own line of the matrix (e.g., Figure 8-1). The assumed value of a parameter or condition affecting the uncertainty (selection basis) is assigned to the uncertainty. The range of possible values that may be observed during implementation is estimated. The key is to try and bound the range with whatever information is available. In the end, if there is no basis for bounding the range, the entire span of possible values is entered.

A threshold value (e.g., decision criterion) is entered as the condition at which a deviation from the assumed value becomes significant (i.e., the point at which a different selection would have been made had the threshold value been the assumed value for the selection basis). Some uncertainties may have multiple thresholds, e.g., if the assumption is that there is no free floating pure phase product, the first threshold may be presence of a sheen which would warrant some pretreatment to protect the GAC, while the second threshold might be a layer in excess of 5 cm at which point free phase extraction would be employed. Thresholds should be associated with a qualitative estimate of the likelihood that actual conditions lie on the other side of the threshold than what has been assumed.

The impact of exceeding the threshold should be identified in the uncertainty matrix (e.g., Figure 8-1) and may prove useful in helping identify promising candidates for the contingency plan. The probability of exceeding the threshold is estimated qualitatively as a means of judging the likelihood that a contingency will have to be implemented and, therefore, the degree to which the contingency should be pre-mobilized.

A means of monitoring for deviations is identified as the way in which the uncertain parameter or condition will be observed to trigger implementation of the contingency. Clearly, the monitoring approach must be sensitive enough to be able to indicate when the threshold has been crossed. Ideally, monitoring provides a means of projecting forward so that there is some advance warning of when a threshold is likely to be exceeded, e.g., the use of dig face contamination data to extrapolate to volume remaining to be excavated.

In addition to the method, it is important to define what constitutes variability versus a deviation of concern. If there is no monitoring method available (i.e., uncertainty will not be resolved during implementation) then the design basis should be changed or a tolerant technology selected (e.g., if there is no follow-up on seeing if institutional controls are working, then they might not be a viable remedial option).

The contingency should indicate what action would be taken when a deviation has been substantiated by the monitoring activity. Finally, some measure of timing is important both with respect to the amount of advance warning afforded by the monitoring and with respect to the amount of response time required to implement the contingency. A comparison of the two time estimates will help with selection of the preferred contingency as well as a determination of the degree of predevelopment of the contingency that is warranted.

The matrix is developed by evaluating each uncertainty separately. Ultimately, it is important to review the content in a broader systems context. If too complex or too many contingencies are required, it may be that an alternate response is needed. There is also an opportunity to identify contingencies that address more than one uncertainty.

Uncertainty matrices in either form are valuable tools for communication with stakeholders. Uncertainty is a primary cause of concern with the public that often leads to requests for more extensive investigations and use of clean closure responses. By demonstrating that uncertainties have been systematically evaluated and monitoring and contingency plans are in place, the public is more likely to accept decisions made with less than complete knowledge. Indeed, the use of monitoring and irrevocable contingency actions has played a major role in gaining acceptance for monitored natural attenuation remedies.

Interpreting the Decision Document

The decision document provides the road map for all post-remedy selection activities. However, the utility of that road map is tied directly to the ability of the PMT to reach a consensus interpretation. In the best of circumstances, the PMT will have followed the Principles and had a heavy hand in preparing the decision document. That being the case, and assuming no changes in personnel on the PMT, a consensus interpretation will already exist. That not being the case, a consensus should be reached as soon as possible. The decision document by design will include requirements such as the identity of the response, its components, criteria and standards to be met, and other requirements. It will also include areas of flexibility and allowance within which there is latitude to meet RAOs using different creative approaches. It is these areas where streamlining and innovation can result in cost and resource savings.

While the decision document prescribes the required response, the level of detail provided will vary greatly. The decision document will also prescribe the constraints on the response (i.e., actions that can not be taken or options that can not be considered). The level of detail contained in the decision document reflects a balance between protection against misinterpretation and less opportunity for flexibility and innovation. Inherently, there is more flexibility when performance standards are specified in place of design standards. This is not meant to suggest that the level of detail or the provisions contained in the decision document are good or bad; rather, that the PMT needs to understand them before they know how to address them.

Standards and criteria should be clearly listed in the decision document. Most will be identified as ARARs or permit conditions. If they are not, the PMT will need to agree on which standards should be attained, and the extent to which they apply (i.e., to which media and at which locations). Decision documents should also include a section containing additional requirements that must be met. These requirements are not necessarily linked directly to solving the original problem; rather, they describe other legal frameworks under which the work must be conducted.

For all design bases, when dealing with environmental response actions, the PMT needs to assume there will be some surprises--no site is completely characterized (i.e., a range of values is always possible). The question then changes from “what if” to “what are the impacts if” the values exceed the estimate.

Essentially, the engineer looks at how the response would be designed if the extremes of the possible range were selected as the design basis. If the design is not significantly different, there may be no need for a contingency. If the design would be altered greatly, then it is prudent to evaluate the tradeoff between cost of a more robust design versus the cost of having a contingency in place to accommodate conditions that deviate from the design basis.

Contingency Development

In selecting a contingency, there are three relevant lines of inquiry:

- What is the impact of the potential deviation (uncertainty) and does it suggest an obvious contingency? (e.g., if the concern were unmapped preferential pathways being missed by a pump and treat system, the contingency would be to treat the receptor well or install new extraction wells when monitoring data reveal leakage.)

- What response would have been selected if the worst case value were assumed for the uncertainty? (e.g., look at the remedy that would have been selected if the deviation were assumed as the baseline condition.)

- Are there obvious options for moving from the selected response to the level of protection required if the worst case prevails? Can adding to the current design accommodate the deviation? (e.g., a second facility to take additional excavated soil if it exceeds capacity of the current facility.)

By pursuing these lines, it is possible to identify candidate approaches for the contingency.

Ultimately, any contingency that is implemented must be developed as fully as the response itself. However, a number of factors need to be considered in deciding how far the development should be taken prior to an indication that the triggering deviation will be encountered.

Clearly, primary importance needs to be placed on evaluating the impact of delays in implementation. The longer it takes to implement a contingency and the greater the impact of delays, the more incentives there are for pre-mobilization. For example, if the response involves open excavation and the contingency would leave the hole open and subject to subsequent releases of contamination during storm events, there is good reason to reduce the response time and minimize that potential or modify the contingency to include immediate cover for the excavation while the rest of the contingency is being mobilized.

In the example of excavation of soil that may contain hexavalent chromium, the health and safety implications are of sufficient importance that protective clothing should be selected on the assumption hexavalent chromium is present (i.e., fully pre-mobilized contingency). With regard to an alternate treatment approach if hexavalent chromium is encountered, the alternate method should be identified and logistics planned, but exhumed soil would not be treated for hexavalent chromium until its presence is confirmed.

The probability of deviations exceeding a threshold is an important consideration. If the probability is very low, there is less likelihood that the contingency will be implemented and, therefore, less incentive to fully develop it. Similarly, if the monitoring will provide warning of the likelihood of a deviation exceeding the threshold well in advance, there will be more time to develop the details of the contingency when it is clear that it is needed. In some respects, a good monitoring program with predictive capability can be viewed as a means of continually updating the probability estimate.

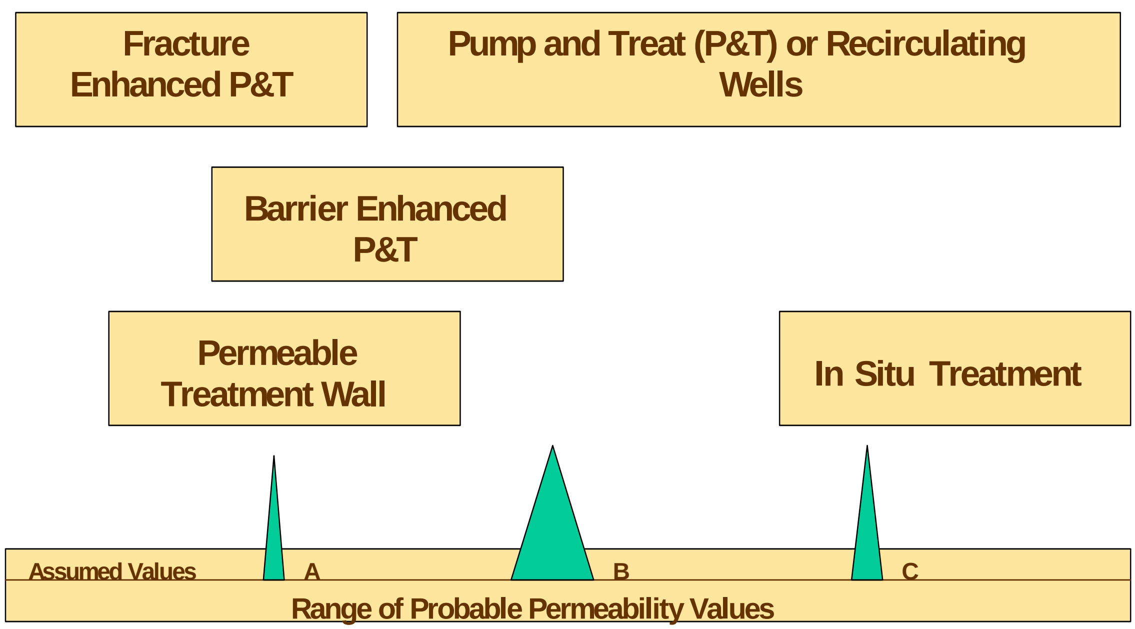
To the extent that a contingency is compatible with a response, it is easier to pre-mobilize than a contingency that will alter the remedy fundamentally. In the latter case, the point at which the trigger is encountered will impact the degree to which there is merit in stopping work and developing detailed plans for the change in direction. Obviously, the greater the resources required by a contingency, the greater the incentive to delay development until need is apparent.

At this point, it is clear that uncertainty mitigation consists of two key elements: 1) a monitoring plan (i.e., a means of determining if a deviation exists), and 2) a contingency plan (i.e., actions that will be taken if it is evident performance will not meet RAOs). Both elements are needed. Hence, any remedy that has a monitoring requirement should also have a contingency plan to be implemented if monitoring results indicate RAOs are not being met. (Monitoring implies there is residual uncertainty about performance. If that is not the case, there is no justification for monitoring in the first place.)

Tolerant technologies are defined as those that can accommodate the broadest range of conditions. Ideally, a technology is available that addresses the full range of probable values for the uncertain parameter. In that case, no contingency is required. In many respects the contingency has been completely pre-mobilized in the remedy design.

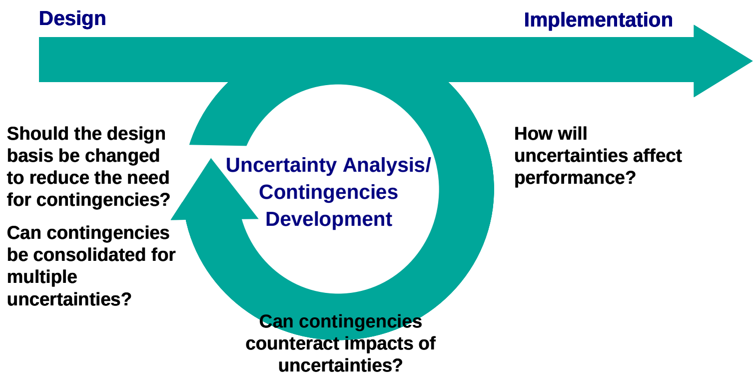
In Figure 8-3, the location of the assumed value (A, B, or C) would alter the selection of the response. The nature of any deviation from the assumed value would also identify candidate contingencies. If the assumed value is A, pump and treat or in-situ treatment cannot be applied. Permeable treatment walls, barrier enhanced pump and treat or fracture enhanced pump and treat would be candidates. If it is likely the assumed value is biased low, the treatment wall is the more robust option. If A is biased high, fracture enhanced pump and treat is the most robust option. If B or C is the assumed value for permeability, pump and treat/ recirculating wells are the most robust option.

Figure 8-3: Identifying Tolerant Technologies



When uncertainties in response selection and design have been addressed, there is an opportunity to step back again and review the plan in a systems context (Figure 8-4). If many and varied contingency plans are needed, there may be merit in looking for more robust contingencies that cover a larger number of uncertainties or to reconsider more tolerant technologies. Robustness may come from the technology itself or from the design.

Figure 8-4: Iterative Nature of Uncertainty Analysis



Uncertainty evaluation and management provide a mechanism to keep the response on track and moving through implementation toward completion. If a different design basis would alleviate the need for contingencies in the design, that basis could be the best probable value for design. Therefore, the uncertainty consideration is not viewed as a sequential process step, but an integral part of design that is reevaluated whenever new information comes to light. It is important to keep procurement staff in the loop as situations that require implementation of contingencies occur.

Ultimately, uncertainty analysis is a feedback mechanism in the design process that affects three areas:

- Final design;
- Procurement; and
- Nature of contingencies.

Summary

Mitigation is required for all residual uncertainties of significance (i.e., those that may cause the response to fail to meet RAOs). Mitigation may be accomplished by selecting technologies or designs that are tolerant of the full range of possible values for an uncertain parameter or by monitoring uncertain parameters during implementation and implementing pre-determined contingencies as appropriate. The best approach to mitigation is determined on the basis of the nature of the uncertainty and the potential impacts of probable deviations from assumed conditions.

Variations of the uncertainty matrix are useful in evaluating alternatives for mitigation in both the pre-decision and post-decision document timeframes. Matrices in any form can be an effective means of communicating with stakeholders and gaining greater confidence in the level of protectiveness that will be provided by a selected response.

The degree to which contingencies are pre-mobilized should be determined on the basis of impacts, resource requirements, and timing. In the extreme, tolerant technologies are selected such that the contingency is fully implemented without knowledge of whether it is needed.

9. DEVELOPING AN EXIT STRATEGY

Introduction

An exit strategy is the plan that determines how and when an activity will be terminated. Experience has shown that without an exit strategy, it is difficult to reach consensus on stopping remediation or monitoring efforts. Uncertainty as to whether unacceptable risk has been mitigated and reluctance to take responsibility for declaring a situation safe, lead to default positions that continually extend operations until some undefined event makes it clear that termination is safe. Unfortunately, without a clear definition as to what that undefined event would look like (i.e., an exit strategy) there is never consensus that it has been observed. Therefore, just as it is prudent to note the fire exits when entering a building, it is prudent to understand what is required to stop an activity before it is begun.

This chapter discusses the concept of end state and its central role in the development of an exit strategy. It notes the different nature of end states that arise from application of different types of responses and introduces the notion of stewardship and long-term care for those responses that result in leaving residues in place for the foreseeable future. Phased exit strategies are discussed as are documentation and knowledge management issues associated with closeout.

Exit Strategies and End States

Exit strategies are needed for any long-term obligations including monitoring, operation, maintenance, or other activities not required in perpetuity. (By definition, there is no exit for requirements in perpetuity.) In general, exit strategies will apply to any remedy in which residues above action levels are left in place under circumstances that reasonably can be expected to ultimately result in concentration reductions below those levels. Hence, an exit strategy may be appropriate for a containment remedy involving a cap over degradable waste, but may not be for inorganic contaminants. Similarly, exit strategies are appropriate for pump and treat and natural attenuation responses regardless of the projected timeframes in which RAOs are expected to be met.

Exit strategies define the conditions or state to be achieved; the actions necessary to reach that condition or state; and the amount, type, and origin of data necessary to demonstrate that the state or condition has been reached. As such, exit strategies must be tailored to the response action and the end state for the response application as specified in the decision document. In order to tailor exit strategies and better understand when they are required, it is first necessary to define some related terms.

In general, completion is defined as the end of installation (i.e., construction complete) and start-up activities (system operational and functional). Construction completion may equate to response completion for some types of response (e.g., excavation, in-situ treatment). For other responses (e.g., pump and treat, monitored natural attenuation), there may be significant activities after construction completion to ensure the remedy stays on the path to response complete. Continuing activities may include operation of pump and treat facilities, monitoring under an MNA response, or similar long-term activities conducted to cause or verify that the site contaminant inventory is continuing to approach the desired long-term monitoring state.

Response complete is defined as the point at which the desired end state has been reached. Response complete can occur with an inventory of contaminant in place if that inventory is within the desired end state (e.g., under a well-maintained cap).

The end state may be defined as target characteristics or conditions for a site that the response has been designed to attain. It describes the physical condition of the site once remediation activities are complete. It can include both clean closure and closure with containment of residuals.

Site Closeout means that the responsible party has completed active management and monitoring at an environmental restoration site and no additional environmental restoration funds are expected to be expended at the site, unless the need for additional remedial action is demonstrated as a result of other unplanned activities.

Exit Strategy Content

An exit strategy should define the data necessary and sufficient to demonstrate that the desired end state or condition has been reached. For some activities such as long-term monitoring, a phased exit plan may be appropriate that includes criteria for ramp downs associated with levels of greater confidence gained through the monitoring data.

An exit strategy should specify several parameters:

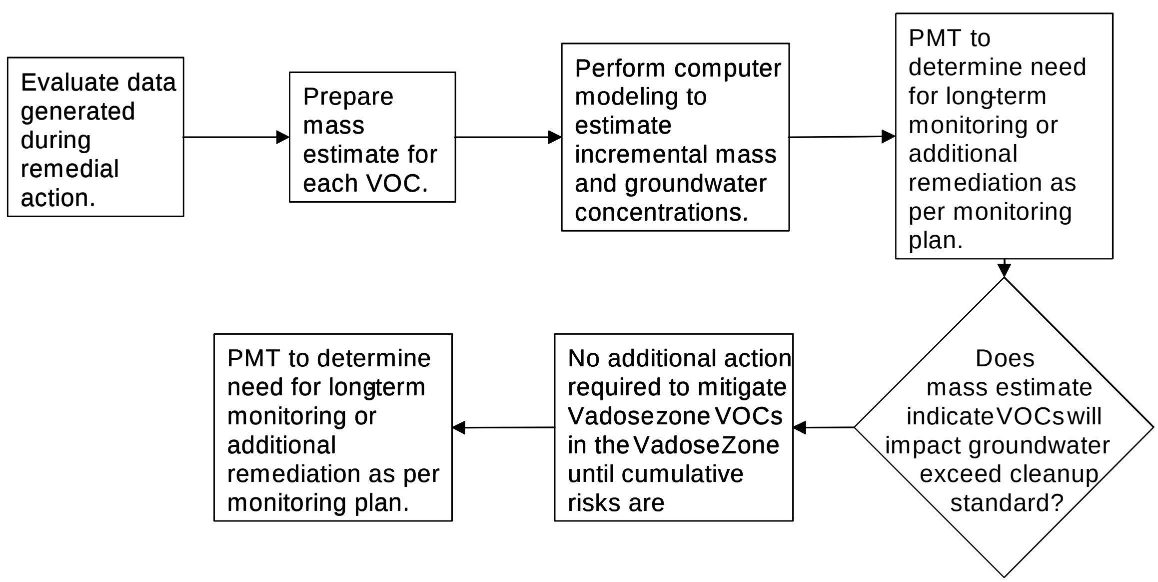
- The type of data required;
- Sample locations;
- Sample frequency;
- Target parameter thresholds characteristic of the desired long-term monitoring state;

- Duration required to demonstrate sustainability; and

- Statistical algorithms to be applied to data (e.g., confidence limit, type of mean, etc.).

Figure 9-1 is a simplified logic diagram illustrating a rudimentary exit strategy for an SVE remedy. Ideally, it would identify the data to be used as input to the model (which wells, etc.) and criteria for stopping the monitoring being conducted to look for evidence of rebound contamination.

Figure 9-1: Example of an Exit Strategy



Monitoring Plan Considerations

Exit strategies for monitoring activities are developed around a set of decision criteria. At a minimum, criteria should be developed that address three potential modes of monitoring reduction, as illustrated by the following examples:

- Eliminate unnecessary analytes, including:

  - Analytes not found in initial samples and for which there is no evidence of a release;

- Analytes not identified above detection limits in three successive samples; and

- Analytes detected at less than half the action level for at least three successive samples and displaying a static or downward trend.

- Eliminate redundant locations (wells), including:

  - Wells in the interior of plumes whose boundaries are defined by other wells (these wells may be needed to support performance monitoring for response such as monitored natural attenuation);

  - Wells outside plumes and not deemed to be in the pathway of on-coming plumes and not required to establish background;

  - Wells duplicated by proximate wells on the same isopleth; and

  - Wells for which analytical data will have no clear use in future decision making such as consideration of when to implement a contingency.

- Reduce sampling frequency:

  - Initial quarterly sampling is needed to establish seasonal variations. Annual monitoring helps identify variations resulting from changes in precipitation (wet versus dry years). Beyond those distinctions, sampling frequency should be selected on the basis of the slope of the observed trend lines, the degree to which empirical data match predictions, and the relative velocity of groundwater. The more predictable the data are, the less need there is for frequent confirmation.

  - Monitoring is only required when there is uncertainty as to the fate and transport of contaminants and the effectiveness of remedies that are implemented. As the uncertainty is reduced, or as its consequences become less significant, the need for further monitoring is diminished. Similarly, slow moving groundwater requires less frequent monitoring because trends are slower to develop and there is more time to respond to them.

Performance monitoring is conducted to determine if performance is meeting expectations. This may include looking at contaminant inventory as well as other indicators, such as geochemical parameters, during monitored natural attenuation. To the extent that performance data verify predicted trends for performance meeting expectations, they can be used to justify reducing monitoring activities in the future. In some situations, monitoring may trigger a re-evaluation of what needs to be done.

Detection monitoring is performed at sentinel wells to ensure that contaminants are not approaching exposure points at concentrations that pose unacceptable risk. Ambient monitoring involves the measurement of background conditions on a regular basis to provide a benchmark for evaluating detection and performance monitoring results. For post-closure monitoring, contingencies may not be well-developed due to assumed low probability of need, but a general response should be identified

In many cases it is technically or economically infeasible to fully remediate a site because of the degree of contamination and the type of contaminants present. At these sites, additional monitoring, maintenance, and contingency plans will be required to ensure that human health and the environment remain protected after RAOs have been met. The PMT will need to describe how to ensure that the response remains protective after it has been determined that the long-term monitoring state has been reached. Activities may be required to maintain an adequate level of protection to human health and the environment from the hazards posed by chemical materials, waste, and residual contamination remaining after cleanup is completed. Activities required may include safeguarding Chemical and Biological Warfare (CBW) materials, monitoring the migration of contamination and the effectiveness of response, inspecting disposal cells, enforcing physical access restrictions, implementing permits and other legal or institutional controls, maintaining relevant information, and generally providing responsible long-term care of a site.

No monitoring program should be implemented without some form of decision criteria or a contingency plan to indicate how unsatisfactory results will be defined (i.e., what constitutes evidence of failure?) and addressed (i.e., what response /contingency will be implemented when unsatisfactory performance is confirmed?) and how success will be demonstrated and what that means with respect to future activities. Because knowledge of the site may increase with collection and review of monitoring data and because technology is continually evolving, monitoring and contingency plans should be subject to review and modification as an integral part of the mandatory 5-year review of remedies.

Documentation

A construction complete report is written after completion of construction activities. The report is intended to document as-builts, define any RAO requirements, identify any long-term care requirements and, when the desired end state is reached, document target achievement. If the PMT adhered to the

Principles throughout the project, this document will mostly be written. It is largely an aggregation of existing by-products of implementation.

Under RCRA, a written post-closure plan is required that will become part of the RCRA permit issued to the owner or operator. This report must detail the activities to be carried out after the response is complete at each hazardous waste management unit. To amend this plan, the owner or operator must submit a written notification of, or request for, permit modification (40 CFR 264.118).

Under CERCLA, in the case of long-term remedial action sites (LTRA), an interim closeout report is developed. LTRAs are sites where achieving the RAOs require continuous operation of the response over several years. When the cleanup levels are achieved, a final closeout report is developed and submitted for EPA review and concurrence.

Figure 9-2 illustrates the essential elements of a closure report. As in the case of the construction complete report, most of the required information is already available (i.e., generated during implementation); thus, documentation should require little new effort at this time.

Figure 9-2: Elements and Source of Completion/Closure Reports

Completion/Closure Report Element	Source
Problem statement	Scoping and decision document decision rules
Description of selected response	Decision document
Details of implementation	"As-builts," notice of modifications
Contingencies executed	Memoranda filed to document need for and use of contingencies
Performance status	Results of performance measurements
Verification of completion/ closure	Evaluation of performance measurement results in the context of the definitions of construction complete
Design of O&M (completion) long-term care (closure)	"As-builts," decision document specifications, operations manual

Depending on the nature of the remedy selected, construction complete and closure may be concurrent (e.g., clean closure or containment) or may be separated by a period of operation and maintenance. If the end state leaves contaminants in place at concentrations above risk thresholds (e.g., capping) closure is followed by long-term maintenance and stewardship.

The role of the PMT changes once response is complete. There is a need to determine lines of authority/responsibility for future actions, including when to invoke contingencies. The PMT is responsible for:

- Sharing appropriate response information and data with long-term care authorities [assures knowledge management (archiving) for future stakeholders];

- Conducting five-year reviews; and

- Delegating authority for future actions as appropriate.

Summary

Exit strategies are devised to define in advance the conditions and confirmatory data needed to receive approval to terminate remedial action activities. Any activity without a defined end point, other than those assumed to continue in perpetuity, requires an exit strategy. Strategies should include a definition of the data required to confirm termination is appropriate and the decision criteria to which those data will be subjected.

Long-term monitoring activities may benefit from adoption of a phased exit strategy that ramps down requirements and cost commensurate with the degree of confidence gained in the remedy's performance. Performance monitoring relates to tracking actual performance against predicted performance. Detection monitoring provides a safety net to protect receptors should contaminants escape capture. Whenever monitoring is required, it should be accompanied by a contingency plan for actions necessary if monitoring results deviate significantly from predictions.

Construction completion and closeout are documented in reports assembled largely from existing information. These documents should be designed to facilitate knowledge transfer to future stewards of LTRA.

APPENDIX A:
REFERENCES: GLOSSARY OF TERMS

Glossary of Terms and Acronyms

The following terms and acronyms have been used throughout this manual. The definitions offered here reflect the intended meaning for these terms as used in this manual.

Allowances – Areas of flexibility within decision document language that allows different approaches or designs to be developed to satisfy a need in the design package. In general, a requirement is defined broadly so that the designer is not overly constrained in how the objective is met.

AOC – Area of Concern.

ARAR – Applicable or Relevant and Appropriate Requirement.

Area of Concern – discrete parcel or area of an installation for which historic information, physical evidence or other information suggests conditions may exist that will require a response.

ASTM – American Society for Testing and Materials.

BRAC – Base Realignment and Closure.

CERCLA – Comprehensive Environmental Response, Compensation, and Liability Act.

Closure – Point at which site reaches desired end state. This is interchangeable with site closeout.

Closure Report – Means of documenting the actions taken to reduce risk at a site to acceptable levels without the requirement for any further long-term care. This document usually coincides with removal of a site from the National Priorities List and includes information on the response taken and the results of all verification monitoring.

Competitive Procurement – A means of obtaining materials or services through solicitation of bids from at least three sources with the selection based on price and/or technical criteria on the basis of which the bidders compete.

Completion – Conclusion of the construction and startup phases of activity related to implementation of an environmental response at a site. (See Closure.)

Completion Report – Means of documenting the actions taken to complete construction at a site**.** Typically contains a statement of the problem that was addressed, a description of the technology employed to resolve the problem, as-builts, results of all monitoring activities conducted during construction, and verification that the objective of construction work was met.

Comprehensive Environmental Response, Compensation, and Liability Act – PL 96-510, also known as Superfund, is the enabling legislation passed in 1980 under which funds are made available and mechanisms are put in place to restore inactive properties that are found to have contamination at levels that pose unacceptable risks to human health or the environment. CERCLA was broadened through passage of the Superfund Amendments and Reauthorization Act (SARA) of 1986.

Conceptual Site Model – A depiction of key elements and interfaces that describe the fate and transport of contaminants from source to receptor at a given site or AOC.

Consensus – Agreement on the part of all parties to a decision as to the course of action. In the context of project management team decisions for environmental response, indicates that no single party is so opposed to the resolution that they will not stand behind the decision. Individual parties may not believe a decision is the best possible decision, but they must believe it is an acceptable decision.

Containment – Response actions with the objective of stopping further migration of contaminants in the environment. Example technologies include capping, hydraulic barriers, and liners.

Contingency – Action or plan of action designed to counteract the impact of conditions observed during implementation that deviate from the conditions assumed as the basis for designing a response. Contingency responses become the primary response when monitoring indicates the designed response cannot meet its objective. Contingencies are employed as a safety net so that implementation can proceed without having to characterize all site conditions to the point where they are known with certainty.

CSM – Conceptual Site Model.

Data Gap – Unknown value or condition, uncertainty.

Data Need – Data gap related to a parameter or condition for which the range of probable values is sufficient to affect a pending decision. Equates to significant uncertainty.

Data Quality Assurance – Process applied to determine the adequacy of data to support defined decisions.

Data Quality Objectives – A seven step planning process devised to focus and optimize data collection activities. Specific steps include:

1 - State the problem
2 - Identify decisions that address the problem
3 - Identify inputs affecting the decision
4 - Define boundaries of the study
5 - Develop decision rules
6 - Specify limits on uncertainty
7 - Optimize design for obtaining data

DataQUEST – EPA DQA software used in evaluating whether collected data support decision making within the constraints of the DQOs.

Decision Criteria – Values or conditions used as a metric for comparison of results indicating the point at which a decision changes. In the context of technology selection, the decision criterion is a threshold value for a parameter at which one technology becomes infeasible and another becomes the preferred alternative. Screening values and action levels are examples of decision criteria for specific phases of work in the environmental restoration program.

Decision Document – Instrument used to document the decision made as to how an environmental response problem is to be resolved. Under CERCLA, the document is a Record of Decision (ROD) or action memorandum. Under RCRA, the document is the statement of basis. In both cases, the document states the nature and extent of the problem being addressed, the objective of the response selected, the alternatives considered in the selection process, and requirements imposed on implementation of the response.

Decision Error Feasibility Trials – EPA DQO software used to identify the number of samples required to make a decision at a specified level of uncertainty.

Decision Logic – Sequencing of decisions and activities required to meet a specific programmatic objective such as categorization of AOCs or selection of a remedy. Decision logic is often depicted graphically with a decision logic flow diagram.

Decision Rule – A concept used to document what constitutes the basis for making a decision. The rule is structured as an "if, then" statement with the "if" portion setting the conditions which if encountered will result in the action prescribed in the "then" portion. One form used to facilitate communication with stakeholders is to make the problem statement the "if" portion of the rule and the planned response the "then" portion.

DEFT – Decision Error Feasibility Trials.

Dense, Non-Aqueous Phase Liquid – Low solubility liquid contaminant such as trichloroethylene that has a higher specific gravity than water, thus allowing it to form a pool of separate phase liquid at the bottom of the saturated zone or in pockets where it can not penetrate the pore throat between soil particles.

Design – The activity undertaken to translate the requirements and objective provided in a decision document into a set of instructions sufficiently detailed to implement the selected response and meet the objective. In a broader context, design includes all activities associated with development of the design package including identification of options during the scoping phase. However, for the purposes of this guidance, design is often referred to as detailed design, the quantitative translation of concepts into plans and specifications.

Design Package – Drawings, plans, specifications and related instructions required to enable the implementation contractor(s) to install the response properly.

Design Basis – Quantitative and qualitative description of the conditions, assumptions and performance specifications upon which a design is based.

Deviation – Condition or parameter which when encountered during implementation is found to differ from the design basis to the degree that it may be necessary to invoke a contingency to ensure meeting restoration objectives. Deviations arise because of an earlier decision to manage an uncertainty by preparing a contingency rather than conducting further investigations until the condition/parameter is characterized more fully.

Deviation monitoring – Procedures employed to observe site conditions or parameters whose values are fully delineated. When deviations are encountered during implementation of a response, they may dictate use of a contingency to ensure restoration objectives are met. This form of monitoring is predicated on the belief that the condition being monitored could have a value so different from that assumed during design that it will impact the ability to restore the site. Results of monitoring are reviewed to determine if a threshold is crossed indicating that the contingency is required.

DNAPL – Dense, Non-Aqueous Phase Liquid.

DOE – Department of Energy.

DQA – Data Quality Assurance.

DQO – Data Quality Objectives.

DQOPRO – EPA DQO software consisting of three programs:

SUCCESS-CALC - determines the number of samples required to detect a specified frequency of a characteristic occurring in the population.
ENVIRO-CALC - determines the number of samples required to estimate the average concentration for an area
HOT SPOT-CALCULATION - determines the number of samples required to locate a suspected circular or elliptical hot spot of specified size.

Dynamic Decision Making – Use of field analytical methods and pre-selected decision criteria to enable team to make decisions in the field on a real-time basis as a means of reducing mobilization/demobilization efforts.

End State – Target characteristics/conditions for site which response has been designed to attain.

Environmental Response – Set of activities performed to ensure that a site is restored to a state that does not pose unacceptable risks to human health or the environment. Environmental response may be conducted voluntarily or in response to programs initiated under RCRA (corrective measures), CERCLA (remedial actions), or analogous state programs.

EPA – U.S. Environmental Protection Agency.

Exit Strategy – Approach used to document site end state, actions necessary to reach that state, and amount, type, and derivation of data necessary to demonstrate that the end state has been reached (i.e., definition of necessary and sufficient information/data to demonstrate when an activity can be terminated). In some cases, such as with monitoring, the exit strategy may involve stages that effectively ramp down the activities as circumstances warrant.

False Negative Error – Analyst concludes the null hypothesis is true when, in fact, it is false.

False Positive Error – Analyst concludes the null hypothesis is false when, in fact, it is true.

Fatal Flaw – Condition or parameter value which impacts the implementability or efficacy of a response to the degree that the response will not meet the objective or is no longer the preferred option. A condition or parameter value that can be accommodated through extensive modification is considered a fatal flaw if the cost or impact of the modification are such that there is a more desirable response action that should be considered first.

Federal Facility Agreement – Instrument used to establish the schedule and framework within which environmental response will be conducted at federal sites. The term is often used interchangeably with Interagency Agreement (IAG). Agreements are negotiated between EPA and the federal entity responsible for the site and, in some cases, the host state.

FFA – Federal Facility Agreement.

Fixed Price – Contracts under which the client agrees to pay a fixed sum for delivery of a prescribed scope of work by the contractor regardless of the cost incurred to complete the scope.

Fixed Unit Price – Contracts under which the client agrees to pay a fixed sum per unit of work performed. Hence the total contract award is calculated as the product of the fixed unit rate and the number of units required.

FWPCA – Federal Water Pollution Control Act.

Gray Zone – The range of values near the decision criterion where the PMT is comfortable accepting the consequences of a decision error.

Hazard – Intrinsic property of a material or situation with the potential to cause harm.

Hierarchy Of Probable Technologies – A list of the technologies most likely to be selected for a response at a site ordered on the basis of most desirable first. The hierarchy is used to focus data collection efforts on parameters needed to evaluate the most likely response actions and to identify early in the process the alternatives that should be evaluated if the preferred technology is found to have a fatal flaw.

Implementability – Aspect of a response that characterizes the ease with which it can be installed and made functional. Contributing factors include availability of essential resources, access and spatial requirements, sensitivity to uncontrollable variables, and logistics.

Implementation – Activities associated with installation of a design through completion. Implementation generally encompasses construction, shakedown and startup. It does not include long-term monitoring.

ITR – Independent Technical Review.

Key Design Parameter – A characteristic of a site or technology the value for which will materially affect the design, cost and effectiveness of a response. Key design parameters are such that significant changes in value may render a technology unsuitable for a site or at least less desirable than an alternate. In the extreme, a key design parameter with an adverse value would be a fatal flaw.

LNAPL – Low Density, Non-Aqueous Phase Liquid.

Long-Term Care – Activities required after completion of construction (i.e., response complete) in order to maintain conditions that are protective of human health and the environment. Long-term care may include operation of response facilities (e.g., treatment plant for extracted groundwater), monitoring, and maintenance of containment and access barriers.

Long-Term Monitoring – Long-term monitoring is associated with responses that do not result in closure upon completion of construction. The intent of the monitoring is to verify that the response is working as designed, or alternately provide an advance warning that the response was not successful.

Low Density, Non-Aqueous Phase Liquid – Low solubility liquid contaminant such as gasoline or diesel fuel that has a lower specific gravity than water, thus allowing it to form a pool of separate phase liquid that will "float" on the surface of the water table.

LTRA – Long-Term Remedial Action site.

MNA – Monitored Natural Attenuation.

Monitored Natural Attenuation – Response action that relies on the presence of natural chemical, hydrogeological and biological conditions to degrade, denature and/or immobilize contaminants so that they do not comprise an unacceptable risk to human health or the environment. Key active elements of the approach are use of monitoring to verify that attenuation is proceeding as predicted and availability of contingencies to mitigate any risks that may arise due to insufficient attenuation.

National Oil and Hazardous Substances Pollution Contingency Plan a.k.a. National Contingency Plan – Regulation (40 CFR Part 300) that sets certain minimum requirements and provides the framework for environmental response actions.

NCP – National Contingency Plan.

Necessary Data – Those data that are required to make an informed decision.

NPL – National Priorities List.

Operations and Maintenance (O&M) – Activities required during period between construction completion and closure.

OU – Operable Unit.

Pathway – Functional chain between a source of contamination and a receptor by which contamination is transported through the environment and poses a risk. To be complete, a pathway must have a source, a release mechanism, a transport medium, an exposure mode and a receptor. Pathways are the building blocks from which the CSM is constructed.

Performance Measurement – Means of monitoring progress during the implementation of response actions and subsequent operation.

Plug-In Approach – Method of selecting a response wherein sets of qualifying conditions are specified and matched with corresponding technologies that would be best suited for those conditions. The plug-in approach is applied at facilities where there are numerous waste management units or release sites with virtually identical characteristics that lend themselves to development of generic responses.

PMT – Project Management Team.

Post-Construction – Period after completion of construction implementation activities. Specific activities or events may include long-term care, long-term monitoring, and closeout depending on the nature of the remedy applied and site conditions.

Pre-Decision Document Phase – Time period prior to issuance of the decision document. Pre-decision activities include scoping of the problem, site characterization, alternative evaluation/selection, and treatability studies.

Pre-Mobilization – Design and staging of required resources for a contingency prior to encountering the deviation that would necessitate implementation of the response.

Presumptive Remedy – Response found to be the preferred action for a given set of circumstances so often that its selection is presumed whenever those conditions prevail. Presumptive remedies are identified by the EPA in guidance documents that prescribe how and when they can be used.

PRG – Preliminary Remediation Goals.

Principles of Environmental Restoration – A set of four underlying concepts that have been identified as key to streamlining environmental response efforts. The principles in the order presented in this manual are:

- Principle One - Developing effective communication and cooperation with a project management team is essential
- Principle Two - Clear, concise, and accurate problem identification and definition are critical
- Principle Three - Early identification of likely response actions is possible, prudent, and necessary
- Principle Four - Uncertainties are inherent and will always need to be managed

Principle Threat Materials – Contaminated media and waste posing a risk at least one order-of-magnitude greater than the threshold of unacceptability. Historically, PTM has included materials posing a cancer risk of 10^{-3} or greater and/or having a hazard index of 1000 or greater. EPA has established programmatic expectations that if at all possible, PTM will be addressed with some form of treatment to reduce toxicity, volume, and/or mobility.

Problem Statement – Clear, concise statement of a site condition posing a real or potential unacceptable risk, or a condition that the PMT determines requires a response. The problem is the essence of why environmental response is necessary at a site and, therefore, relates to chemical contamination above thresholds of concern. The problem statement is derived to provide a simple focus for restoration activities. The use of problem statement here is broader than that applied in the DQO process wherein a problem statement refers to a specific decision that must be made and, therefore may address one subelement (e.g., the viability of a single pathway) of the problem in this larger context.

Project Delivery Strategy – Plan for how goods and services will be provided to accomplish the project objectives. The strategy typically addresses what will be performed in house, what will be contracted, how contracting will be conducted, and what type of contract vehicle will be employed.

Project Management Team – Primary decision making entity responsible for directing and overseeing prosecution of the project. The PMT usually includes the Base Environmental Coordinator or lead installation representative and the remedial project manager from the EPA and the lead state environmental regulatory agency. Only representatives from organizations with the ability to say "no" are on the PMT. Entities with advisory capacity may attend meetings, but if they do not have a vote, they are not on the PMT.

PTM – Principle Threat Materials.

PMT – Project Management Team.

QAPP – Quality Assurance Project Plan.

RAOs – Remedial Action Objectives.

RBCA – Risk Based Corrective Action.

RCRA – Resource Conservation and Recovery Act.

Regulator – Federal, state or local official with the authority to enforce the Federal Facility Agreement or other programs affecting environmental response activities. For DOD sites, the federal and state officials are the primary regulators in a decision-making role.

Regulatory Community – Officials with status as a regulator with regards to environmental response at a site.

Remedial Action Objectives – Desired outcome of response action(s) taken pursuant to an identified problem.

Remedial Action Operations – Activities conducted after construction and startup of a remedy pursuant to maintaining protectiveness. Examples include operation of treatment facilities and conduct of monitoring.

Requirements – Elements of a decision document which constrain the design and implementation activities by defining what must be included and what can not be included in the response. Specific areas incorporated in requirements include the problem being addressed, the objective of the restoration effort, the nature of the response, the definition of an acceptable end state, and other applicable or relevant and appropriate requirements. The latter category refers to items arising from the need to comply with other related federal, state, and/or local regulations.

Residual Uncertainty – Conditions or parameters not sufficiently characterized through investigation to be able to affirm their state or value with a desired level of confidence. A conscious decision has been made to manage these uncertainties through contingencies on the basis of lower projected costs or inability to reduce them through further investigation.

Resource Conservation and Recovery Act – PL 98-616, the enabling legislation passed in 1976 and amended by the Hazardous and Solid Waste Amendments in 1984 under which the generation, transportation, storage, treatment, and disposal of hazardous wastes are regulated. The corrective action segment of the regulatory program provides the framework for EPA and states to require restoration of contaminated sites as a condition for obtaining permits to continue hazardous waste-related activities. The corrective action program for restoration of active sites is the analog for the CERCLA remedial action program for inactive sites.

Response – The specific action or actions taken to resolve the condition creating a problem (regulatory requirement or unacceptable risk) at a site. In the RCRA program, the response may be a removal, stabilization or corrective action. In the CERCLA program, a response may be a removal or a remedial action.

Response Complete – The point at which cleanup goals for a site or group of sites under an operable unit have been met, the decision has been documented, and any necessary regulatory requirement for notification or application for concurrence has occurred.

Response Selection – The decision with regard to what technology to apply in order to accomplish environmental response objectives. This decision is formalized with issuance of the decision document.

Risk – The likelihood that impacts associated with a hazard will be realized. Risk is often calculated as the product of the probability of an event and the consequences of that event.

Risk Assessment – Evaluation of site characteristics, contamination levels and pathways to estimate the level of risk that exists under current and potential future use conditions.

Risk Management – Decisions made with respect to what actions will be taken to attain a state of acceptable levels of risk.

ROM – Restoration Oversight Manager.

SACM – Superfund Accelerated Cleanup Model.

SAFER – Streamlined Approach for Environmental Restoration.

SAP – Sampling and Analysis Plan.

SARA – Superfund Amendments and Reauthorization Act.

SCEM – Site Conceptual Exposure Model.

SCEM Builder – Software available on the internet to assist in construction of CSM.

Significant Uncertainty – Unknown condition or parameter value whose range of probable values spans a threshold or decision criterion such that a key decision may be altered pending resolution of the true value of the uncertainty. Significant uncertainties are equated to data needs in that resolution is required to make the pending decision. Resolution can be achieved by collecting relevant data to better specify the parameter value or condition, or by changing the decision being made so the threshold value or criterion is moved to a point where all probable values for the parameter fall above or below the criterion.

Sole Source – A procurement offered to a single supplier on the basis that the supplier is so uniquely qualified to provide the goods or services that there is nothing to be gained from attempting a competitive procurement or that a competitive procurement would delay time critical activities. Grounds for sole source justification may include access to proprietary technology or information; unique skills, knowledge or experience that would be difficult or impossible to duplicate; or ability to mobilize more quickly for time sensitive activities.

Source – Location or inventory of contaminants at concentrations that could pose an unacceptable risk if a complete pathway exists. Primary sources may include containers or accumulations of chemicals or wastes. Secondary sources may include media such as soil, groundwater, building surfaces and surface water that have been contaminated through migration of chemicals from a primary source.

Stakeholder – Individual or organization that is or will be impacted directly by site contamination or the restoration effort. At DOD sites, stakeholders include the DOD, state and federal regulators, Indian Nations, the local community, the public in general, and special interest groups such as environmental organizations and recreational users.

Stewardship – Term used to encompass post-construction activities such as operation and maintenance, long-term care, access restrictions, and long-term monitoring. In essence, stewardship is required for any site for which the response involves activities during an extended period between completion and closure, implying that a steward is needed to ensure that activities are conducted when required and in the required manner.

Streamlined Approach For Environmental Restoration – Approach to accelerating environmental response through application of data quality objectives and the observational approach as a means of focusing efforts to conserve resources.

Streamlining – Generic term for the organization of environmental response efforts in a manner that reduces cost and schedule from the baseline, process oriented approach that has historically been applied. Streamlining is an attempt to move quickly to the essential decisions in the restoration program by eliminating unnecessary data collection, redundant activities, and unproductive confrontations between stakeholders.

Sufficient Data – The set of all data adequate to make a decision at the PMT's desired level of confidence.

Superfund Accelerated Cleanup Model – Approach to environmental response that utilizes removal authority and early actions to promote material progress as quickly as possible, as well as, consolidating site assessment activities and response selection. SACM encourages use of presumptive remedies and related guidance to take advantage of experience gained from application of restoration programs over the years at sites with common characteristics.

Technology – General approach to a response action encompassing use of a particular chemical or physical phenomenon capable of meeting project objectives. Technologies are not specific to a unique design, but are specific to the underlying principles that make the technology effective

for its intended purpose. Biological treatment would be a technology. Within that technology, there would be numerous unit process options such as activated sludge, trickling filter, and extended aeration. Example technologies include:

Removal Technologies
- Excavation
- Extraction wells
- In-Well Stripping
- Soil Flushing
- Soil Vapor Extraction
- Solvent Flushing

Treatment (In-Situ or Ex-Situ)
- Biological Treatment
- Physical-Chemical Treatment
- Phytoremediation
- Soil Washing
- Stabilization/Solidification
- Thermal Destruction

Containment
- Barrier Walls
- Capping
- Permeable Treatment Barriers

Technologies can be defined more narrowly by indicating a subset of unit process options such as membrane separation technologies or in-situ bioremediation technologies.

Tolerant Technology – Technology that is sufficiently robust to accommodate the full range of probable values for an uncertain parameter or condition. Selection of a tolerant technology removes a significant uncertainty by changing the decision criterion to a point above or below the range of probable values for an uncertain parameter or condition.

Threshold – Specific value which divides the range of all possible values for a key design parameter into two subranges, such that presence in one subrange would change a decision on response selection or design when compared to presence in the other subrange. Thresholds are used in uncertainty management during design and implementation to indicate when a contingency is needed to counteract the potential impacts of encountering a deviation. May be synonymous with decision criteria for decisions related to selection and design of a remedy. For purposes of this manual, threshold is also referred to in the context of screening levels and levels for problem definition.

Unacceptable Risk – The level at which residual risk creates a situation deemed not protective of human health and /or the environment. There is no point of zero risk. As a consequence, it is necessary to define a level below which risk is small enough to be acceptable. Generally, that level is identified in the context of value relative to natural, unavoidable risk to which everyone is exposed. For the purposes of risk management at hazardous waste sites, the threshold of unacceptable risk has been defined as a cancer risk of 10^{-6} to 10^{-4} or a hazard index of 1 to 100.

Uncertainty – Parameter or condition for which a discrete value or state can not be determined with sufficient confidence. Synonymous with unknown. This is a broader definition then that used with the DQO Process. In the latter, uncertainty refers to the level of confidence with which a decision can be made.

Uncertainty Management – Approach to accommodating the reality that uncertainty is inherent in environmental response. Management is performed by balancing two alternative courses of action:

1) Reducing uncertainty by further characterizing the parameter or condition to narrow the range of possible values/states; and
2) Developing contingencies that counteract the impact of encountering values/states that cross a threshold value for the parameter/condition.

Uncertainty Matrix – A tool used to organize and facilitate consideration of uncertainty and its impacts on decisions. During pre-decision document activities, the uncertainty matrix is employed to assist in planning investigations and evaluating the effects of uncertainty on response selection. After issuance of a decision document, a design uncertainty matrix is used to assist in evaluating the effect of residual uncertainty on the design basis.

Uncertainty Mitigation – Selection of tolerant technologies or contingency plans that effectively move the decision criterion or threshold value above or below the range of probable values, thus removing the significance of an uncertainty.

Uncertainty Reduction – Collection of information to narrow the range of probable values for an uncertain parameter or condition. If uncertainty is not reduced to a range that does not span a threshold value, an alternate design or contingencies are needed to effectively move the threshold above or below the range of probable values.

USAEC – United States Army Environmental Center.

APPENDIX B:
DECISION DIAGRAMS

Decision Diagram - Subsurface Vapor Convection

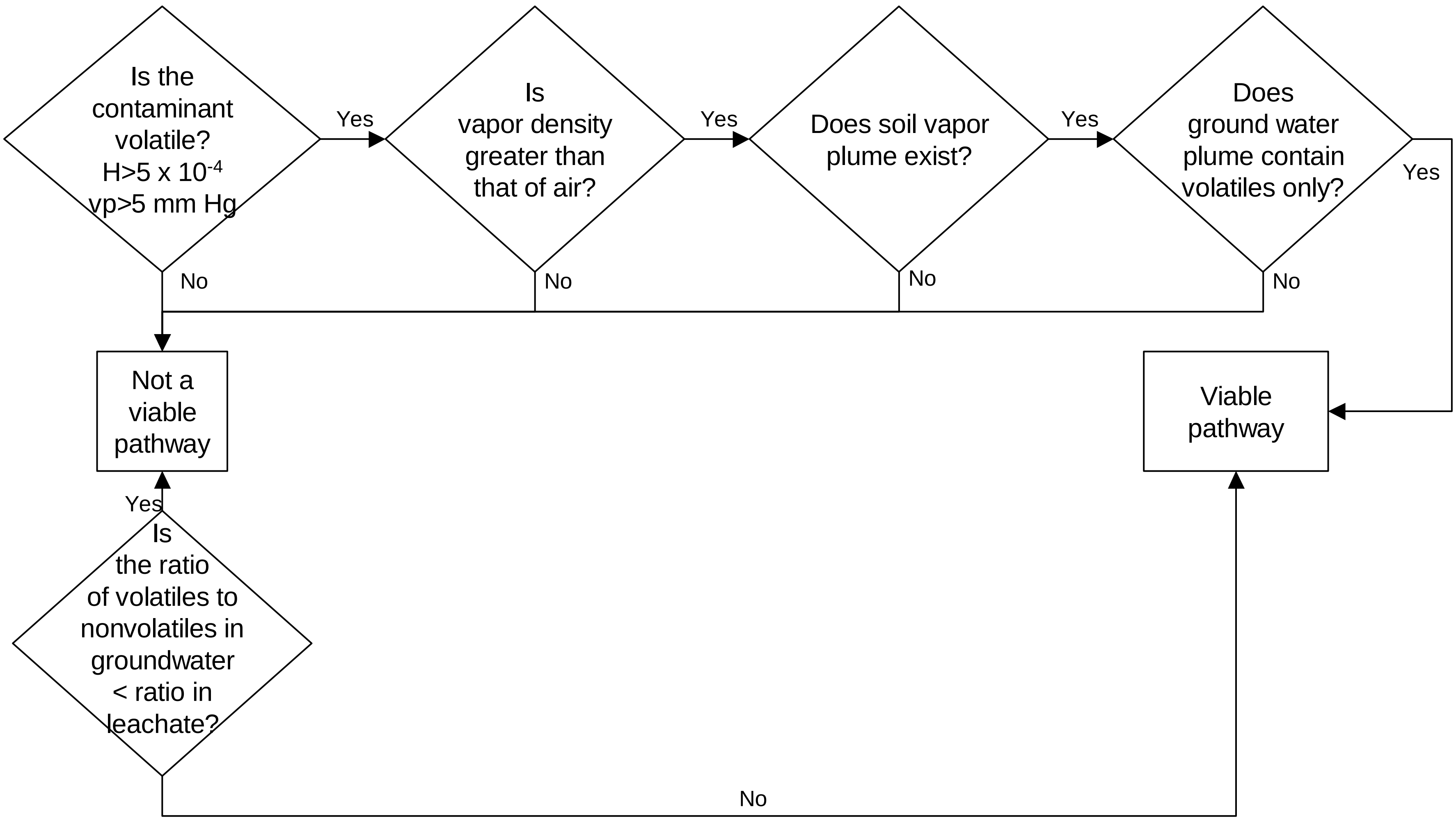
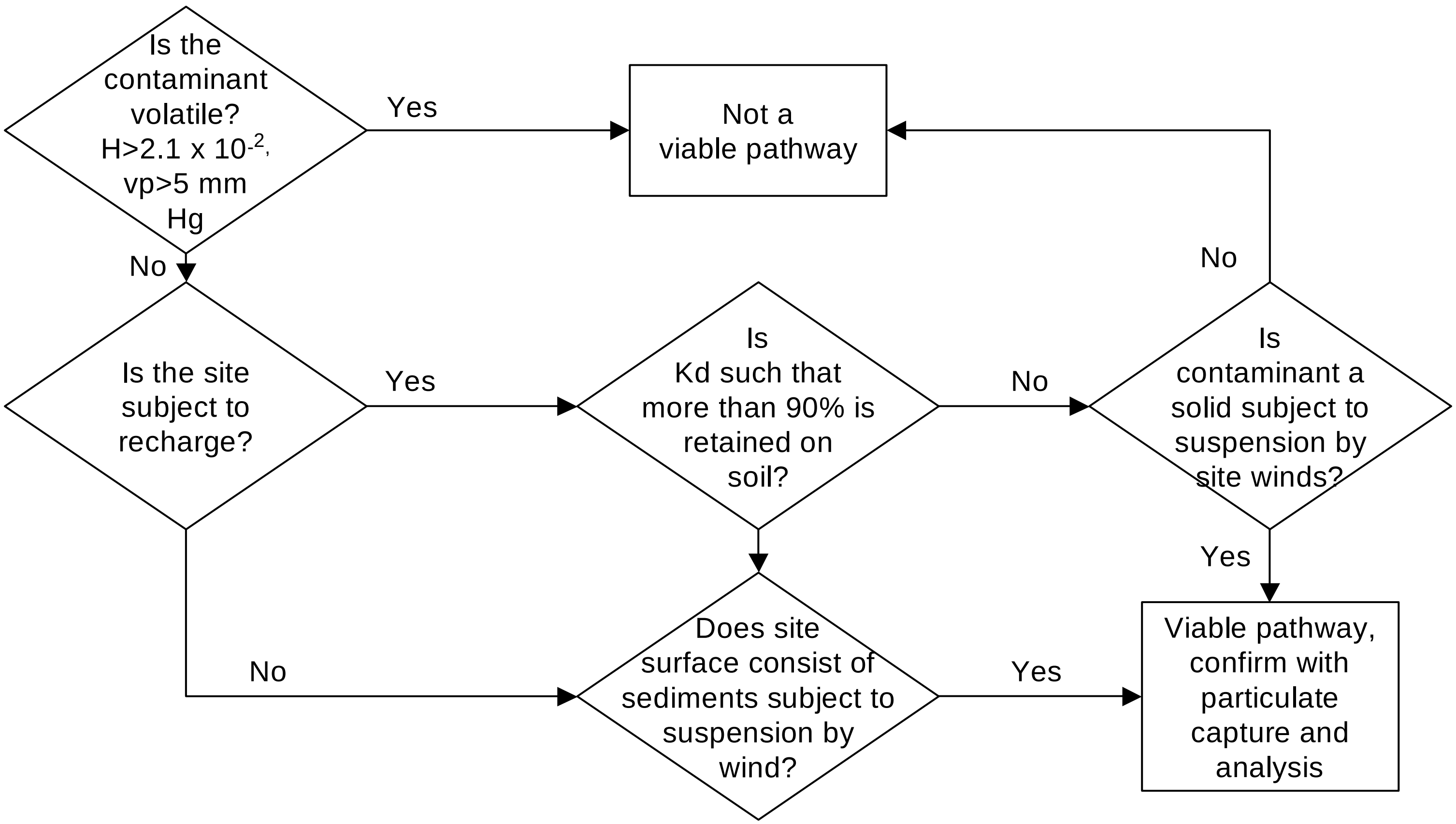
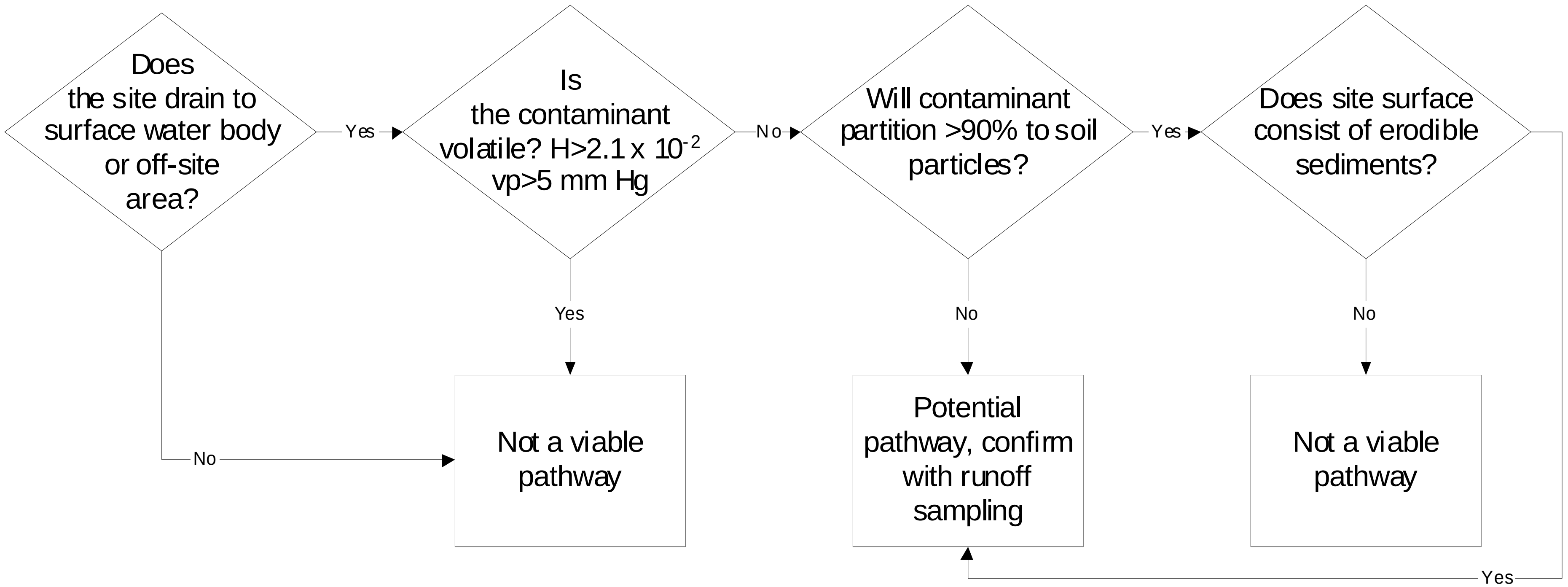


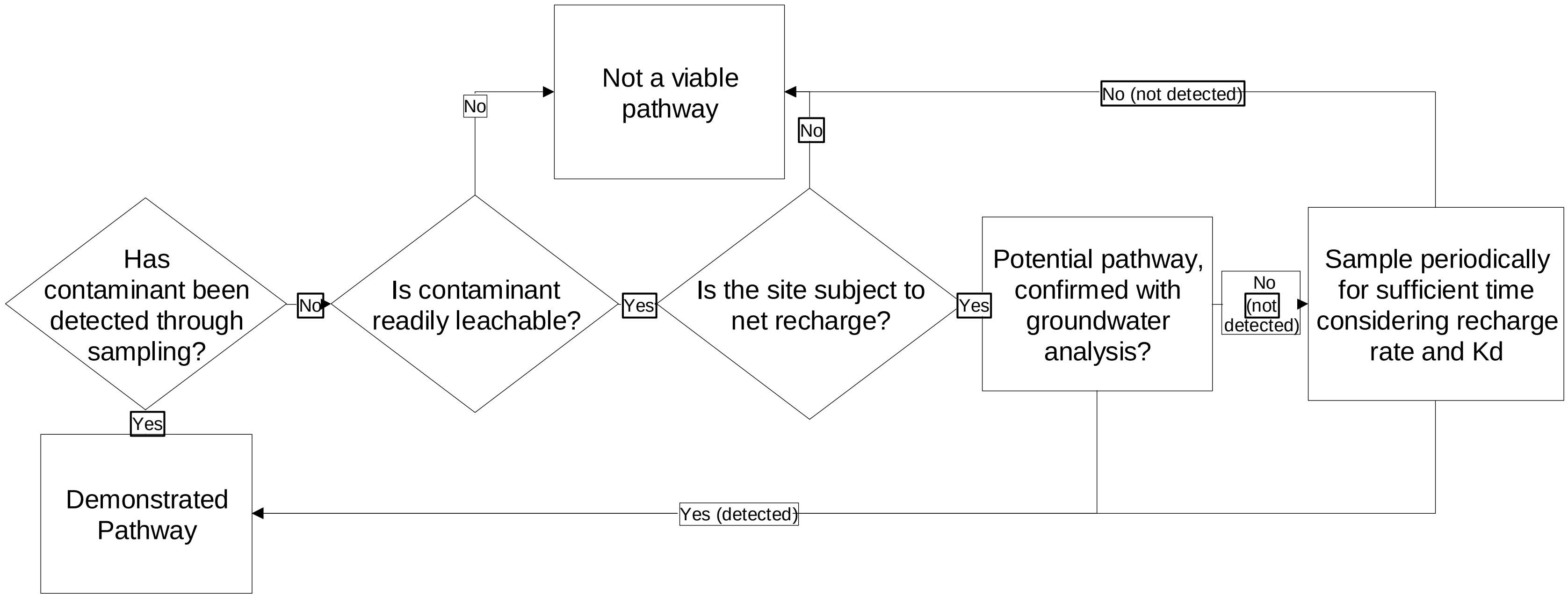
Diagram for Resuspension/ Deposition Pathway



Decision Diagram--Surface Runoff



Decision Diagram--Infiltration Pathway



APPENDIX C:
DESIGN BASIS ELEMENTS AND GENERAL IMPLEMENTATION CONSIDERATIONS

1: SOIL--IN-SITU BIOREMEDIATION

Design Basis Elements

- Contaminant concentrations to determine nutrient requirements and period of performance (high contaminant concentrations can inhibit biodegradation, very low contaminant concentrations may not support biological activity; range of favorable concentrations varies by contaminant and site)
- Contaminant type to determine applicability and interferences (Kows greater than 1,000 are strongly sorbed to soil organic carbon and are less bioavailable)
- Contaminant types to determine oxygen needs (nonhalogenated aromatics, polynuclear aromatics, and nonhalogenated polar and nonpolar organics, generally are biodegraded more rapidly under aerobic conditions, certain halogenated aliphatics, halogenated aromatics, and polychlorinated biphenyls, or PCBs are more readily degraded anaerobically)
- Metals and radionuclides (generally not applicable)
- Multiple contaminants (presence of other contaminants; easily degradable contaminants will degrade first while more recalcitrant are left undegraded)
- Depth and areal extent of contamination (injection of nutrients is limited by drill-rig depth capabilities)
- Nutrient requirements (Nutrients that must be available in sufficient quantities for bioremediation to occur include C, H, O N, P, S, K, Ca, Fe, Mg, and Mn)
- Redox conditions (bioremediation can take place under aerobic or anaerobic conditions; aerobic biodegradation requires oxygen as the terminal electron acceptor (TEA) while anaerobic biodegradation uses TEAs such as NO_3^-, SO_4^{2-}, CO_2, Fe^{3+}, Mn^{4+}, oxygenated organics, and halogenated compounds)
- Rate-limiting nutrients (nitrogen and/or phosphorus are most frequently the rate-limiting nutrients in soil and are added to promote biodegradation, deficiencies of other nutrients are rare but should not be ignored)
- Bioaugmentation (soils typically contain the necessary soil bacterial communities to degrade contaminants; microbial additions may be desirable if the native community lacks the necessary bacteria to degrade the target compounds)
- Treatability tests (normally used to support remedy screening, selection, or design and to quantify biodegradation rates)
- Chemical and biological properties (COD and BOD are required to determine whether environmental conditions are conducive to microbial activity)
- Nutrient ratios (optimum carbon:nitrogen:phosphorus ratio is approximately 120:10:1; ratio is required to determine the need for additional nutrients)
- Oxygen (for an aerobic system require a minimum air-filled pore space of about 10 percent and soil gas oxygen concentrations greater than 5 percent)
- Temperature (generally, temperature should be in the range of 10 to 70 degrees

C for bioremediation to proceed)

- Moisture content (moisture contents < 40 percent of field capacity limit biological activity; moisture contents > 80 percent of field capacity reduce oxygen availability in soil)
- Soil physical characteristics (clay content greater than 10 percent may limit contaminant bioavailability and reduce biodegradation kinetics)
- Soil chemical characteristics (pH outside range of 4.5 to 8.5 limits biological activity)
- Soil organic carbon (SOC) content (high SOC content may limit contaminant bioavailability and reduce biodegradation kinetics)
- Site accessibility (helps determine maximum size of equipment)
- Presence of cultural resources/artifacts

General Implementation Considerations

- Process monitoring requirements (continuous monitoring is necessary to ensure that the appropriate ratios of nutrients are maintained)
- Regulatory requirements (faults, flood plains, artifacts, wetlands, wildlife refuge, etc.)
- Security requirements

2: SOIL--IN-SITU STABILIZATION

Design Basis Elements

- Depth and areal extent of contamination to determine volume requirements and limitations (in-situ mixing is limited by equipment torque capabilities; in-situ injection is limited by drill-rig depth capabilities)
- Depth of freezing (freeze/thaw cycles may impact efficacy of stabilization; stabilization mixtures above the freeze line may require special formulations)
- Depth of water table (contaminants located below the water table may require soil dewatering prior to stabilization)
- Soil temperatures (low temperatures (less than 5^{o}C) may impede solidification process and result in substandard solidification products)
- Contaminant types (limited effectiveness for organic compounds, primarily suited to inorganic compounds e.g., metals, radionuclides)
- Contaminant concentrations (soils containing more than a few percent organic material may be difficult to stabilize and require special additives and/or increased quantities of stabilization agent)
- Contaminant volatility (additional safety precautions and or containment may be required due to contaminant volatilization caused by reagent heat of hydration)
- Radionuclide concentrations (cuttings brought to the surface may require measures to reduce and control worker risk)
- Soil physical characteristics (soil particle-size distribution, hydraulic conductivity, moisture content, plasticity, shear strength etc. are required to size equipment (auger size, power requirements, etc.) and select solidification reagents and estimate volumes and composition)
- Soil chemical characteristics (low pH soils may require neutralization prior to treatment with cement solidification reagents)
- Treatability study (normally used to determine appropriate solidification agents and mixing ratios, includes leaching data on treated and untreated soils to determine extent to which contaminant mobility is reduced)
- Site accessibility (helps determine maximum size of equipment)
- Space availability (technology has relatively large space requirements for equipment operations and material stockpiling)
- Surface structures (buildings etc., may prevent equipment access to site, angled or horizontal drilling with mixing has not been demonstrated)
- Post remediation options (may limit disposal and treatment options)
- Natural and waste debris (boulders, trees, buried drums and tanks can impede auger advancement)
- Contaminant/Reagent compatibility (sulfates, borates, or organic materials may interfere with the effectiveness of cementitious and pozzolanic reagents)
-

- Means of introducing reagent
- Reaction time
- Product stability (structural properties , chemical leachability, estimated life)
- Presence of cultural resources/artifacts

General Implementation Considerations

- Process monitoring requirements (continuous monitoring is necessary to ensure that the appropriate ratios of stabilizing agent to contaminated soil are maintained)
- Volume increases (volume increases due to addition of stabilization agent may impact final site grading)
- Regulatory requirements
- Security requirements
- Final closure (may require cap to limit infiltration and contaminant migration)
- Maintenance and monitoring (may require groundwater monitoring and post closure care of cap etc.)

3: SOIL--IN-SITU VITRIFICATION

Design Basis Elements

- Depth and areal extent of contamination to determine staging and limitations (maximum demonstrated melt depth is approximately 20 feet, dictates electrode placement and enhancement techniques)
- Volume reduction/backfill availability (typically 20 to 40% reduction in volume, will be necessary to backfill if it is desired to restore site to grade)
- Electrical requirements (3-phase, 12,500-13,800 V, 200 amps, special multiple-tap transformer that converts power to 2-phase and transforms it to required voltage)
- Type of contamination (organics containing sulfur, phosphorus, or halogens may generate acid gases requiring off-gas treatment, immiscible-phase organics may limit technology)
- Radionuclides (high Plutonium loading in soil may pose a criticality threat)
- Soil particle-size gradation and composition (must have 30% minimum SiO_2 and 1.4% minimum combined Na_2O and K_2O, additives may be required for certain soil types)
- Depth to groundwater (soil may need to be dewatered for high water tables and permeable soils prior to implementation)
- Location of underground structures(required to avoid electrical short circuits or damage to structures, heat protection may be required if structure is within 6 meters of melt zone)
- Treatability study (normally used to confirm that final product meets leachability requirements)
- Topography (equipment requires relatively flat topography (+/- 5% slope) within equipment staging area)
- Space availability (must have space for 3 full-size tractor trailers, power generation equipment (if required), and 17-meter wide off-gas collection hood)
- Metal concentration (should not exceed 5% of the melt weight material)
- Organic liquid content (should not exceed 1-7% depending on BTU value)
- Sealed containers (drums and tanks should be removed from area prior to treatment)
- Combustible solids (must be mixed with soil prior to treatment)
- Tritium (completely removed and released out stack)
- Radon, cesium, and other volatile and semi-volatile radionuclides (may present an exposure concern because of accumulation of off-gas system)
- Off-gas treatment requirements
- Electrode spacing
- Product stability (structural properties , chemical leachability, estimated life)

- Presence of cultural resources/artifacts

General Implementation Considerations

- Treated glass must meet TCLP requirement of RCRA
- Permitting/other legal requirements (if governing regulatory agency considers this incineration, a trial burn may be necessary)
- Security requirements

4: SOIL--SOIL VAPOR EXTRACTION

Design Basis Elements

- Depth of contaminated soil zone to determine extraction depth and limitations (when installing vent wells to depths < 10 feet a surface seal may be required to prevent drawing air from atmosphere instead of contaminated vadose zone)
- Areal extent of plume and access to install wells/piping system (buildings or utilities which may limit access)
- Presence/impact of underground utilities (do they act as preferential pathways, will they interfere with drilling/trenching/piping)
- Contaminant volatility (applicable to contaminants having vapor pressures greater than 0.5 mm Hg at ambient temperatures and dimensionless Henry's Law constants greater than 0.01)
- Soil permeability to determine radius of influence and flow rates (only applicable to permeable soils; soils with permeabilities to air flow exceeding 10^{-8} cm^2 [10^{-3} m/sec hydraulic conductivity] are commonly regarded as permeable)
- Soil moisture content (not applicable if liquid volume is equal to or greater than 90 percent of pore volume because air cannot be effectively transported through wet soils)
- Site uniformity (layers or abrupt changes is permeability limit effectiveness because air will move through more permeable areas and leave less permeable areas untreated)
- Site access for equipment (drilling, treatment plant)
- Depth to water table (only effective above water table; water table may have to be lowered if contamination extends below water table)
- Efficiency (up to 98 percent removal can be obtained, total removal not practical using this method)
- Soil organic carbon (high soil organic carbon contents limit its effectiveness)
- Removal times (ten days to three year time frames have been reported for maximum removal)
- Contaminant concentrations (required to determine removal rates and off-gas treatment needs)
- What type of surface seal is in place or can be used to prevent vertical short circuiting
- Soil character (site stratigraphy and porosity are required to determine radial influence and contaminant removal rates of wells)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, air permits)
- Volume of contaminated soil to be treated (number of wells, network of piping system)

- Air flow rate, layout of vent wells and pattern of soil air flushing through contaminated soil zone
- Pore volume flushing time for contaminated soil zone (volume of contaminated media divided by air extraction rate)
- Other properties affecting chemical removal (presence of NAPL, low permeability zones)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers)
- Unit process steps for treatment (entrained liquid /condensate separation, heating for humidity control, contaminant removal, discharge)
- Treatability study (required during remedy screening and selection process to determine effectiveness)
- Combination of unit treatment processes (air extraction, conveyance, treatment, discharge, process control system)
- Residuals/waste streams generated (condensate water, chemicals removed in off-gas treatment system, discharge of treated air)
- Monitoring required (influent air stream, discharge air stream, flow rates and mass fluxes from wells)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (condensate generation, freeze protection for any liquids generated)
- Operating procedures manual
- System optimization for maximum contaminant removal as conditions change
- Permitting/other legal requirements(applicable patents)
- Security requirements

5: SOIL--DIG AND TREAT WITH SOIL WASHING/SIZE SEPARATION

Design Basis Elements

- Depth of contamination (physical constraints of equipment, shoring requirements)
- Water table (Excavation of soils below the water table requires dewatering operations)
- Areal extent and access to excavate with equipment (buildings or above ground utilities which may limit access)
- Presence/impact of underground utilities (can utilities be shutdown and/or rerouted)
- Depth of contamination (treatable contamination depends on equipment and excavation technique; Draglines and backhoes can reach depths of 30-50 feet, clamshells can be used to 100 feet)
- Presence of cultural resources/artifacts
- Capacity (typically, 6-40 tons/hr of soil)
- Treatability studies (small-scale studies using site-specific soils and contaminants are the best way to predict effectiveness)
- Natural and waste debris (boulders, trees, and buried drums can impede site excavation)
- Contaminant properties (water solubility and chemical form are needed to help predict the contamination distribution in the Coarse and fine soil fractions)
- Types of contaminants (applicable to any contaminant retained in the fine-grained portion of the soil)
- Permits required (utility clearance, NPDES/Stormwater, excavation, air permits)
- Soil characteristics (clay soils may preclude use of soil separation because of limited volume reductions)
- Soil physical and chemical properties (particle size distribution, organic carbon content, and mineral composition needed to predict effectiveness, slope stability, etc.)
- Volume of soil to be treated (staging/storage areas required, throughput capacity of treatment process)
- Site access for equipment (excavation zone , staging area, treatment equipment, storage piles, backfill)
- Chemical characteristics of contaminants (low/high level radionuclides, mixed waste, metals, organics)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers, portable generators)
- Unit process steps for treatment (initial screening, size separation, washing/separation vessels, filtering of wash liquor)

- Combination of unit treatment processes (materials handling/storage/movement through treatment steps)
- Residuals/waste streams generated (concentrated waste soil, wash liquor, filter material)
- Monitoring required (cleaned soil, concentrated waste soil, dust emissions, wash liquor)
- Handling of residuals(drumming, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)
- Restore site (backfill, recompaction, utility reconnect, resurfacing)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (freeze protection for process solutions, wind erosion protection for storage piles, runoff collection from storage piles)
- Fugitive dust emissions
- Operating procedures manual
- Permitting/other legal requirements
- Security requirements

6: SOIL--DIG AND TREAT STABILIZATION/SOLIDIFICATION

Design Basis Elements

- Depth of contamination (treatable contamination depends on equipment and excavation technique; Draglines and backhoes can reach depths of 30-50 feet, clamshells can be used to 100 feet)
- Removal rates (ranges from 5 - 400 yd^3/hr)
- Areal extent of contamination (larger excavations may require backhoes and draglines, clamshells are used for contamination that is narrow or of limited areal extent)
- Soil temperatures (low temperatures (less than 5^oC) may impede solidification process and result in substandard solidification products)
- Water table (Excavation of soils below the water table requires dewatering operations)
- Contaminant types (limited effectiveness for organic compounds, primarily suited to inorganic compounds e.g., metals, radionuclides)
- Contaminant concentrations (soils containing more than a few percent organic material may be difficult to stabilize and require special additives and/or increased quantities of stabilization agent)
- Contaminant volatility (additional safety precautions and or containment may be required due to contaminant volatilization caused by reagent heat of hydration)
- Radionuclide concentrations (excavated materials brought to the surface may require measures to reduce and control worker risk)
- Strength and/or other waste acceptance criteria (strength typically required to evaluate physical stability and handling characteristics. EPA recommends unconfined compressive strength, UCS, of 50 psi.)
- Leachability (TCLP is required to determine whether a waste is hazardous because of its leaching characteristics)
- Solidification reagent/waste ratio (cement to waste ratios typically vary from 1:5 to 1:1; lime/ waste ratios from 5:100 to 30:100 ; bitumen/thermoplastic resin to waste ratios vary from 1:2 to 1:1)
- Volume increases (typical volume increases of 20 to 50 percent result from mixing reagent with waste)
- Permeability (permeabilities of stabilized material higher than 10^{-5} cm/s are usually unacceptable)
- Soil characteristics (soil type and strength are required to evaluate the side and bottom stability and design slope protection)
- Soil physical characteristics (soil particle-size distribution is required to select solidification reagents and estimate volumes and composition)
- Soil chemical characteristics (low pH soils may require neutralization prior to treatment with cement solidification reagents)

- Bench-scale laboratory treatability study (usually performed to determine reagent/waste mix design)
- Obstructions (locations of utilities, structures, and other obstructions are required so that they can be avoided during excavation)
- Drums, debris, and tanks (special precautions are required when these items are present in the soil)
- Site accessibility (required to establish maximum size of equipment that can be used)
- Distance to treatment/disposal facility (needed to determine costs; increases in weight and volume from solidification process may render solidification uneconomical)
- Space availability (technology has relatively large space requirements for equipment operations and material stockpiling)
- Natural and waste debris (boulders, trees, buried drums and can impede site excavation)
- Contaminant/Reagent compatibility (sulfates, borates, or organic materials may interfere with the effectiveness of cementitious and pozzolanic reagents)
- Reaction time (curing time is required to estimate throughput)
- Product stability (structural properties , chemical leachability, estimated life)

General Implementation Considerations

- Process monitoring requirements (continuous monitoring is necessary to ensure that the appropriate ratios of stabilizing agent to contaminated soil are maintained)
- Slope protection may be required depending on excavation depth and soil type
- Fugitive dust emissions (must be controlled if site is near a populated area)
- Regulatory requirements
- Post remediation options (may limit disposal and treatment options)
- Security requirements
- Final closure (may require cap to limit infiltration and contaminant migration)
- Maintenance and monitoring (may require groundwater monitoring and post closure care of cap etc.)

7: SOIL--DIG AND TREAT - SOIL WASHING/CHEMICAL EXTRACTION

Design Basis Elements

- Depth of contamination (treatable contamination depends on equipment and excavation technique; Draglines and backhoes can reach depths of 30-50 feet, clamshells can be used to 100 feet)
- Volume of washing solution (usually 1-2 times volume of soil per washing step, several washing steps may be required depending on the removal efficiency of the washing solution and the desired residual levels in soils)
- Capacity (typically, 6 to 40 tons of soil per hour)
- Removal rates (ranges from 5 - 400 yd^3/hr)
- Types of contaminants (applicable to any contaminant that will partition into the wash solution, effectiveness is soil and contaminant specific)
- Areal extent of contamination (larger excavations may require backhoes and draglines, clamshells are used for contamination that is narrow or of limited areal extent)
- Water table (excavation of soils below the water table requires dewatering operations)
- Radionuclide concentrations (excavated materials brought to the surface may require measures to reduce and control worker risk)
- Bench-scale laboratory treatability study (small-scale studies usually conducted using site-specific soils and contaminants to determine effectiveness
- Contaminant properties (water solubility and chemical form are required to select washing reagents)
- Soil physical and chemical properties (needed to predict effectiveness and select equipment type and washing reagents)
- Soil volume (needed to size equipment)
- Obstructions (locations of utilities, structures, and other obstructions are required so that they can be avoided during excavation)
- Drums, debris, and tanks (special precautions are required when these items are present in the soil)
- Soil texture (clays may be hard to disperse which will increase reaction vessel size and washing time)
- Soil organic carbon content (high concentrations of organic carbon may decrease effectiveness because of adsorption of contaminants)
- Space availability (must be adequate for soil washing equipment and temporary storage of contaminated and washed soils)
- Natural and waste debris (boulders, trees, buried drums and can impede site excavation)
- Soil characteristics (clay soils may preclude the use of soil washing; soil minerals may act as buffers and preclude the use of washing solutions that rely on acids

or bases)

General Implementation Considerations

- Process monitoring requirements (continuous monitoring is necessary to ensure that appropriate ratios of washing solution to contaminated soil are maintained and that desired removal efficiencies are obtained)
- Slope protection may be required depending on excavation depth and soil type
- Wash solution may require treatment before disposal
- Fugitive dust emissions (must be controlled if site is near a populated area)
- Regulatory requirements
- Security requirements

8: SOIL--DIG AND HAUL FOR DISPOSAL

Design Basis Elements

- Depth of contamination (physical constraints of equipment, shoring requirements, proximity to water table; draglines and backhoes (modified) can reach depths of 30-50 feet, clamshells can reach depths of 100 feet)
- Removal rates (ranges from 5-400 yd^3/hr)
- Areal extent and access to excavate with equipment (buildings or above ground utilities which may limit access)
- Obstructions (locations of underground utilities, structures must be noted so they can be avoided during excavation and utilities can be shutdown and/or rerouted)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, NPDES/Stormwater, excavation, air permits)
- Volume of soil to be excavated (staging/storage areas required)
- Drums, debris, and tanks (special precautions are required when these items are present in the soil)
- Site access for equipment (excavation zone , staging area, storage piles, backfill)
- Physical characteristics of media (slope stability of excavation sidewalls)
- Chemical characteristics of media (low/high level radionuclides, mixed waste, metals, organics)
- Residuals/waste streams generated (waste soil, runoff from storage piles)
- Natural and waste debris (boulders, trees, and buried drums can impede site excavation)
- Monitoring required (waste soil, dust emissions)
- Distance to treatment/disposal facility (needed to determine costs)
- Disposal requirements (manifesting, transport & disposal of waste)
- Restore site (backfill, recompaction, utility reconnect, resurfacing)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (wind erosion protection for storage piles, runoff collection from storage piles)
- Suitable access routes for trucks to disposal facility
- Permitting/other legal requirements
- Security requirements

9: SOIL--CAPPING

Design Basis Elements

- Areal extent of contaminated zone and access to cap (buildings or utilities which may limit access)
- Presence of cultural resources/artifacts
- Soil cover (usually range in thickness from 2-4 feet of compacted clay with permeabilities less than 10^{-7} cm/sec; should be placed below frost line)
- Flexible membranes (usually range in thickness from 20-100 mils; typically placed below frost layer)
- Slopes (top slope is usually from 3-5 percent after allowing for settling or subsidence)
- Contaminant characterization (required to assure that cap addresses all contaminant hazards e.g., thickness to mitigate radiation hazards)
- Erosion control (vegetative covers are used if climate will support them; if not, armored covers are used)
- Biointrusion layers (required when intrusion from burrowing animals is a problem; consists of large pebbles)
- Effectiveness (reduce infiltration for clay caps to 3 cm or less per year while more elaborate designs may reduce infiltration to 0.5 cm/year or less)
- Combined topsoil/native soil layer (combined thickness is the greater of 2 feet or the depth of frost penetration)
- Granular drainage layer (thicknesses range from 0.5 to 5 feet; may not be required if soil protective layer is adequate)
- Temperature fluctuations (large temperature fluctuations may cause cracking in synthetics because of a large coefficient of thermal expansion)
- Volatile gas generation (some wastes may generate gases that require venting through cap)
- Potential waste volume changes (changes in waste volume through settling or gas generation may affect waste performance; stabilization may be required to preclude problems with waste volumes)
- Local climate (wind speeds, precipitation data are needed to design cap and covers)
- Permits required (utility clearance, excavation, air permits)
- Surface structures (types and locations of surface structures are required to account for these structures in cap design)
- Adjacent sites (locations of adjacent sites are required to assure that runoff is properly managed and whether a single cap is desirable or if multiple caps are preferable)
- Runoff collection system from capped area

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Permitting/other legal requirements
- Security requirements, access restrictions after capped is placed
- Cap maintenance (long-term cap maintenance will be required; includes surface and perimeter monitoring)

10: SOIL--BIOVENTING

Design Basis Elements

- Depth of contaminated soil zone (vent well construction depths, screen intervals, shallow contamination or groundwater may preclude this technology because of diminished radius of influence and cheaper alternatives)
- Areal extent of plume and access to install wells/piping system (buildings or utilities which may limit access)
- Presence/impact of underground utilities (do they act as preferential pathways, will they interfere with drilling/trenching/piping)
- Types of contaminants (contaminants susceptible to aerobic biodegradation; not applicable to inorganic elements and compounds)
- Concentrations of contaminants (contaminant concentrations too high may inhibit biological activity while concentrations too low may not support biological activity)
- Contaminant source (should be eliminated to the extent possible before beginning bioventing)
- Presence of multiple contaminants (an easily degradable contaminant will be degraded first leaving behind more recalcitrant undegraded contaminants)
- Solubility (contaminants with aqueous solubility less than 1 mg/l are difficult to biodegrade)
- High hydrophobicity (contaminants with Kows greater than 1,000 are difficult to biodegrade because they are highly adsorbed to organic carbon and less available)
- Site access for equipment (drilling, treatment plant)
- Time to complete remediation (most economically-feasible systems achieve remediation in 1-3 years; may not be appropriate if a short (< 6 months) cleanup time is required)
- Soil permeability (with soils not very permeable to air flow (i.e., permeability < 10^{-11} cm^2) oxygen delivery and biodegradation rates will be low)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, air permits)
- Volume of contaminated soil to be treated (number of wells, network of piping system)
- Layout of vent wells and pattern of soil air flushing and oxygen delivery through contaminated soil zone
- Rate of oxygen delivery to contaminated soil zone
- Properties affecting biodegradation rate (moisture content, pH, other nutrients)
- Other properties affecting chemical degradation (presence of NAPL, low permeability zones)
- Physical characteristics of media (hydraulic conductivity of soil, radial influence of vent wells, pressure induced in vent wells)

- Chemical characteristics of media (low/high level radio nuclides, mixed waste, metals, organics)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers)
- Unit process steps for treatment (air injection, monitoring)
- Monitoring required (air injection rates, 0_2 and $C0_2$ levels in soil gas)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (condensate generation, freeze protection for any liquids generated)
- Operating procedures manual
- System optimization for maximum contaminant removal as conditions change
- Permitting/other legal requirements(applicable patents)
- Security requirements

11: GROUND WATER--PUMP AND TREAT

Design Basis Elements

- Depth of ground water plume (well construction depths, screen intervals, lift requirements for submersible pumps and type of system employed; suction-lift pumps are only effective to 15-20 feet)
- Areal extent and depth of contamination (required to determine number of wells, placement and design)
- Types of contaminants (determine removal rates, treatment type and discharge limitations)
- Presence/impact of underground utilities (do they act as preferential pathways, will they interfere with drilling/trenching/piping)
- Soil characteristics (porosity, organic carbon content, hydraulic conductivity, and grain-size distribution are required to determine how contaminant will partition between the aqueous and gaseous phases)
- Aquifer characterization (storativity, permeability, gradient, flow direction, and available drawdown required for good well design)
- Presence of other well fields or surface water bodies (to determine if drawdown in pumping wells will impact flow patterns of other wells and/or water levels)
- Site access for equipment (well drilling, treatment plant)
- Casing diameters (chosen to accommodate pump and prevent uphole water velocities greater than 1.5 m/sec; typical diameters range from 4-inch that can handle up to 200 gal/minute at 1.5 m/sec to 24-inch that can supply up to 6,500 gal/minute at 1.5 m/sec)
- Screens and open area (may range from 5 percent open area for high-strength screens with small openings to 75 percent for low-strength screens with large openings)
- Multiple aquifers (groundwater extraction from a single aquifer may have adverse effects because gradients created can cause contamination of other aquifers)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, air permits, NPDES, water resource use)
- Pore volume flushing time of contaminated ground water zone (plume volume divided by pumping rate)
- Hydraulic conductivity (soils with hydraulic conductivities less than 10^{-4} cm/sec are difficult to remediate because of a limited ability to extract water)
- Other properties affecting chemical removal (presence of NAPL, low permeability zones)
- Seasonal or intermittent pumping schedules of water use wells in the area

- Chemical characteristics of media (low/high level radio nuclides, mixed waste, metals, organics, presence of other water quality parameters [iron, calcite, etc.] which indicate potential for scale formation in piping/treatment equipment)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers)
- Unit process steps for treatment (pretreatment, contaminant removal, polishing treatment)
- Combination of unit treatment processes (extraction, conveyance, treatment, discharge, process control system)
- Off-gas treatment requirements (air stream dehumidifying, carbon adsorption efficiency, oxidation system)
- Residuals/waste streams generated (chemicals removed, discharge of treated water)
- Monitoring required (influent water, treated water, contaminant waste stream)
- Handling of residuals (containerizing, labeling, storage)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (freeze protection for process solutions)
- Operating procedures manual
- Permitting/other legal requirements
- Security requirements

12: GROUND WATER--IN-WELL STRIPPING WITH RECIRCULATING WELLS

Design Basis Elements

- Depth of ground water plume (generally should be 10 feet or greater to provide sufficient space to recharge water; well construction depths, extraction and recharge screen intervals, submersion requirements for pumping)
- Areal extent and depth of plume and access to install wells/piping system (buildings or utilities which may limit access)
- Presence/impact of underground utilities (do they act as preferential pathways, will they interfere with drilling/trenching/piping)
- Stratigraphy (impervious layers between the vadose-zone discharge point and the water table will require specialized designs)
- Hydraulic conductivity (must be greater than 10^{-4} cm/sec to move sufficient water)
- Contaminant strippability (contaminant should have a Henry's Law constant greater than 5×10^{-4} atm-m^3/mole)
- Site access for equipment (well drilling, treatment plant)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, air permits)
- Plume volume of contaminated ground water to be treated (number of wells, network of piping system)
- Pore volume flushing time of contaminated ground water zone (plume volume divided by pumping rate)
- Properties controlling chemical desorption from soil (retardation of chemical movement/recovery in flushing calculations)
- Other properties affecting chemical removal (presence of NAPL, low permeability zones)
- Physical characteristics of media (possible presence of low permeability lenses in plume, hydraulic conductivity/yield of aquifer, treatment zone of recirculating wells, drawdown in pumping wells, grain-size distribution for screen and filterpack sizing)
- Chemical characteristics of media (low/high level radio nuclides, mixed waste, metals, organics, presence of other water quality parameters [iron, calcite, etc.] which indicate potential for scale formation in recharge zones)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers)
- Off-gas treatment requirements (air stream dehumidifying, carbon adsorption efficiency, oxidation system)
- Residuals/waste streams generated (chemicals removed, condensate water collected)

- Monitoring required (influent water, treated water, off-gas air stream before and after treatment)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (freeze protection for process streams)
- Operating procedures manual
- Permitting/other legal requirements (applicable patents for technology)
- Security requirements

13: GROUND WATER--DUAL-PHASE EXTRACTION

Design Basis Elements

- Depth of ground water plume (well construction depths, extraction intervals, vacuum and lift requirements for pumping)
- Areal extent of plume and access to install wells/piping system (buildings or utilities which may limit access)
- Presence/impact of underground utilities (do they act as preferential pathways, will they interfere with drilling/trenching/piping)
- Aquifer permeability (generally should be 10^{-4} cm/sec or lower so that water renters treatment zone slowly)
- Site access for equipment (well drilling, treatment plant)
- Types of contaminants (generally applicable to contaminants with Henry's Law constants greater than 2.5 X 10^{-4} atm.-m^3/mole or vapor pressures greater than 1 mm Hg. at ambient temperatures)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, air permits, NPDES, water resource use)
- Plume volume of contaminated ground water to be treated (number of wells, network of piping system)
- Pore volume flushing time of contaminated ground water zone (plume volume divided by pumping rate)
- Properties controlling chemical desorption from soil (retardation of chemical movement/recovery in flushing calculations)
- Other properties affecting chemical removal (presence of NAPL, low permeability zones)
- Physical characteristics of media (hydraulic conductivity/yield of aquifer, capture zone from extraction well, drawdown in pumping wells, grain-size distribution for screen and filterpack sizing)
- Chemical characteristics of media (low/high level radio nuclides, mixed waste, metals, organics, presence of other water quality parameters [iron, calcite, etc.] which indicate potential for scale formation in equipment)
- Provision of suitable electric power for equipment (site electric service, capacity, transformers)
- Unit process steps for treatment (liquid/gas phase separation, pretreatment, contaminant removal, polishing treatment)
- Combination of unit treatment processes (extraction, conveyance, treatment, discharge, process control system)
- Off-gas treatment requirements (air stream dehumidifying, carbon adsorption efficiency, oxidation system)

- Residuals/waste streams generated (chemicals removed, condensate water collected)
- Monitoring required (influent water, treated water, off-gas air stream before and after treatment)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (freeze protection for process streams)
- Operating procedures manual
- Permitting/other legal requirements (applicable patents for technology)
- Security requirements

14: GROUND WATER--CONTAINMENT BARRIERS

Design Basis Elements

- Depth to bottom of ground water plume (total depth of barrier wall, presence of an aquitard to tie in base of barrier wall)
- Areal extent of plume and access to install barrier system (buildings or utilities which may limit access)
- Surface capping to prevent precipitation infiltration into contained area
- Presence/impact of underground utilities (will they interfere with barrier construction/installation, can they be shutdown/rerouted)
- Types of contaminants (applicable to all contaminants present in groundwater)
- Wall permeability (typical values for wall permeability range from 10^{-6} to 10^{-7} cm/sec)
- Wall thickness (24 - 48 inches is typical for slurry, soil mixed, and jetted wall)
- Slurry levels during construction (height of slurry wall should be maintained 2 to 4 feet above groundwater level to maintain trench stability)
- Backfill slope range (typical horizontal to vertical backfill slope ranges from 6:1 to 10:1)
- Site access for construction equipment (excavator, slurry mix area, driving hammer for sheet pile)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, NPDES/stormwater)
- Linear length and depth of barrier to be installed (total square feet of barrier required)
- Physical characteristics of the soil (grain-size distribution for slurry mix, blow counts and density for sheet pile)
- Chemical characteristics of contaminated ground water (compatibility with slurry wall, corrosion potential for sheet pile wall)
- Residuals/waste streams generated during construction (excavated soils)
- Protection from burrowing animals
- Slope and surface with respect to surface water runon and runoff
- Vegetative cover
- Water budget from contained/capped area
- Monitoring required (hydraulic head inside and outside of contained area, contaminant concentrations outside of contained area)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)
- Restore site(backfill, recompaction, utility reconnect, resurfacing)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)
- Weather related considerations (wind erosion protection for storage piles, runoff collection from storage piles, difficulties in system construction in heavy precipitation)
- Permitting/other legal requirements
- Security requirements

15: GROUND WATER--IN-SITU PERMEABLE TREATMENT ZONE BARRIERS

Design Basis Elements

- Depth to bottom of ground water plume (total depth of barrier wall, presence of an aquitard to tie in base of barrier wall)
- Areal extent of plume and access to install barrier system (buildings or utilities which may limit access)
- Presence/impact of underground utilities (will they interfere with barrier construction/installation, can they be shutdown/rerouted)
- Site access for construction equipment (excavator, driving hammer for sheet pile)
- Presence of cultural resources/artifacts
- Permits required (utility clearance, excavation, NPDES/stormwater)
- Linear length, depth and thickness of barrier to be installed (total square feet and volume of barrier required)
- Physical characteristics of the aquifer and permeable media (travel time to and across permeable reaction zone)
- Chemical characteristics of contaminated ground water (plugging/fouling/precipitates)
- Installation as a funnel and gate approach or as a complete permeable barrier treatment wall (conceptual configuration and hence permeable cross section and flux rates)
- Groundwater flux through the barrier 9 required media permeability)
- Residence time in the barrier treatment zone (thickness and capacity of media)
- Chemistry of treatment/removal in the permeable segment (identify interferences and residency requirements)
- Life of the treatment media (determine need to replenish or regenerate media)
- Anticipated period of performance (determine capacity or regeneration requirements)
- Means of regenerating/replacing treatment media if relevant (logistics of regenerating media)
- Residuals/waste streams generated during construction(excavated soils)
- Monitoring required (contaminant concentrations upgradient and downgradient of permeable wall)
- Handling of residuals(containerizing, labeling, storage)
- Disposal requirements (manifesting, transport & disposal of waste)
- Restore site(backfill, recompaction, utility reconnect, resurfacing)

General Implementation Considerations

- H&S, PPE requirements for dealing with exposure potential (airborne dust, dermal contact, vapors)

- Weather related considerations (wind erosion protection for storage piles, runoff collection from storage piles)
- Permitting/other legal requirements (applicable patents for technology)
- Security requirements

16: GROUNDWATER--IN-SITU BIOREMEDIATION

Design Basis Elements

- Location (contaminant location in relation to ground surface and water table determines bioreclamation approach)
- Weather (infiltration rates may affect dissolved oxygen levels)
- Site hydrology (ability to deliver nutrients and terminal electron acceptors to contaminated subsurface zone is affected by permeability; minimum permeability should be > 10^{-3} cm/sec)
- Contaminant concentrations (high contaminant concentrations can inhibit biodegradation, very low contaminant concentrations may not support biological activity; range of favorable concentrations varies by contaminant and site)
- Particle-size distribution (extreme heterogeneity in soil particle-size distribution leads to inconsistent bioreclamation of contaminated media)
- Contaminant types (most frequently used to treat soil/water systems contaminated with gasoline, diesel, jet fuel, and BTEX. Cometabolic biodegradation of chlorinated aliphatic solvents has also been demonstrated)
- Contaminant types (certain halogenated aliphatics, halogenated aromatics, and polychlorinated biphenyls, or PCBs are more readily degraded anaerobically)
- Metals and radionuclides (generally not applicable)
- Multiple contaminants (presence of other contaminants; easily degradable contaminants will degrade first while more recalcitrant contaminants are left undegraded)
- Depth and areal extent of contamination (injection of nutrients is limited by drill-rig depth capabilities)
- Rate-limiting nutrients (nitrogen and/or phosphorus are most frequently the rate-limiting nutrients in soil and are added to promote biodegradation, deficiencies of other nutrients are rare but should not be ignored)
- Bioaugmentation (soils typically contain the necessary soil bacterial communities to degrade contaminants; microbial additions may be desirable if the native community lacks the necessary bacteria to degrade the target compounds)
- Substrate addition (adding substrates such as methane and phenol has been demonstrated effective for the aerobic oxidation of chlorinated solvents through cometabolism)
- Treatability tests (normally used to support remedy screening, selection, or design and to quantify biodegradation rates)
- Redox potential (redox potential greater than 50 mV for aerobic/facultative system; < 50mV for anaerobic system)

- Terminal electron acceptor (aerobic biodegradation requires oxygen as the terminal electron acceptor (TEA) while anaerobic biodegradation uses TEAs such as NO_3^-, SO_4^{2-}, CO_2, Fe^{3+}, Mn^{4+}, oxygenated organics, and halogenated compounds)
- Chemical and biological properties (COD and BOD are required to determine whether environmental conditions are conducive to microbial activity)
- Nutrient ratios (optimum carbon:nitrogen:phosphorus ratio is approximately 120:10:1; ratio is required to determine the need for additional nutrients)
- Oxygen (for an aerobic system, dissolved oxygen concentrations should be > than 1 mg/l; < 1 mg/l for an anaerobic system)
- Oxygen (may need to add hydrogen peroxide to injection system to increase oxygen concentrations; care is needed as hydrogen peroxide is toxic to bacteria at high concentrations. Hydrogen peroxide at 40 mg/l has been reported to provide sufficient oxygen without inhibiting bacterial growth)
- Temperature (generally, temperature should be in the range of 10 to 70 degrees C for bioremediation to proceed) biodegradation kinetics)
- Soil chemical characteristics (pH outside range of 4.5 to 8.5 limits biological activity)
- Soil organic carbon (SOC) content (required to determine sorption characteristics of aquifer soil which may impact contaminant bioavailability and mobility)

General Implementation Considerations

- Reinjected water augmented with nutrients, etc. (must be reinjected into the aquifer from which it was extracted and meet standards similar to surface water discharge standards if practicable.
- Process monitoring requirements (continuous monitoring is necessary to ensure that the appropriate ratios of nutrients are maintained)
- Regulatory requirements (faults, flood plains, artifacts, wetlands, wildlife refuge, etc.)
- Security requirements

APPENDIX D:
EXAMPLE CONCEPTUAL SITE MODEL

Example Conceptual Site Model

1. ***General Background.***

The Charles E. Kelly Support Facility (CEKSF) is an active U. S. Army facility located near Oakdale, in Collier Township, Pennsylvania. CEKSF was first occupied in 1958 by the U.S. Army Air Defense Command (ARADCOM) Headquarters, Headquarters Battery and 18th Artillery Group, and the 662nd Radar Squadron of the U. S. Airforce (USAF) (USATHAMA 1993). ARADCOM Headquarters at Oakdale supported 12 Nike sites in the Pittsburgh area, as well as other Nike sites in defense of Cincinnati, Cleveland, Detroit, and Buffalo. Both Nike Ajax and Hercules systems were used. Headquarters U. S. Army Support Detachment, Oakdale, Pennsylvania moved to the Oakdale post in 1961. The Federal Aviation Administration (FAA) assumed part of the radar mission from USAF in 1962, and in 1972, it assumed the complete radar mission. As a result of developments in the air defense system, many of the Nike sites were deactivated and excessed. Ten of the 12 Pittsburgh area Nike sites were excessed between 1962 to 1974. Subsequently the ARADCOM operation at Oakdale was deactivated in June 1975, leaving U.S. Army Support Detachment and FAA as the main activities at Oakdale.

The CEKSF facility currently consists of numerous separate areas: the main post, former Nike Missile Site 63, the Readiness Group (also known as the former Nike Missile Site 62), the GATR SAGE (Ground to Air Transmission Radar, Surface Air Guidance Equipment) site, and remote facilities at Neville Island, former Nike Missile Site 36 in Irwin, PA, and facilities at Camp Dawson, West Virginia (*1998 Installation Action Plan*). Its current mission is to provide administrative and logistical support to tenant and satellite units and activities and organizations, departments, or agencies of the government as prescribed in appropriate regulations, directives, or agreements[1]. Its primary tenants include:

- 99th Regional Support Command;
- 5th Training Battalion;
- Federal Aviation Administration (FAA);
- GSA Fleet Management;
- Defense Commissary Agency; and
- Army/Air Force Exchange System (AAFES).

Building S-15 (DSERTS Site #8) is located on a hill within CEKSF's main post near Oakdale, PA. Building S-15 is located in Allegheny County, Pennsylvania approximately 10 miles southwest of Pittsburgh. Historically, Building S-15 was the primary generator building of the NIKE Missile Master Control Facility. After the site was

[1] U.S. Army. Charles E. Kelly Support Facility Webpage. Available URL: http://www.dix.army.mil/cekelly/hq.htm. Retrieved 22 September 1999.

deactivated in 1974, the Army Maintenance Support Activity (AMSA) used the property for military vehicle storage and later (from 1985 to 1990) for vehicle maintenance. The 420th U.S. Army Reserve then used the property for vehicle and equipment storage and maintenance until April 1995. Since 1995, the 99th Army Reserve Command (ARCOM) Logistics Unit has used the site for vehicle storage and maintenance.

A 650-gallon used-oil underground storage tank, located on the southwest side of Building S-15 was installed in 1985 and removed 9 years later on April 4, 1994. No obvious holes were observed in the tank but some of the soils in contact with the tank were stained black (Engineering Science [ES] 1994a). Samples taken at the bottom of the excavation and in the stockpiled soil revealed lead and TPH_d contamination (ES 1994a). The excavation was lined with Visqueen™ and the contaminated stockpiled soils returned to the excavation until a site assessment could be completed and a corrective action plan prepared. In May 1994, Engineering Science conducted a Site Assessment to investigate the extent and magnitude of the residual petroleum hydrocarbons. They installed 11 soil borings, ten of which were completed as monitoring wells. Samples were analyzed for only TPH, lead, and BTEX compounds, and identified contamination in both the soil and groundwater (ES 1994b). Engineering Science then completed a Remedial Action Plan in January 1995 that called for extended excavation of the site and offsite disposal of the contaminated soil (ES 1995). Efforts were initiated to complete these activities through the Army Corps of Engineers (ACE).

In December 1995, Parson's Engineering Science collected soil and groundwater samples for volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) analyses for comparison to the preliminary remediation goals (PRGs) included in the Relative Risk Site Evaluation (RRSE) Primer. These data were needed for input into the DSERTS database and to aid prioritization and funding of further environmental restoration activities at this site. Unfortunately, the analytical detection limits were inadequately sensitive to determine if these samples exceeded the PRGs, and thus provided little value in reducing the number of potential contaminants of concern. These data did confirm the presence of SVOCs (e.g. naphthalene) and BETX, and suggested the presence of solvent contamination (e.g. 1,1-Dichloroethane)[2]. These results lead to changes in the scope of work being negotiated between CEKSF, ACE, and the ACE subcontractor (GZA GeoEnvironmental, Inc. [GZA]) from a focus on TPH contamination to include VOC contamination.

In July 1997, GZA performed a groundwater quality study to gather current groundwater data concerning the presence of VOCs and naphthalene (GZA 1998a). PNNL recommended changing analytical methodologies to be able to identify compounds indicative of natural degradation and/or to help define the source(s) of contamination (i.e., fingerprinting). PNNL performed these analyses on spilt samples jointly collected with GZA (Liikala 1998). In addition, GZA sampled and drummed up a small soil pile overlying the site. This study confirmed the presence of BETX and chlorinated solvent

[2] Parsons Engineering Science, Inc. (PES). 1996. Letter to Mark Bishop, Armstrong Laboratory, dated 23 February 1996, from Gary Wm. Gray.

compounds, with benzene, TCE, 1,1-DCA, and naphthalene exceeding the PADEP's statewide health standards for residential groundwater, and that the contamination originated on-site.

In September 1997, PNNL performed a soil gas survey to determine the source and extent of VOC contamination (Liikala 1998). Results suggested that the BETX and TCE contamination emanated from the general vicinity of the former used oil tank, and defined the lateral extent of this contamination. In addition, the study found that fluctuating water levels, perched water conditions, poor flush to ground well completions, improperly backfilled direct push boreholes, numerous underground utilities, and stormwater drain systems were allowing surface contamination to fast-track into the subsurface, thereby impacting the site. Interim remedial actions were subsequently taken to 1) redesign and seal the well heads and boreholes (Schalla and Newcomer 1998), 2) to cap the site of the former UST and 3) to redirect stormwater away from the UST site.

At the 1997 Installation Action Plan meeting, (CEKSF 1998) PADEP requested that additional efforts be made to define the site's vertical extent of groundwater contamination, and recommended sampling of groundwater seeps and installation of a deeper groundwater well(s). CEKSF and AEC agreed on this additional scope and PNNL prepared sampling and analysis plans for both these activities and completed an initial cataloging of adjacent landowners. PNNL also prepared a preliminary site conceptual model and risk analysis to evaluate transport pathways and risks posed by this contamination and to help determine if additional data were indeed necessary (Bjornstad et al., 1998). However, the perched water and partially saturated fractured rock environment makes interpretation of the potential transport pathways extremely difficult.

In the Fall of 1998, a round of groundwater samples was collected to evaluate the effectiveness of the interim remedial actions taken to revamp the well vaults and to stop localized recharge over the site. However, these samples continued to reveal that several contaminants (benzene, TCE, vinyl chloride, PCE, 1,1-DCA, naphthalene, and bis(2-ethylhexyl)phthalate, lead, and manganese) remain above the statewide health standard[3].

In July 1999, PNNL was authorized to prepare a Site Characterization Report in accordance with PADEP's Corrective Action Process and Land Recycling Act. The objective of this report was to document all available data and current interpretations, and to seek a determination that no further action would be necessary at this site. At the July 1999 Installation Action Plan meeting, USARC agreed with PADEP's recommendation to sample groundwater seeps around the S-15 site, and to install a deep well to define the vertical extent of the groundwater contamination. Proposed changes to the workplan have been prepared to incorporate this new work.

[3] "Recent Groundwater Data from S-15". Letter from George V. Last to Sonja Scancar, dated January 27, 1999.

2. *Regulatory Drivers/Identification of Problem.*

Environmental restoration of the Building S-15 site is being conducted under the U.S. Army's Installation Restoration Program (IRP) and in accordance with the Multi-Site Agreement (MSA) and Pennsylvania's Land Recycling Act (Act 2). Environmental contamination at the site was found, at least in part, during the removal and assessment of an Underground Storage Tank. Thus, completion of the environmental restoration of the site is being conducted in accordance with the Corrective Action Process (CAP) of Pennsylvania's Storage Tank Program (Act 32, as amended) and the Act 2 cleanup standards[4]. Act 2 basically has three types of cleanup standards: background, statewide-health, and site-specific. The presence of anthropogenic contaminants (e.g. benzene, trichloroethene, 1,1-DCA) in wells clearly indicates that contamination originated on site and that use of the background standards would not be appropriate. Concentrations of benzene, TCE, vinyl chloride, PCE, 1,1-DCA, naphthalene, bis(2-ethylhexyl)phthalate, lead, and manganese in some groundwater samples exceed statewide-health standards for residential use of groundwater. However, lead and manganese are believed to be natural background and ultimately not of concern. To date, virtually no efforts have been directed at developing site-specific cleanup standards for the site. To do so requires a very detailed process, both technically and administratively, in which the human and ecological receptors need to be addressed either through elimination of exposure pathways or a risk assessment, and also provides an opportunity for public participation.

Thus, to date all contaminant concentrations have been compared to the Statewide Health standards. Based on these standards, the primary concern at the site is the presence of benzene, trichloroethene, 1,1-dichloroethane, and naphthalene. Benzene has been detected in 4 monitoring wells at levels between 1 and 3 times the 5 μg/L standard. Trichloroethene has been detected in a single well at a level greater than 4 times the 5 μg/L standard. 1,1-dichloroethane has been detected in 3 wells at levels above regulatory standards (up to 3 times the standard). Naphthalene has been detected in 3 wells at levels over 2 to 4 times the 20 μg/L standard. The wells are completed in a perched aquifer that does not extend off site. However the extent of contamination with depth has not been determined.

No on-site wells are believed to use water from this site. Engineering Science (ES 1994a) did not find a potable water well within one-half mile radius of the site. However, the Pennsylvania Geologic Survey's data base of groundwater wells, searched by ES, is far from complete, mainly because there is no requirement to register groundwater wells within the state.

[4] "Project Scoping Meeting for FY99…" 18 December 1998. Meeting Minutes. From George V. Last to Attendees and Distribution.

No offsite private wells have been located in the vicinity of Building S-15. Although most residences are believed to be supplied by a private water utility, there is no guarantee that groundwater is not and will not be used for either drinking water or for irrigation/livestock. There is no requirement to register groundwater wells within the state. Thus, the State's position is that the only applicable statewide health standards are those for "used aquifers".

The CE Kelly Support Facility does handle and store hazardous waste, however it qualifies as a small quantity generator and is not a RCRA permitted facility.

Apparently there is a NPDES permit for the site that is associated with the old (now defunct) sanitary sewage treatment facility. This site is now plumbed into a municipal publicly owned treatment works (Collier Township Sanitation).

PADEP has repeatedly stated that their first concern is with defining the full extent of the groundwater contamination, whether that is onsite or offsite. They have suggested sampling of offsite groundwater seeps to help locate potential perched aquifers that may have been impacted beneath the site. However, the Army is reluctant to sample (and to date has not sampled) offsite.

The site is currently one of the "scheduled sites" listed in the Multi-Site Agreement (see http://www.dep.state.pa.us/dep/deputate/airwaste/wm/REMSERV/DOD_MSA/dod_msa.htm). The Multi-Site Agreement is a cooperative agreement between the PADEP, the United States Army, Navy, Air Force and Defense Logistics Agency, in coordination with the Department of Defense (DoD). This agreement addresses the assessment and remediation of selected sites in the Commonwealth by 2010. Under this agreement, Pennsylvania's Land Recycling and Environmental Remediation Standards Act (Act 2) approaches will be used, including cleanup standards, site assessment procedures, liability relief, and the options to use site specific, risk-based remediation criteria. The use of innovative technologies, state funding, work sharing, the creation of economic and job opportunities, as well as new ways to assure mutual accountability and long term planning are among the concepts addressed.

The Agreement includes an inventory of over 1000 military sites in Pennsylvania, which are listed as:

1. Scheduled sites (53 sites);
2. Deferred sites (364 sites); and
3. Study sites (659 sites).

The "Scheduled Sites" are those locations at which actual assessment and remediation is already planned under the Agreement. The Building S-15 site is one of the "scheduled sites".

3. <u>Overview of Site Geology/Hydrology.</u>

Building S-15 is located in the Appalachian Plateau physiographic province of western Pennsylvania. Building S-15 lies at an elevation of ~1260 ft above mean sea level near the top of an eroded and dissected portion of the uplifted Appalachian Plateau. Topographically, Building S-15 lies in a saddle near the top of a drainage divide between the Robinson Run watershed and the Thoms Run watershed (Figure 1). Building S-15 rests on well-consolidated sedimentary rocks overlain by a thin ($\leq$20 ft) mantle of silty clay. The Building S-15 site lies near the summit of a topographic high, 360 feet above the adjacent valley floor of Robinson Run.

Much of the surface beneath the area of Building S-15 is covered with asphalt over a gravel and/or slag substrate, which altogether may be up to 2.5 ft thick. Below this is a nearly continuous layer of mostly silty clay 8-15 feet thick (Figure 2). The silty clay has been described as moist, slightly plastic, and well sorted. Trace amounts and lenses of sand and/or gravel occur sporadically. The silty clay layer grades downward into bedrock of the Monongahela Formation and represents a residual soil formed as a result of in situ, surficial weathering of the underlying bedrock over time. Bedrock beneath the silty clay layer is mostly shale and/or siltstone; lesser amounts of sandstone and limestone are also present. A thin layer of sandstone directly underlies the silty clay layer beneath the UST removed from Building S-15 (Figure 2).

Beneath Building S-15 the Pennsylvanian Monongahela Formation is nearly flat-lying. Beds exposed in a roadcut 500 feet west-southwest of Building S-15, have an average strike of about N25E and dip gently (~4.5 degrees) to the southeast. The Monongahela Formation, along with the underlying Casselman Formation of the Conemaugh Group, comprise cyclic sequences of shale, limestone, sandstone and coal (Wagner et al. 1975), but are characterized by an abundance of freshwater carbonates (limestone and dolomite) and a relative lack of sandstone (Cate and Heyman 1974). Up to one-half of the total thickness of the Monongahela Formation is limestone, which is interbedded with shale, sandstone, and coal (Gallaher 1973). About 200 ft below Building S-15 lies a 60-foot-thick coal bed referred to as the Pittsburgh Coal Member, which forms the upper boundary of the Conemaugh Group (Figure 3). The Pittsburgh Coal is a prominent coal bed that has been extensively strip-mined in the area. It is uncertain at this time whether some of the coal may have been underground-mined from below Building S-15.

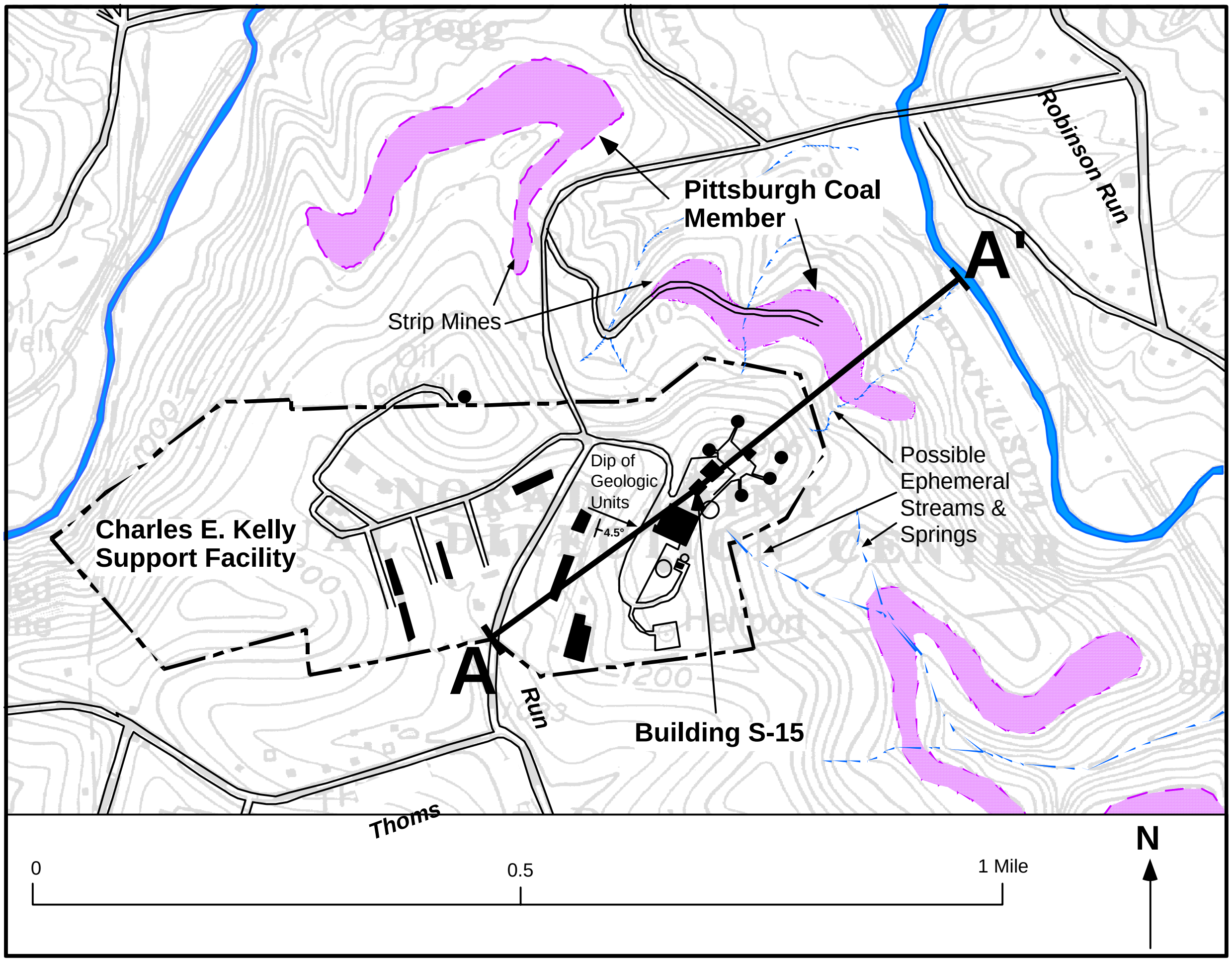


Figure 1. Geohydrologic Map of the Building S-15 Area. Cross section A-A' shown on Figure 3.

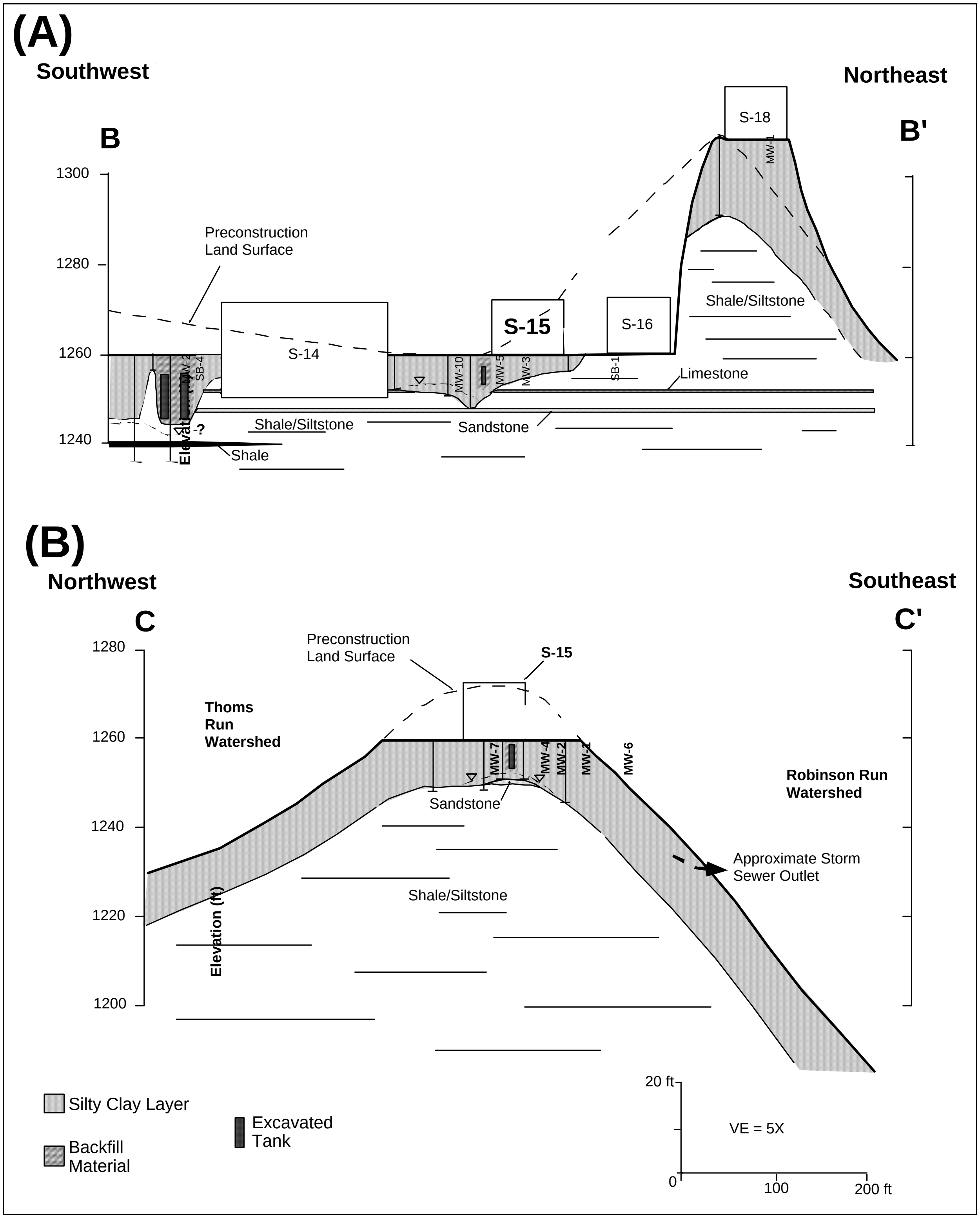


Figure 2. Geohydrologic Cross Sections Through the Building S-15 Site (See Figure 4 for the locations of these cross sections.

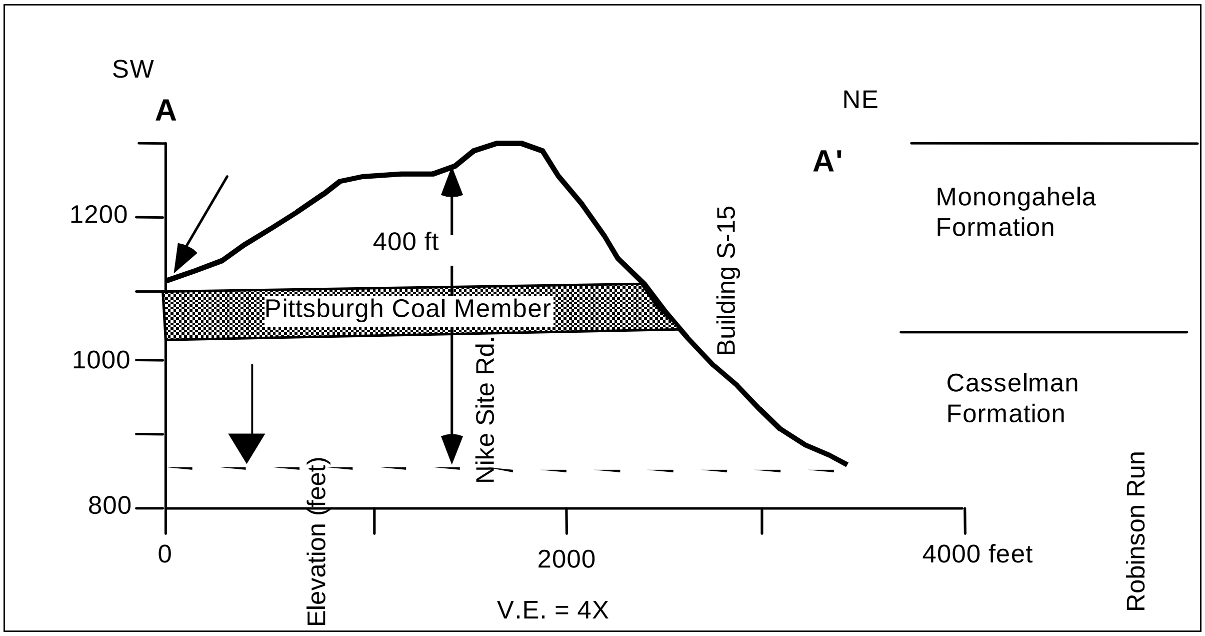


Figure 3. Generalized Geohydrologic Cross Section (see Figure 1 for location).

Because the Building S-15 site lies at the top of a ridge, surface water and groundwater move laterally away from the site, along steep gradients that occur on either side (Figure 4). The region receives large amounts of precipitation (average of 37 inches of precipitation annually) (Gallaher 1973).

There are a total of ten groundwater monitoring wells and one soil boring (SB-1) at Building S-15. Other nearby boreholes include four monitoring wells and 12 shallow borings at Building S-14, and three monitoring wells at Building S-18. Due to the low permeability and slow well-recharge rates, groundwater was generally not encountered in boreholes during drilling, with the exception of MW-8 at Building S-15. Since the wells were installed, depth-to-water measurements show that some of the wells (MW-6, -7, and –10) are frequently dry (Table 1).

Table 1. Recent water level data.

Monitor Well No.	2"PVC Inside	8/13/98		8/14/98		9/3/98		7/14/99		9/11/99	
		D/W (ft)	Elev. (ft)	D/W (ft)	Elev. (ft)	D/W (ft)	Elev. (ft)	D/W (ft)	Elev. (ft)	D/W (ft)	Elev. (ft)
MW1	1290.51	8.14	1282.37	NM	NA	8.19	1282.32	8.20	1282.31	8.51	1282.00
MW2	1290.60	7.77	1282.83	NM	NA	NM	NA	7.20	1283.40	7.58	1283.02
MW3	1290.33	7.86	1282.47	NM	NA	7.92	1282.41	8.20	1282.13	8.48	1281.86
MW4	1290.62	8.92	1281.70	NM	NA	8.50	1282.12	7.43	1283.19	7.95	1282.67
MW5	1290.00	NM	NA	6.72	1283.28	6.23	1283.77	6.17	1283.83	7.33	1282.68
MW6	1290.31	dry	NA	NM	NA	dry	NA	dry	NA	dry	NA
MW7	1290.62	dry	NA	NM	NA	dry	NA	dry	NA	dry	NA
MW8	1289.50	NM	NA	9.56	1279.94	8.52	1280.98	7.96	1281.54	9.01	1280.49
MW9	1290.44	14.45	1275.99	NM	NA	14.49	1275.95	14.45	1275.99	14.42	1276.03
MW10	1290.55	NM	NA	NM	NA	NM	NA	dry	NA	NM	NA

Limited groundwater occurs in the silty clay above bedrock (ES 1994b). Despite the relatively impermeable soil matrix there exists a near-surface aquifer, probably perched atop the shaly bedrock substrate that underlies most of the area in the vicinity of

Building S-15 (Figures 2 and 4). Based on a water level survey performed at Building S-15 in July 1995, a near-surface aquifer of limited areal extent is approximately centered over, and moves radially away from, well MW-5 (Figure 4). Other subsequent water-level surveys performed in August and September of 1998, and July 1999 (Table 1), corroborate the existence of this perched aquifer in the surficial silty clay layer. The mounded aquifer, with a hydraulic gradient up to 0.13 ft/ft or 7.4 degrees, does not appear to extend far laterally beyond the saddle (Figure 4).

The near-surface groundwater mound is coincident with a storm sewer drain that collects water running off the Building S-15 parking lot (Figure 4). It is possible that this storm sewer leaks leading to the development of the groundwater mound. The perched groundwater mound may also be topographically controlled, since it lies within a saddle, and therefore may be collecting groundwater from higher-elevation areas along the ridgeline (Figure 4). Another scenario for the source of the groundwater mound is from enhanced recharge associated with a roof drain that discharged water into an unpaved portion of the asphalt, where the 650-gallon UST used to be. This situation existed between tank removal (1994) and July, 1998, when the area over the excavated tank was paved. In 1997, it was discovered that many of the flush-mounted well housings were defective and leaking; these may also have resulted in recharge to the uppermost groundwater zone in the vicinity of Building S-15. The defective well housings have since been repaired (Schalla and Newcomer 1998).

Nearby, just south of Building S-14 (Figure 4), groundwater was found stratigraphically lower than at S-15, perched atop a shale bed within a shale-siltstone sequence (Figure 2). Similar perched zones within the bedrock beneath Building S-15 probably exist, but no wells have been drilled below the clay layer, into the bedrock, to confirm their presence. Similarly, no groundwater has been observed at the Building S-18 site (Figures 2 and 4), which only has wells in the surface silty clay layer and not in bedrock. The behavior of the perched aquifers is poorly understood at this time, but it is likely that multiple discontinuous perched aquifers exist above 850 ft, which is the elevation of the top of the regional water table in this area (Gallaher 1973). The top of the regional water table lies within the Casselman Formation, approximately 400 ft below Building S-15 (Figure 3).

In roadcuts multiple perched-water zones and lateral spreading are apparent along less permeable beds of the Monongahela and Casselman Formations in the vadose zone. Similar perched water zones likely exist in the bedrock beneath Building S-15. Some of the groundwater may travel vertically along fractures before moving laterally along less permeable (i.e., shale) beds. It is believed that the predominant flow direction in the uppermost perched aquifers is horizontal with discharge to the soil mantle along the hillslope. However, the possibility of some flow and contaminant transport downward to other perched aquifers has not been ruled out. Groundwater moving laterally above the 850-ft in elevation will eventually sap out onto the surface in the form of springs. Increased fracturing and dewatering of perched groundwater aquifers could occur beneath Building S-15 just above the Pittsburgh Coal bed (Figure 3) if any unsupported roof material in underlying worked-out coal mines exists (Gallaher 1973).

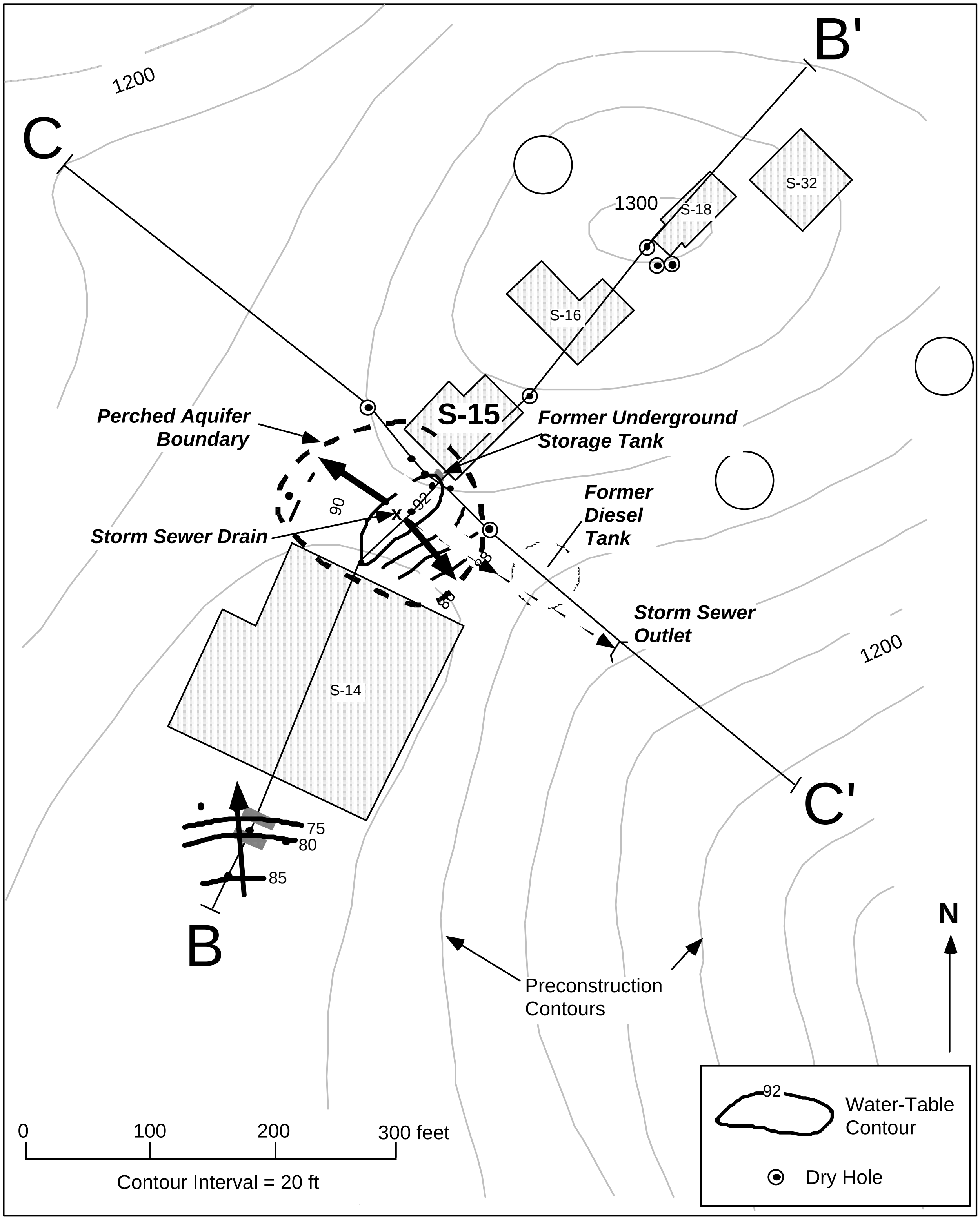


Figure 4. Potentiometric Surface of Uppermost Perched Aquifers

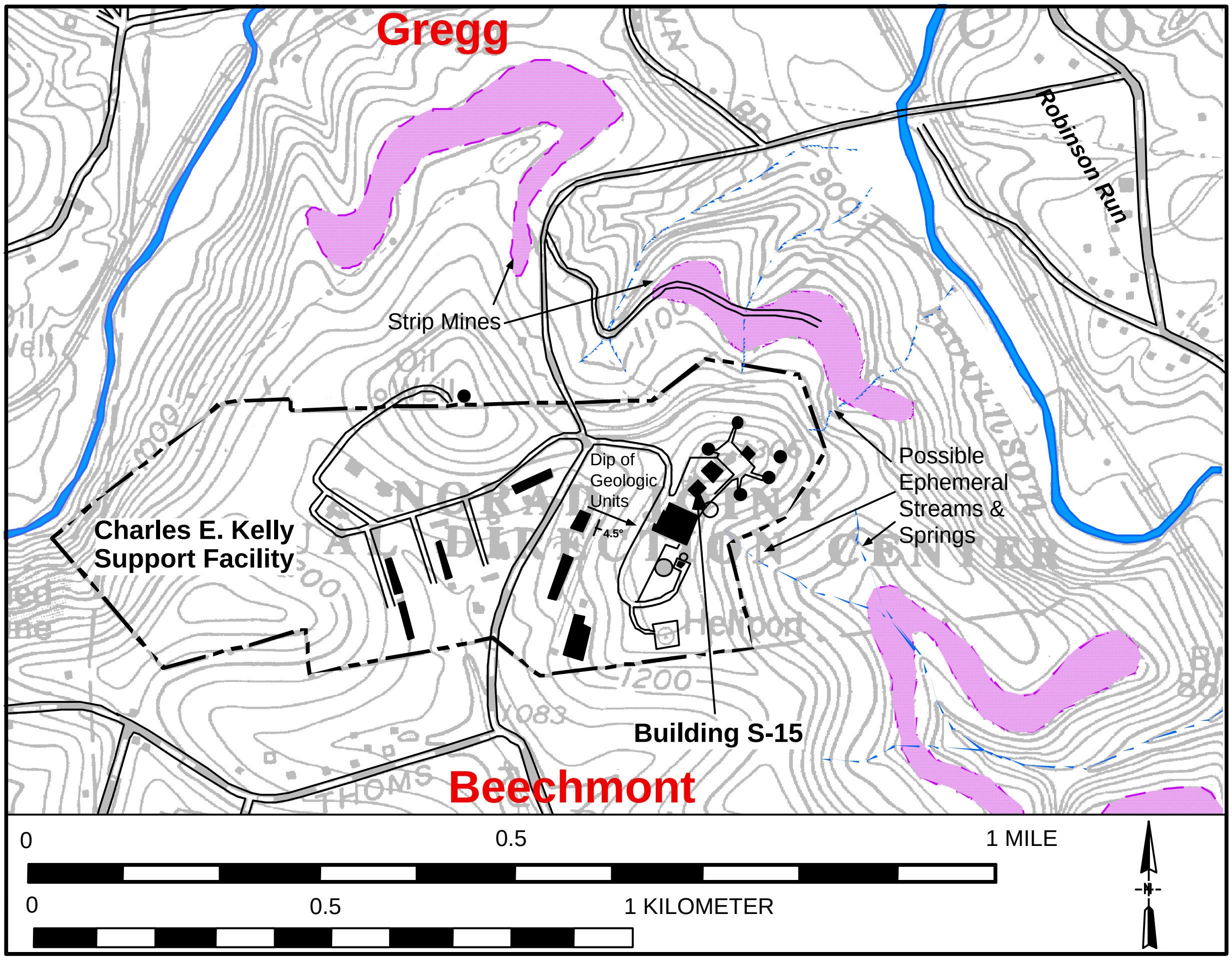


Figure 5. Location of nearby residents.

Groundwater flow in the vicinity of Building S-15 appears to be to the northwest and southeast, mimicking the topography and surface drainages. The site is surrounded by small rural communities, the closest of which are Gregg, Rennerdale, and Beechmont, all located within 0.5 miles of the site. Of these, the most likely impacted residents would be those in the vicinity of Rennerdale. Perhaps the shortest route to these receptors maybe via groundwater flow to seeps and then via ephemeral streams to Robinson Run.

The principal surface water body of concern is Robinson Run, which is fed by ephemeral seeps and streams, and perhaps feed by stormwater discharged from the site.

Table 2. Well Specifications.

Well Number	Coordinates [a]		Well Vault Lid Elevation [a]	Inner Casing (Riser) Elevation [a]	Drill Depth [b]	Inner Casing (Riser) dia. [b]	Casing Material [b]	Screen Length [b]	Screen Slot Size [b]	Depth of Screened Interval [b]		Sand Pack [b]	
	North	East								Top of Screen	Bottom of Screen	Top of Sandpack	Bottom of Sandpack
			(ft)	(ft)	(ft)	(in.)		(ft)	(in.)	(ft)	(ft)	(ft)	(ft)
MW-1	397,258.14	1,329,340.61	1290.98	1290.51	9	2	PVC	6	0.010	3.0	9.0	2.0	9.0
MW-2	397,273.76	1,329,323.03	1291.00	1290.60	9	2	PVC	6	0.010	3.0	9.0	2.0	9.0
MW-3	397,259.67	1,329,324.27	1290.85	1290.33	11	2	PVC	8	0.010	3.0	11.0	2.0	11.0
MW-4	397,285.85	1,329,310.54	1291.08	1290.62	11	2	PVC	8	0.010	3.0	11.0	2.0	11.0
MW-5	397,238.40	1,329,310.26	1290.47	1290.00	9	2	PVC	6	0.010	3.0	9.0	2.0	9.0
MW-6	397,224.55	1,329,376.32	1290.90	1290.31	13	2	PVC	10	0.010	3.0	13.0	2.0	13.0
MW-7	397,327.83	1,329,279.02	1291.08	1290.62	11	2	PVC	8	0.010	3.0	11.0	2.0	11.0
MW-8	397,255.08	1,329,207.21	1290.10	1289.50	14	2	PVC	10	0.010	4.0	14.0	3.0	14.0
MW-9	397,179.83	1,329,317.19	1290.80	1290.44	15.5	2	PVC	10	0.010	5.5	15.5	4.0	15.5
MW-10	397,199.67	1,329,263.28	1291.00	1290.55	8	2	PVC	5	0.010	3.0	8.0	2.0	8.0

[a] = from Alstate's Survey on 12/15/98
[b] = from ESE, 1995
[c] = from Schalla and Newcomer, 1998

The contaminants of concern (i.e., those that exceed PADEP's statewide health standard) are benzene, TCE, vinyl chloride, PCE, 1,1-DCA, naphthalene, and bis(2-ethylhexyl)phthalate. Lead and manganese also exceed the statewide-health standards, but only in unfiltered samples, and are believed to be naturally occurring. In addition, a thin LNAPL layer has been occasionally observed in MW-2. Fingerprint analyses indicate that this LNAPL is diesel fuel.

Contaminant plumes for the most widespread of these contaminants are provided on the attached pages.

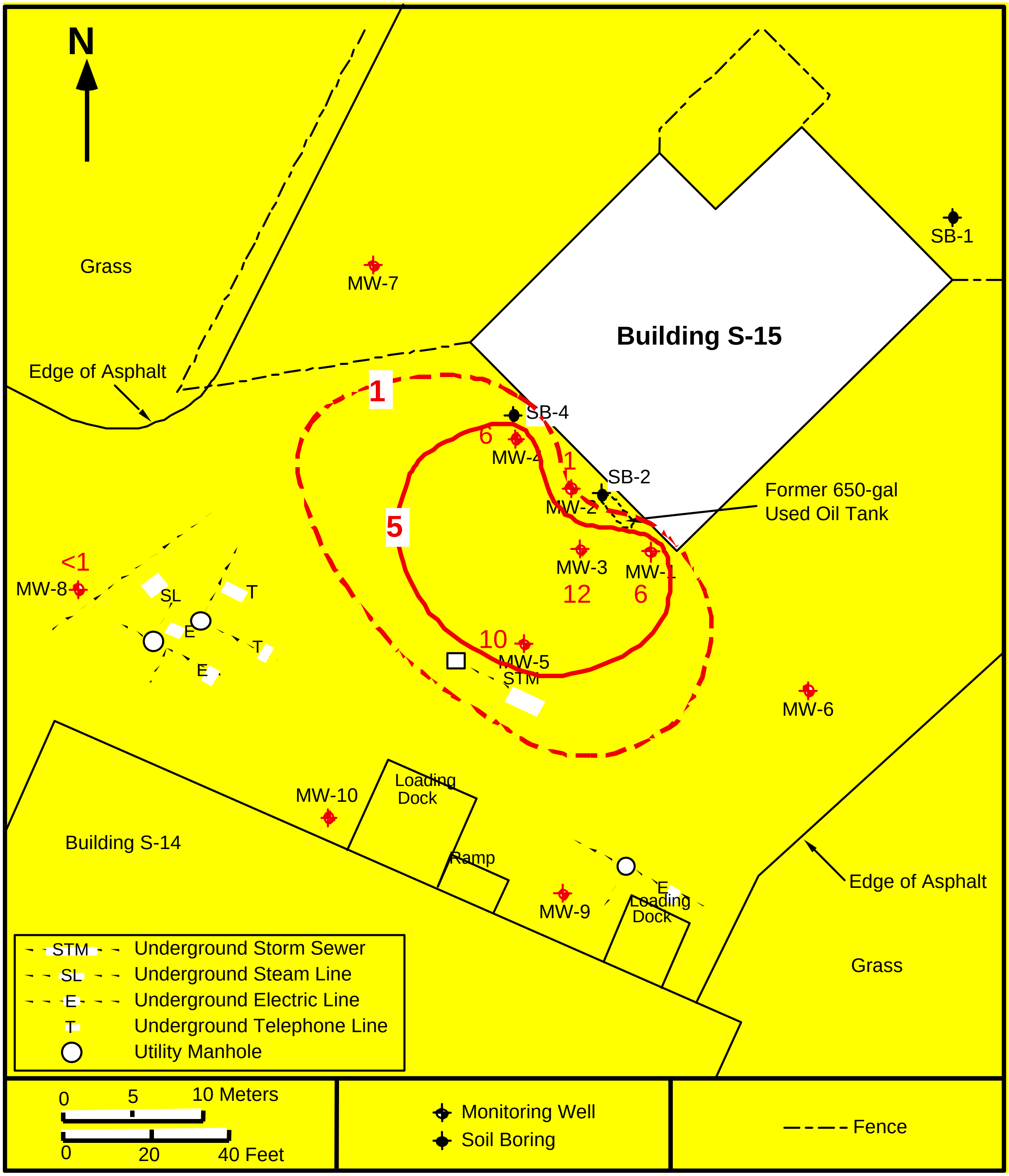


Figure 6. Concentration of Benzene in Groundwater (µg/L), October, 1998.

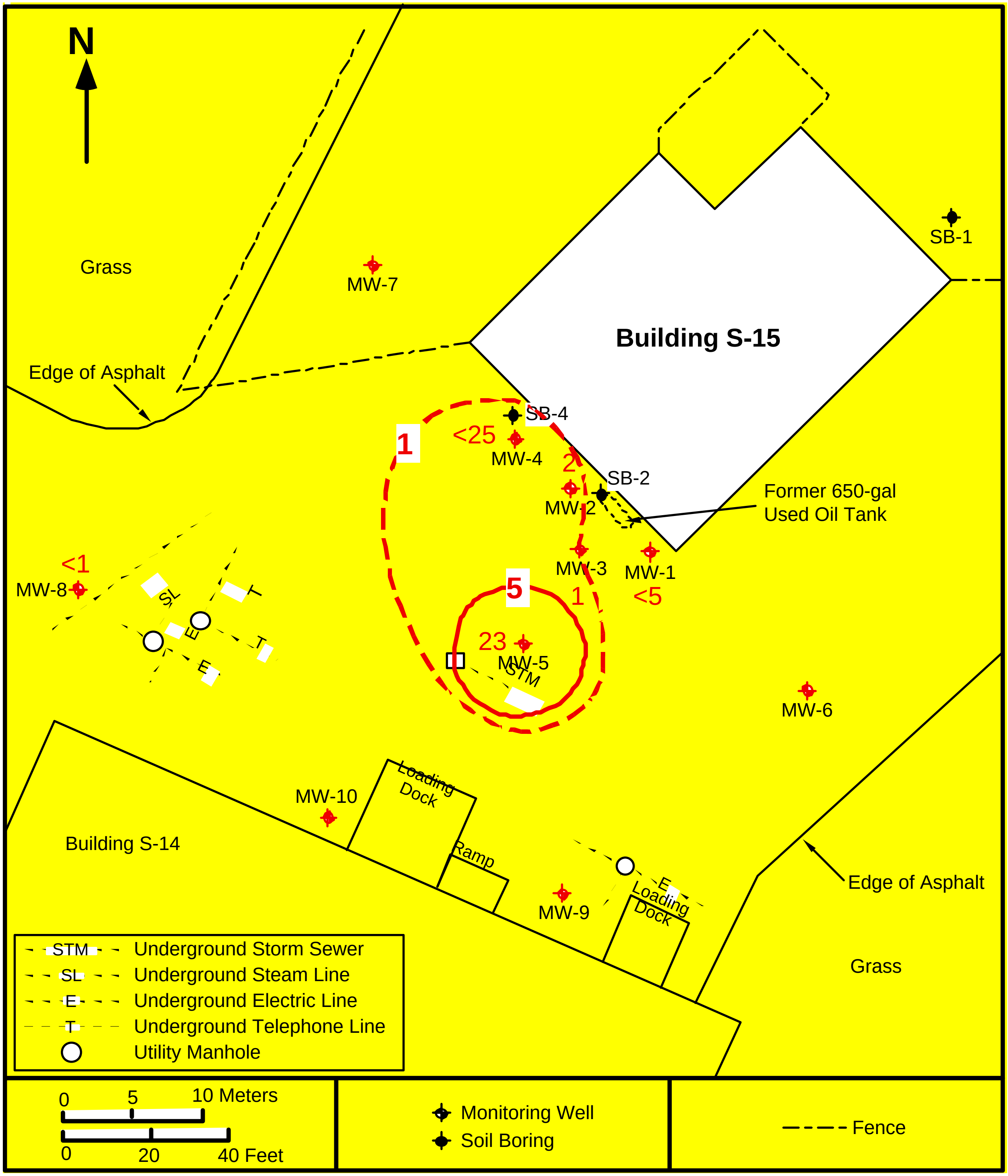


Figure 7. Concentration of TCE in Groundwater (µg/L), October 1998.

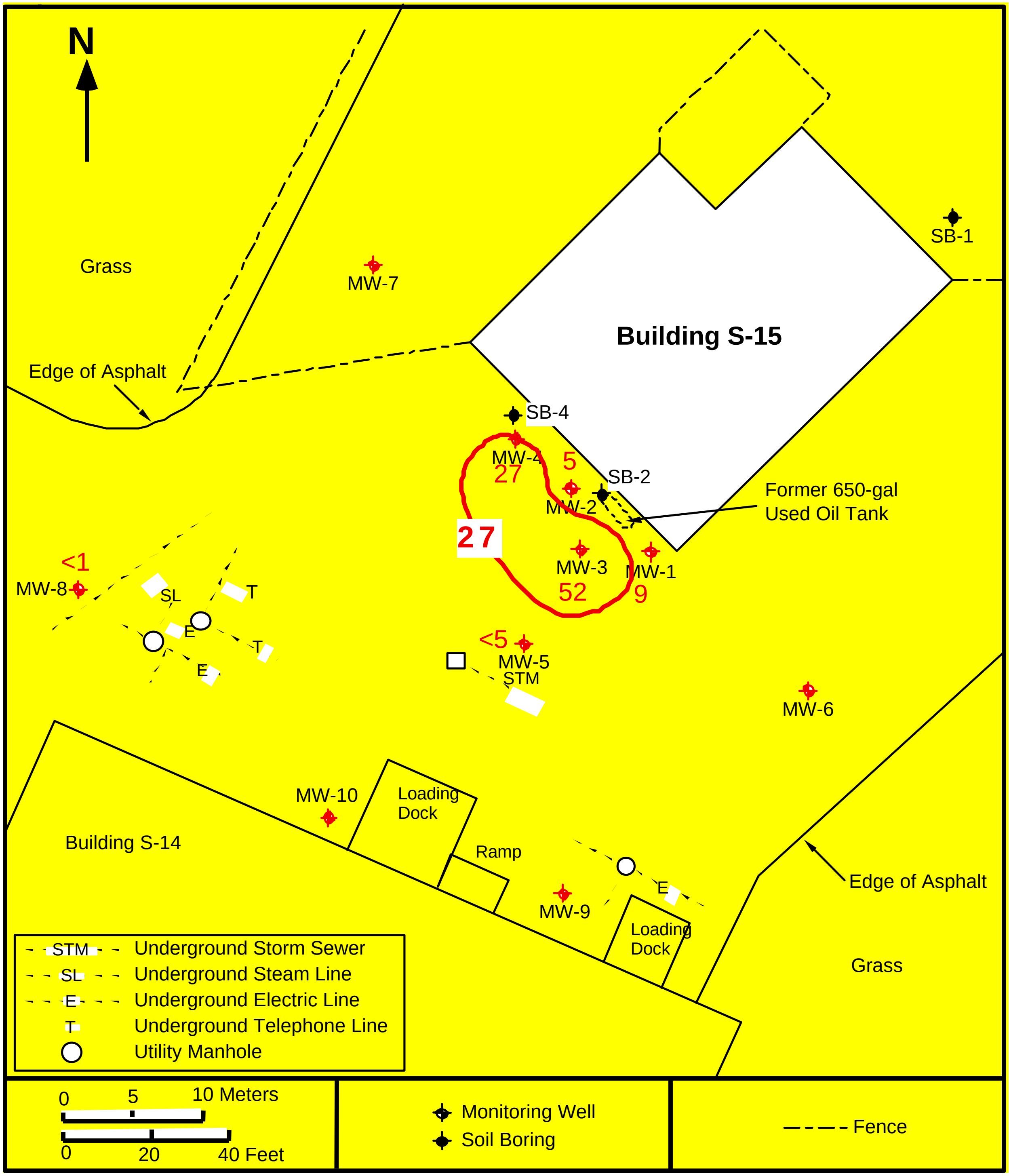


Figure 8. Concentration of 1,1-DCA in groundwater (µg/L), October, 1998.

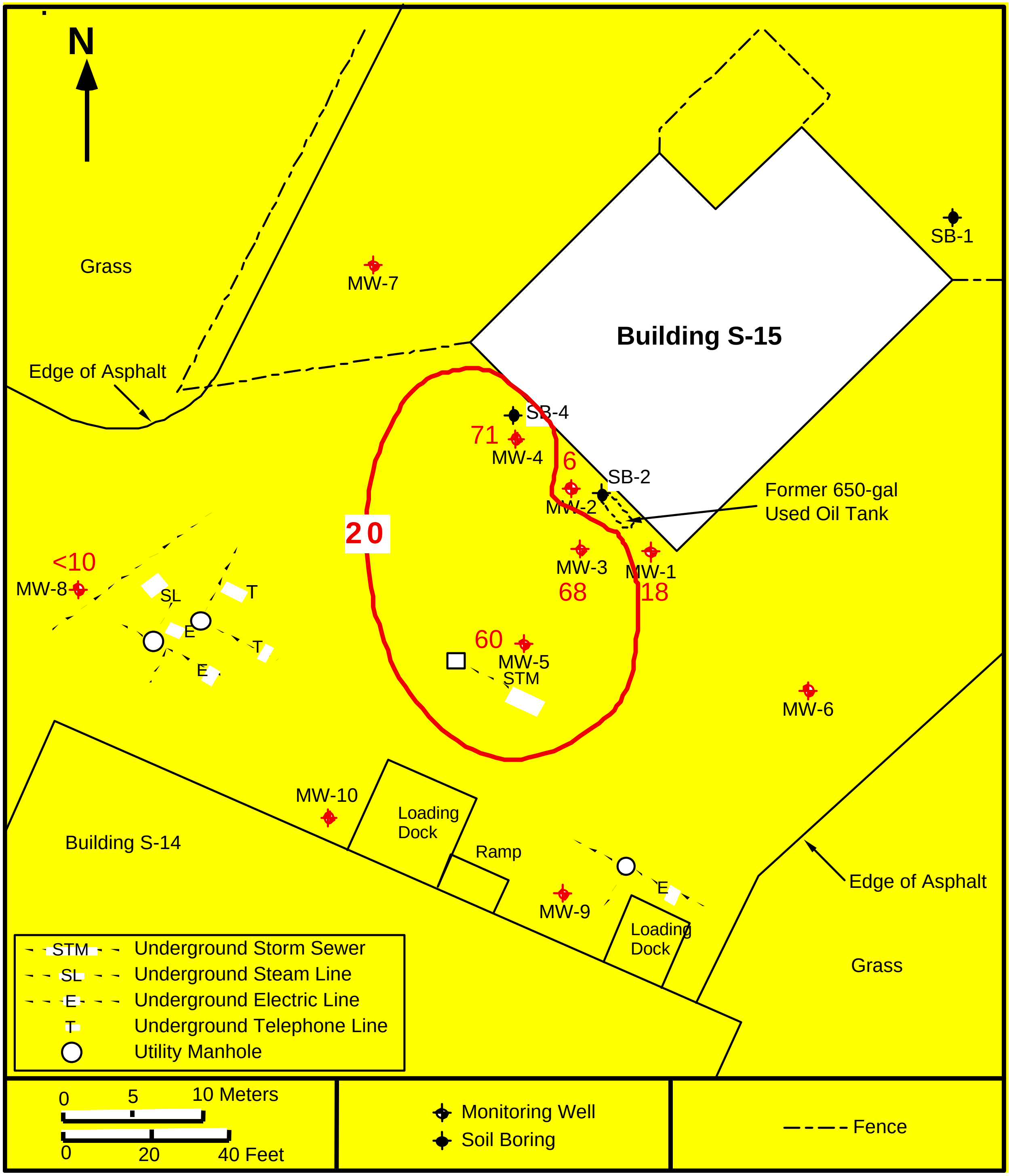


Figure 9. Concentration of Naphthalene (µg/L), October 1998.

See enclosed Excel spreadsheet for a summary of groundwater quality data.

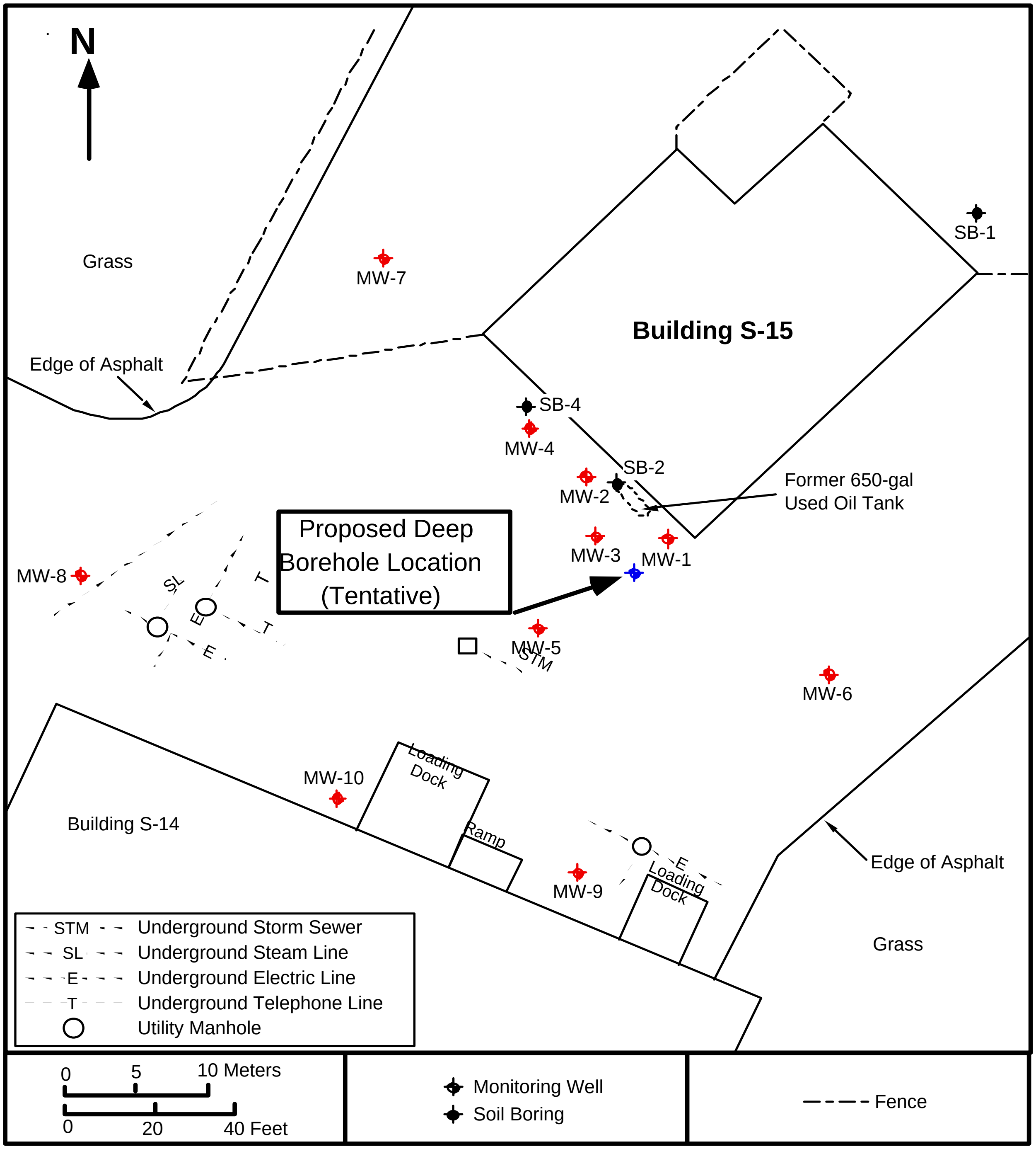


Figure 10. Proposed Deep Borehole Location.

4. Fate and Transport of Contaminants.

The used oil storage tank was removed from the site, however, contaminated soil was placed back in the tank excavation on top of a visqueen liner. The location was later backfilled and paved. The soil contamination on site is concentrated under a paved area southwest of Building S-15. The site is expected to remain industrial for the foreseeable future. Groundwater in the uppermost perched aquifer is contaminated with hydrocarbons and volatile organic compounds at levels greater than regulatory criteria for residential groundwater. The primary offsite exposure route of concern is through groundwater to either springs and seeps or to wells. Both ecological and human receptors are of concern.

The conceptual model for contaminant transport is through partitioning into the infiltrating precipitation (possibly leakage from storm drains) and groundwater from contaminated sediments and residual petroleum product (LNAPL). Some lateral flow along the top of the bedrock may occur, followed by flow through colluvium on the hill slopes to seeps. In addition there is the potential for vertical flow downward through fractures in the bedrock from the contaminated perched aquifer to lower perched aquifers which may flow off site. The number and depths of potential lower aquifers are unknown. The regional aquifer is located below the Pittsburgh coal member. It is considered unlikely that contamination would penetrate to the regional aquifer. The organic contaminants potentially would sorb to the Pittsburgh and other coal seams.

Additional data are needed to assess the presence and impacts of lower perched aquifers. A proposed well to be drilled at the site would be used to decide if lower perched aquifers are present and are contaminated. In addition, the presence of contamination in springs and seeps has not been assessed. If contamination is not detected in lower perched aquifers and is not detected in springs, then this will be considered evidence that significant impact from the site is unlikely. Hence it is extremely important that the proposed test well be drilled and completed very carefully so as to not drag or smear contamination along the section.