Introduction

At most sites, the objective of site restoration is to achieve MCLs in all impacted media, but this goal is often technically and/or economically impracticable within reasonable time frames. However, it is possible to develop remedies that address the most critical risks, foster partial cleanups, and address community concerns over time frames of a few years while continuing progress toward more complete restoration in the long term. Implementing such remedies requires careful development of reasonable functional objectives for actions that may not meet the concentration-based criteria established in regulations but that will reduce risks, enable development and use of sites, or allow transitions to relatively passive remedial options such as MNA.

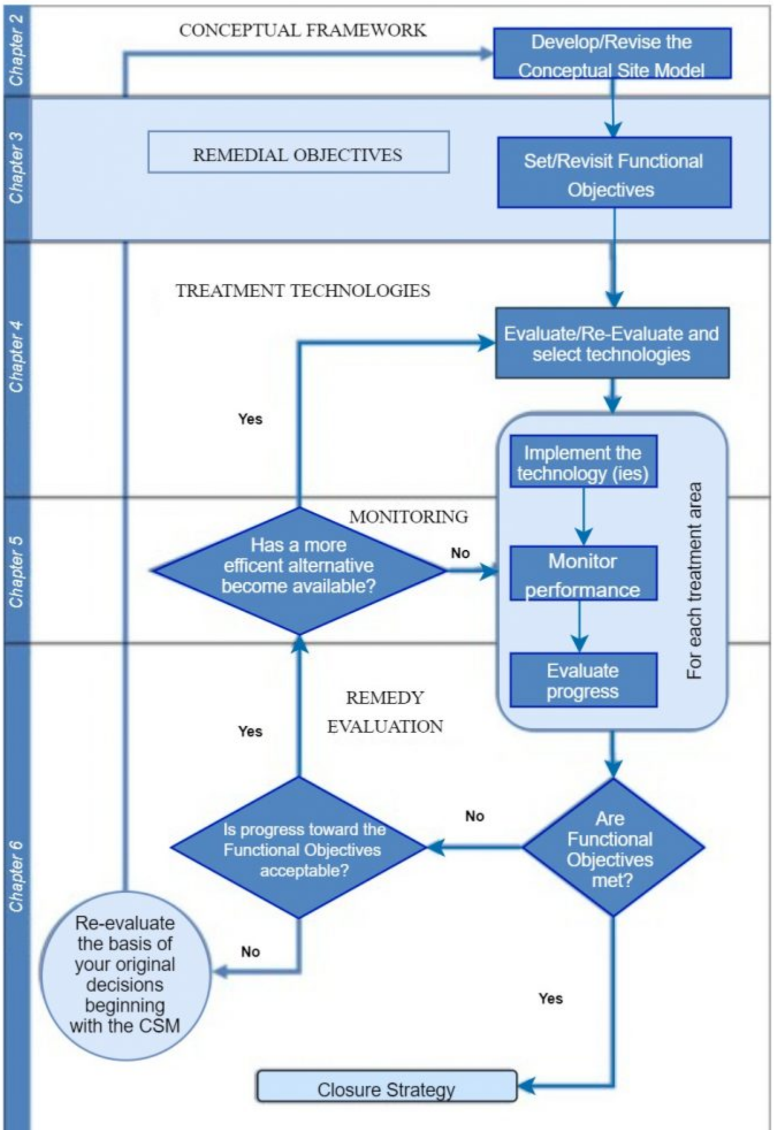

Figure 1-1 Integrated DNAPL Remediation Decision-making

This chapter describes a process for establishing absolute remedial objectives and developing functional remedial objectives to achieve those absolute objectives. Functional objectives are developed by considering the short- and long-term requirements of all parties involved and should conform to SMART attributes (i.e., be specific, measurable, attainable, relevant, and time-bound) (Doran 1981).

3.1 Historical Perspective of Absolute and Functional Objectives

Environmental regulations and laws require that cleanup objectives for the remediation of multiple media at a given site be established and achieved. In CERCLA terminology, cleanup objectives are called remedial action objectives (RAOs) and can be either interim or final. In this document objectives are defined as either absolute or functional (NRC 2005; ITRC 2008b). Absolute objectives are based on broad social values, such as protection of public health and the environment. Functional objectives are the steps or activities that are taken to achieve absolute objectives. Functional objectives are in fact RAOs (i.e., the objectives for a given set of actions), and they can be interim or final. But at many chlorinated-solvent sites, the functional objectives established for short-term actions do not represent final RAOs because the final RAOs often are not attainable within a reasonable time frame. An example of an interim functional objective might be to replace an impaired water supply with an alternative supply to prevent exposure within a month, while an example of a final functional objective might be to meet water quality objectives in the downgradient plume by 2020. Meeting all properly constructed and complete functional objectives should ensure that the absolute objectives are attained.

Text-box 3-1 Dry Clean USA, Well-Defined Objectives (see Appendix A)

At Dry Clean USA the primary project goal was to see whether treatment could reduce PCE concentrations to the Florida MCL of 3 µg/L throughout the aquifer and to 30 µg/kg for soil (based on leaching potential) so that closure (i.e., no further action) could be obtained from the state regulatory agency. Additional soil objectives (set by the state's drycleaner program) included 30 µg/kg TCE, 400 µg/kg cDCE, 700 µg/kg *trans*-DCE, and 7 µg/kg VC. Having such well-defined objectives allowed the appropriate technologies to be applied and a Site Rehabilitation Completion Order was issued within 10 years of the initial treatment.

The problem is that remedial objectives for chlorinated-solvent site cleanups have often been ill- defined, difficult to measure, or unattainable (NRC 2005, Kavanaugh et al. 2003), largely due to the difficulties achieving final RAOs based on MCLs or similarly low numeric standards in DNAPL source zones, which include uncertain

expectations for remediation effectiveness, technical and economic limitations, and problems such as measurability and accountability associated with long time frames (e.g., decades to centuries). Therefore, the challenge is to parse the problem (see Text Box 3-1) and develop SMART functional objectives for different locations or phases or develop functional objectives for an alternative end point of an overall site cleanup. SMART functional objectives add credibility to subsequent remedial design and implementation and establish a metric for monitoring remedial approaches that offer measurable and predictable progress over a credible period of time (≤20 years) while still meeting applicable regulatory requirements.

Text-box 3-2 Well 12A, Tiered Remedial Action Objectives (see Appendix A)

Tier 1: Address residual sources, including principal threat wastes, minimize the risk to receptors due to contaminated surface soils, and achieve at least a 90% reduction in contaminant discharge from the high-concentration source area to the dissolved-phase contaminant plume. **Tier 2:** Achieve the cleanup levels at interim performance monitoring points. **Tier 3:** Determine whether cleanup levels can be achieved in a reasonable time frame throughout the entire contaminant plume by discontinuing the groundwater extraction and treatment system operation and implementing MNA of remaining contamination. If the Tier 3 compliance is deemed infeasible, additional remedial alternatives will be evaluated, and/or a technical impracticability waiver may be sought for the noncompliant portions of the aquifer.

Site managers have used various approaches to set remediation objectives. A common approach has been to assess exposure pathways and pursue risk-based numerical cleanup standards throughout all applicable compartments impacted by the chlorinated-solvent release. Another approach is to pursue the most immediate risks/threats or develop objectives for specific locations within the plume or source zone. Other common approaches include developing objectives for when to transition to a more passive remedy or to pursue an alternative end point (Text Box 3-2). For example, if a determination is made that MCLs cannot be achieved in the DNAPL source zone in a measurable or relevant time frame, federal and state regulatory programs have allowed for other cleanup standards or objectives.

Examples of alternative objectives that can be used in specific instances include alternative numeric standards, under some programs referred to as “alternative concentration limits” (Title 40 Code of Federal Regulations, Part 264.94 [40 CFR §264.94]) or “containment” of the plume (e.g., contained within a slurry wall or upgradient of a permeable reactive barrier (PRB) or hydraulically with P&T). Under some programs, cleanup standards that differ from regulatory standards such as MCLs require exemptions or waivers, such as technical impracticability waivers under CERLCA.

At some sites it is possible to apply aggressive treatment of the source zone and dissolved phase and attain remedial objectives relatively quickly. At other sites, the time frame to attain the final functional objectives could be different for the DNAPL source zone than for the downgradient aqueous-phase plume. For example, a remedial approach could be designed to stabilize or treat the plume and control associated risks first, with reduction of mass discharge from the source zone as an interim objective. At Well 12A (see Text Box 3-2) compliance with RAOs was divided into three tiers to allow for implementation of the multicomponent remedy and decision making, such as when to transition from one treatment technology to another and when the site is transitioned to operation and maintenance (O&M). Reduction of mass discharge could be achieved using containment, treatment, or even partial removal of the source. This approach would allow use of a large portion of the aquifer, while the inherently difficult source remediation is addressed separately. Similarly, it may be necessary to immediately address off- site concerns, such as vapor intrusion, while plume remediation continues over a much longer time frame.

3.2 Developing SMART Objectives

The American Management Association (AMA), among others, recognizes the crucial role of developing good objectives prior to starting virtually any project. The AMA provides the acronym “SMART” to convey the attributes of good objectives listed earlier (Doran 1981). Functional objectives can be confirmed or adjusted to meet the SMART attributes by asking the diagnostic questions about each (see Text Box 3-3).

As pointed out earlier, the objectives set for cleanup of chlorinated-solvent sites have rarely been attainable or readily measurable. A handful of chlorinated-solvent sites have been remediated to the point of closure and unrestricted use (USEPA 2009a), but it is far more common to have residual contamination above MCL values even after aggressive treatment (NRC 2005) so that interim/alternative functional objectives are needed. Examples of such interim/alternative functional objectives might be to reduce concentrations and mass discharge to the point that passive site management can be used to contain and treat the residual contamination or to reduce risks to the point that development can proceed with appropriate exposure controls. The measurability of the objectives can be a concern, especially given the difficulties in measuring mass and concentrations in some compartments (e.g., lower-permeability zones) and the natural variations in groundwater data.

The planning time frame is an important consideration that deserves special discussion. A wide range of restoration time frames has been used for site cleanups, generally 30 to >100 years (based on team experience) or even longer. The time frame required to treat chlorinated solvents in groundwater to concentrations less than MCLs (typically an absolute objective) may be several decades to centuries, so shorter-term functional objectives are needed for meaningful and measurable interim steps. The consensus of the IDSS Team is that detailed predictions beyond a human generation (~20 years) are generally inappropriate when setting functional objectives.

Do not confuse the maximum 20-year time frame used for setting SMART functional objectives (a planning time frame) with the time frame for completion of the absolute objectives (site restoration time frame).

Text Box 3-3 Diagnostic Questions to assure compliance with SMART Attributes

S Specific—The objectives should specify what is to be achieved through a remedial action. They should be concrete, detailed, and well defined.

· Diagnostic questions:

o What exactly are we going to do?

o Is the objective well understood?

o Will this objective lead to a desired result?

· *S does not mean "shifting"!*

M Measurable—Managers should be able to measure whether or not the objectives are being met. Numbers, quantities, or comparisons should be specified, and the uncertainty in key measurements should be understood.

· Diagnostic questions:

o How will we know that the change has occurred?

o Can these measurements be obtained?

· *M does not mean "magical"!*

A Attainable—Objectives should be realistic, given the proposed time frame, political climate, and/or the amount of money available.

· Diagnostic questions:

o Can we get this done in the proposed time frame?

o Do we understand the limitations and constraints?

o Can we do this with the resources we have?

o Is this possible?

o Has anyone else done this successfully?

· *A does not simply mean "ambitious"!*

R Relevant—The objective should have a value and represent a realistic expectation.

· Diagnostic questions:

o Does the outcome of the objective directly support achievement of the absolute objective?

o Do we have the resources available to achieve this objective?

· *R does not mean "remarkable"!*

T Time-bound—The time allotted for achieving the objective should be clearly defined and short enough to ensure accountability.

· Diagnostic questions:

o When will this objective be completed?

o Is someone still going to be accountable for meeting the time frame?

· *T does not mean "timeless"!*

There are four key reasons for restricting the time frames for SMART functional objectives at chlorinated-solvent sites:

- While absolute objectives may not be achieved for decades or more, functional objectives that extend beyond a generation (>20 years) do not encourage accountability by the decision makers involved.
- Natural variations in concentrations and aquifer conditions (e.g., groundwater elevations, geochemistry) make it difficult to measure progress towards objectives with longer time frames.
- The ability to make accurate predictions of performance beyond 20 years is questionable.
- Scientific and technical abilities are not static, and longer time frames do not account for these advances.

Although defining functional objectives with time frames of ≤20 years is encouraged, it is important to remember that the absolute objectives may well require management and even subsequent active remediation well beyond such durations. Further, some sites may show little change over 20-year time frame, but some reassessment after 20 years seems prudent in light of likely technology improvements and possible changes in priorities. It is also important, however, to remember that sites will not be abandoned after this time, and responsible parties may well have to reserve funds for site management extending far beyond 20 years. Planning-level estimates of how long contamination and liability will remain under various remedial alternatives will still be required, and predictive models such as REMChlor REMChlor-MD (https://www.serdp-estcp.org/Program-Areas/Environmental-Restoration/Contaminated-Groundwater/Persistent-Contamination/ER-201426) will still be useful for such long-term planning.

Selecting objectives that reflect SMART attributes makes subsequent decisions more valid and remedial approaches more successful. The following two sections help the user understand the range of input in the development of absolute and functional objectives for a site and how SMART functional objectives can be developed for the example site described in Section 2.6. Even though each stakeholder has an interest in the outcome and a unique perspective (e.g., the mayor of the city wants job creation, a developer wants unrestricted land use, and residents want future assurance of clean water), cooperation, consensus, and often some compromises are necessary to define the small number of SMART functional objectives for a given site.

These functional objectives, which are focused on potential exposure pathways and resource protection, then become the driving force for the remedial manager and define the steps necessary to design a remedial approach. The following section illustrates the range of potential perspectives and input into the development of possible objectives for chlorinated-solvent sites. Through discussions of these perspectives with all stakeholders, SMART functional objectives that eliminate, reduce, and control exposure and protect the environment can be better defined.

3.3 Examples of Possible Objectives for Chlorinated-Solvent Sites

The objectives in Table 3-1 represent examples of possible generic objectives for decision makers tasked with managing a chlorinated-solvent release (Sale and Newell 2011). It is unlikely and unwarranted that every objective be incorporated into one cleanup project as a SMART functional objective. However, applicable functional objectives from Table 3-1 could evolve into site-specific SMART functional objectives given a process of systematically evaluating each functional objective against the SMART attributes and diagnostic questions in Text Box 3-3.

The IDSS Team tested the process of making multiple objectives for a single site SMART and found that many of them become considerations rather than objectives. For example, "Longevity—Reduce the time period during which contaminants in source zones and plumes will provide persistent releases to the groundwater and or soil gas" and "Land use—Restore beneficial use of impacted lands" feed information into the risk objective "Prevent active adverse human exposure via groundwater or soil gas." This latter risk functional objective can then be used to drive remediation in a particular direction. This functional objective can then be tested against the SMART attributes and made to be specific, measurable, attainable, relevant, and time-bound. (These could evolve into SMART functional objectives.)

Table 3-1. Examples of possible generic objectives for chlorinated-solvent sites
(These could evolve into SMART functional objectives.)

Absolute Objectives
Protect human health and the environment.
Conserve natural resources.
Address adverse community impacts.
Minimize the burden of past practices on future generations.
Functional Objectives
Risks • Prevent active adverse human exposure via groundwater or soil gas. • Prevent active ecological exposure via groundwater or soil gas. • Prevent adverse work-related exposures via soil, groundwater, and/or soil gas. • Avoid actions that create new risks (do no harm).
Extent • Prevent expansion of source zones and plumes. • Reduce the extent of source zones and plumes.
Longevity • Reduce the time period during which contaminants in source zones and plumes will provide persistent releases to the groundwater and/or soil gas.
Regulatory • Comply with local, state, and federal regulations.
Community • Address adverse impacts to communities.
Land use • Restore beneficial use of impacted lands.
Economic • Select actions that have practical near-term capital costs and minimal life-cycle cost. • Avoid undue interruptions to communities, government, and industry activities. • Remove or control adverse impacts to property values.
Sustainability • Select measures that have a net positive environmental benefit. • Restore the site to a state for which passive remedies will control residual impacts. • Enhance the effectiveness of complementary technologies.
Resource Conservation • Limit future degradation of resources. • Restore impacted groundwater to beneficial use. • Protect sensitive biological receptors.

3.4 Examples of SMART Objectives for a Chlorinated Solvent–Contaminated Site

Using the example introduced in Section 2.6, the following section illustrates how difficult, yet important, it is to define the absolute objectives and associated SMART functional objectives for remediation of the example site. The drivers for site remediation are not only risk of exposure, but in this case, enhancement of property use or reuse and economic development as well.

Regardless, the performance metrics for remediation ultimately address risks to human health and the environment.

3.4.1 The Risk at the Example Site

Approximately 130 tons of DNAPL containing soil was excavated and disposed of as a hazardous waste in 1990. Residual PCE contamination has been measured in the soil at 4000 µg/kg and in groundwater at 180 µg/L near the point of release (i.e., source area). No remaining DNAPL has been confirmed/identified at the site; however, residual PCE continues to discharge into the underlying groundwater. PCE contamination has migrated approximately 200 feet downgradient of the point of release (Figure 3-1). There are no commercial buildings or residential homes downgradient of the site and no potential adverse impacts to nearby drinking water wells.

A risk assessment showed the site did not pose an unacceptable risk to human health under the existing conditions. However, an assessment of the risks posed to potential occupants of a building that would be constructed at the site showed that the residual PCE in the soils would pose an unacceptable risk via vapor intrusion to indoor air. In addition, PCE concentrations in the groundwater would also support unacceptable vapor concentrations in indoor air. The assessments determined that residual concentrations of 40 µg/kg PCE in soil and 8 µg/L PCE in groundwater would reduce the risk via indoor air exposure to or below the de minimus level of a 1×10^{-6} incremental excess cancer risk. It was also determined that concentrations exceeding 45 µg/kg PCE could leach to the groundwater at an unacceptable rate (see Section 2.6 to review details of the site characteristics and the 14-Compartment Model representation).

3.4.2 Drivers for Redevelopment at the Example Site

Institutional controls and monitoring might have been sufficient under existing conditions to protect against unacceptable exposure. However, the developer wanted to return the property to beneficial use in a relatively short time frame while avoiding any institutional controls. The redevelopment plan necessitated the evaluation of active remediation alternatives.

The community, health department, and regulatory agencies conditionally approved the redevelopment of the dry cleaning lot and the construction of a grocery store. The local developer hired a consultant to remediate the site within a year to regulatory requirements, which will protect future employees (i.e., absolute goal). To achieve this goal, the functional objectives were agreed upon by the regulators, community, health department, and developer. Time frames were determined by development needs.

3.5 Creating SMART Functional Objectives

To redevelop this property in consideration of the site characterization, the drivers for redevelopment with no land use restrictions applied after completion, and a defined time frame, the absolute objectives were determined to be as follows:

- Protect human health and the environment.
- Redevelop the mall area within its intended use.

Table 3-2. Washington Square Mall PCE contamination in soil and groundwater

Zone/ phase	Source		Plume	
	Low permeability	Transmissive	Transmissive	Low permeability
Vapor	2	3	1	1
DNAPL	0	0		
Aqueous	1	2	2	
Sorbed	3	3	2	

[a] Concentrations in aqueous-phase equivalents (orders of magnitude):

0 depicts >1 µg/L	1 depicts >10 µg/L	2 depicts >100 µg/L	3 depicts >1000 µg/L

Using the 14-Compartment Model to illustrate the general distribution of contaminants (Table 3-2), we recognize that we have the following (Figure 3-1):

1. source and plume vapor intrusion exposure pathway from the groundwater
2. source and plume vapor intrusion pathway from the underlying soils
3. PCE loading to the aquifer from the unsaturated zone
4. PCE and degradation products in the aquifer

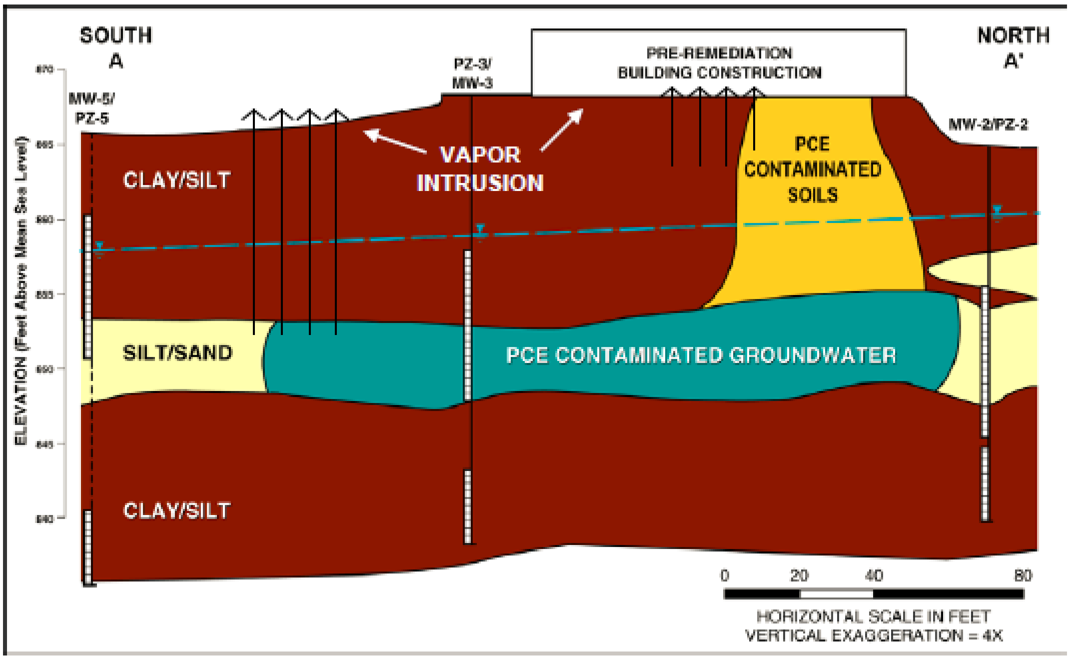

Figure 3-1. Cross-sectional representation illustrating potential exposure pathway according to 14-Compartment Model in Table 3-2.

Table 3-3 lists the functional objectives required to achieve the absolute objectives. Not unexpectedly, contingencies require institutional controls be established to control vapor intrusion if attainment of any of the first four objectives is delayed. All objectives must comply with all applicable federal, state, and local regulations during and following remediation.

Table 3-3. Functional objectives for Washington Square Mall conforming to the SMART attributes

Absolute Objective #1: Protect human health and the environment. Absolute Objective #2: Redevelop the mall area within its intended use.
Vapor intrusion pathway (soils): Reduce concentrations of volatile organics in the vadose zone that will allow “no further action” determination for unrestricted use, with no administrative or engineering controls required, for the soils within 6 months (vapor intrusion indoor air objective). Specific—Yes: 40 µg/kg PCE highest measured residual concentration, an approximately 2 OoM reduction (1.0% residual) estimated from the high soil concentration of 4000 µg/kgMeasurable—Yes: achieving 40 µg/kgAttainable—Yes: e.g., removal, SVE, in situ chemical oxidation (ISCO); institutional controls may be required if 40 µg/kg is not achievedRelevant—Yes: intended reuse of the propertyTime-bound—Yes: 6 months (development time frame)
Vapor intrusion pathway (groundwater): Reduce concentrations of volatile organics in the groundwater that will allow for “unrestricted use” of the property, with no administrative or engineered controls, within 18 months (protection against vapor intrusion). Specific—Yes: approximately 2 OoM reduction from the highest groundwater concentrationsMeasurable—Yes: achieving 8 µg/L PCE; values for other VOCs and other pathways will be determined if necessaryAttainable—Yes: ISCO and/or bioremediationRelevant—Yes: intended use of the propertyTime-bound—Yes:, 18 months (determined by development needs)
PCE loading to the aquifer: Reduce concentrations of PCE in the vadose zone to eliminate/prevent further discharge of PCE into the underlying aquifer (prevent loading to the groundwater plume, stabilize and eliminate the groundwater plume). Specific—Yes: approximate 2 OoM reduction is needed based on modelingMeasurable—Yes: achieving 40 µg/kgAttainable—Yes: e.g., removal, SVE, ISCO; institutional controls may be required if 40 µg/kg is not achievedRelevant—Yes: to meet developer’s desire for unrestricted use of the propertyTime-bound—Yes: 18 months (determined by development needs)

PCE and degradation products in the aquifer: Reduce concentrations of volatile organics in groundwater to background concentrations or drinking water quality in 2 years, allowing for no restrictions on the ability to use the water. Specific—Yes: meet drinking water standards and/or background concentrationsMeasurable—Yes: meet drinking water standards and/or background concentrationsAttainable—Yes: small extent, favorable hydrogeology, and coarse-grained soil allow ISCO and/or bioremediation or similar technologyRelevant—Yes: eliminates potential impact to existing or potential water supplies and the need for deed restriction that the developer does not wantTime-bound—Yes: 24 months

To confirm that we have SMART functional objectives, Table 3-3 documents that the functional objectives for the example site remediation conform to the SMART attributes. It contains a list of the functional objectives and SMART attributes with a corresponding rationale for "claiming" that the functional objective accommodates each SMART attribute given the level of detail known about the characteristics of the site and the maturity of the release (see Chapter 2). Each functional objective was collectively refined so that it meets all SMART attributes, based on the CSM. If an objective does not meet a SMART attribute, the result can, and likely will, be "less than optimal" or "unachievable." That result will likely require additional resources and more time and may never achieve the performance metric.

Table 3-3 describes each SMART attribute as it applies to each functional objective. Understanding the rationale used to claim the functional objectives meet all of the SMART attributes forms an important basis that can be referred to throughout the remedial process under any of the following circumstances:

- The chosen technologies do not perform as expected.
- An alternative treatment technology or system must be implemented.
- It is realized that the functional objective cannot be achieved.

In this case, the basis of the original functional objective can be reviewed and potentially used to understand what led to the wrong initial decision. If a problem should occur in the performance of the remediation, the basis of these claims can be revisited and used to assess the accuracy of the information that went into the claim. For example, Functional Objective 1 (Table 3-3) is as follows:

Reduce concentrations of volatile organics in the vadose zone that will allow "no further action" determination for unrestricted use, with no administrative or engineering controls required, for the soils within 6 months (vapor intrusion indoor air objective).

Functional Objective 1 is based on a good understanding of the mass transfer properties of the contaminants, the aquifer, and the vadose zone and the requirement that the property can be used for any purpose within 6 months. If at the end of 6 months unrestricted use is not possible, the data used to determine that such use was achievable in the given time frame and the technology to be used will come into question.

There is no assurance that each SMART objective can be achieved. There are financial restrictions on all projects, and the site professionals must make assumptions and inferences using the available data. Remediation of most chlorinated solvent–contaminated sites requires revisiting the CSM, the technologies and combinations of technologies implemented, and the functional objectives before the project is completed. Even after characterization compliance, process, and performance monitoring provide data that enhance what was previously known or suspected at a site. Use these data to refine the CSM, adjust or modify technologies, and reevaluate the likelihood of success.

In summary, it is a good idea to consider contaminant mass in all environmental compartments to develop SMART functional objectives at a chlorinated solvent–contaminated site. The 14-Compartment Model discussed in Section 2.5 and Table 2-2 is a tool that can help visualize compartments and set objectives. Compartmentalization offers a simplified representation of potential mass transport between phases and compartments of a chlorinated solvent– contaminated site. Subsequently, it helps define the applicable functional objectives for the phases or potential exposure pathways. Time frames for completing a functional objective should not exceed 20 years to remain relevant and maintain accountability, and progress toward objectives should be measureable within shorter time frames such as a few years. Following the flow diagram in Figure 1-2, Chapter 4 discusses the selection of an appropriate technology or combination of technologies (treatment trains) to achieve the functional objectives listed in Table 3-3.

3.6 ITRC Indian Tribe and Public Stakeholder Perspective of

SMART Functional Objectives

The ITRC tribal and public stakeholder representatives note that applying SMART attributes to functional objectives increases the reliability of remedial objectives for a site. Even though the initial or interim functional objectives may not fully meet the absolute objectives without further management, iterative progress is more accurately promoted toward protection of human health and the environment. Specific diagnostic questions (Text Box 3-3) for applying SMART attributes give a succinct direction to the tribal and public stakeholder as to what should be asked and addressed when collectively developing remedial objectives for a site. In addition, setting time frames for SMART functional objectives of no more than 20 years establishes clearer individual responsibility for projections of progress than planning remediation and remedial objectives for 50, 100, or more years. Chlorinated solvent–contaminated sites are admittedly difficult, and the community and tribal stakeholders consider cleanup time frame and level of cleanup the most adverse impacts to the community. The functional objectives for the Washington Square case is a great example of the proper application of the SMART attributes that can be followed and used as a guide for the tribal and public stakeholders. Some flexibility is often necessary in the remediation process. This flexibility may be a cause for stakeholder concern since it might be seen as a loss of regulatory control over the remediation process. Using functional objectives with SMART attributes that are developed and accepted by all parties involved may alleviate some of the uncertainty in the approach of achieving long-term (absolute) objectives.