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Standard Guide for Remedy Selection Integrating Risk-Based Corrective Action and Non-Risk Considerations[1]

This standard is issued under the fixed designation E2616; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This guide covers the selection of appropriate remedial actions at sites where a release of chemicals (for example, vapor-phase, dissolved-phase, or non-aqueous phase liquids (NAPL)) into the environment has occurred. This overall remedy selection process is illustrated in Fig. 1. The guide is intended to be applied within a risk-based corrective action (RBCA) framework.

1.2 The purpose of this guide is to facilitate the selection of acceptable remedial actions and to minimize bad decisions leading to the selection of remedial actions that do not satisfy both the risk-based remedial action objectives and the non-risk remedial action objectives.

1.3 This guide is intended to be applied at sites that require a remedial action to address unacceptable human heath or ecological risks, other regulatory requirements, and/or other unacceptable site conditions. Prior to use of this guide, a site assessment should be completed resulting in: *(1)* the establishment of remedial action objectives, *(2)* a determination that a remedial action is required to achieve the remedial action objectives, *(3)* an identification of site areas requiring a remedial action, and *(4)* a conceptual site model that reflects the results of the site assessment. The risk-based remedial action objectives are assumed to have been established using RBCA or another risk-based assessment method that results in the identification of appropriate remedial action objectives based on an evaluation of sources, exposure pathways, and potential receptors. Remedial action objectives may be established using Guide E1739, Guide E2081, and/or Guide E2205. In addition, applicable federal, state, and local regulations, statutes, and policies should be followed and should form the basis for determining risk-based and non-risk remedial action objectives. The remedial action objectives may include resource protection standards and the prevention of aesthetic or nuisance impacts in addition to protection of human health and the environment.

1.4 Each risk-based remedial action objective for an exposure pathway will typically include numeric remedial action levels for each chemical of concern (COC). Remedial action levels may also be developed for non-risk remedial action objectives such as resource protection standards. The non-risk remedial action levels may include thickness or mobility criteria for NAPL. The selected remedy must be effective and timely for each remedial action objective based on the consideration of the associated exposure pathway or resource protection standard.

1.5 To facilitate the selection of acceptable remedial actions, this guide establishes a process for remedy selection (Fig. 2) that involves:

1.5.1 *Development of risk-based remedial action objectives* that includes identification of complete exposure pathways and numeric remedial action levels (Section 5).

1.5.2 *Development of non-risk remedial action objectives* based on resource protection and other non-risk considerations. Resource protection objectives typically include numeric remedial action levels while other non-risk criteria are typically non-numeric and may include: remediation timeframe, implementability, cost effectiveness, regulatory compliance, property use requirements, liability control, and community concern (Section 5).

1.5.3 *Evaluation of protectiveness* to identify protective remedial actions that will be effective and timely for each risk-based remedial action objective for the site (Section 6).

1.5.4 *Evaluation of the retained remedies using the non-risk remedial action objectives* to identify acceptable remedial actions that satisfy the minimum level for each non-risk criterion (Section 7).

1.5.5 *Remedial action selection* to select the acceptable remedial action to be implemented at the site (Section 8).

1.5.6 *Remedy design and implementation* to ensure that the selected remedy is effectively implemented at the site and satisfies the remedial action objectives (Section 9).

1.6 This guide is intended for use in the selection of final remedial actions. This guide may also be used in the selection of interim measures provided that risk-based remedial action objectives and non-risk remedial action objectives are available for the evaluation of these interim measures.

[1] This guide is under the jurisdiction of ASTM Committee E50 on Environmental Assessment, Risk Management and Corrective Action and is the direct responsibility of Subcommittee E50.04 on Corrective Action.

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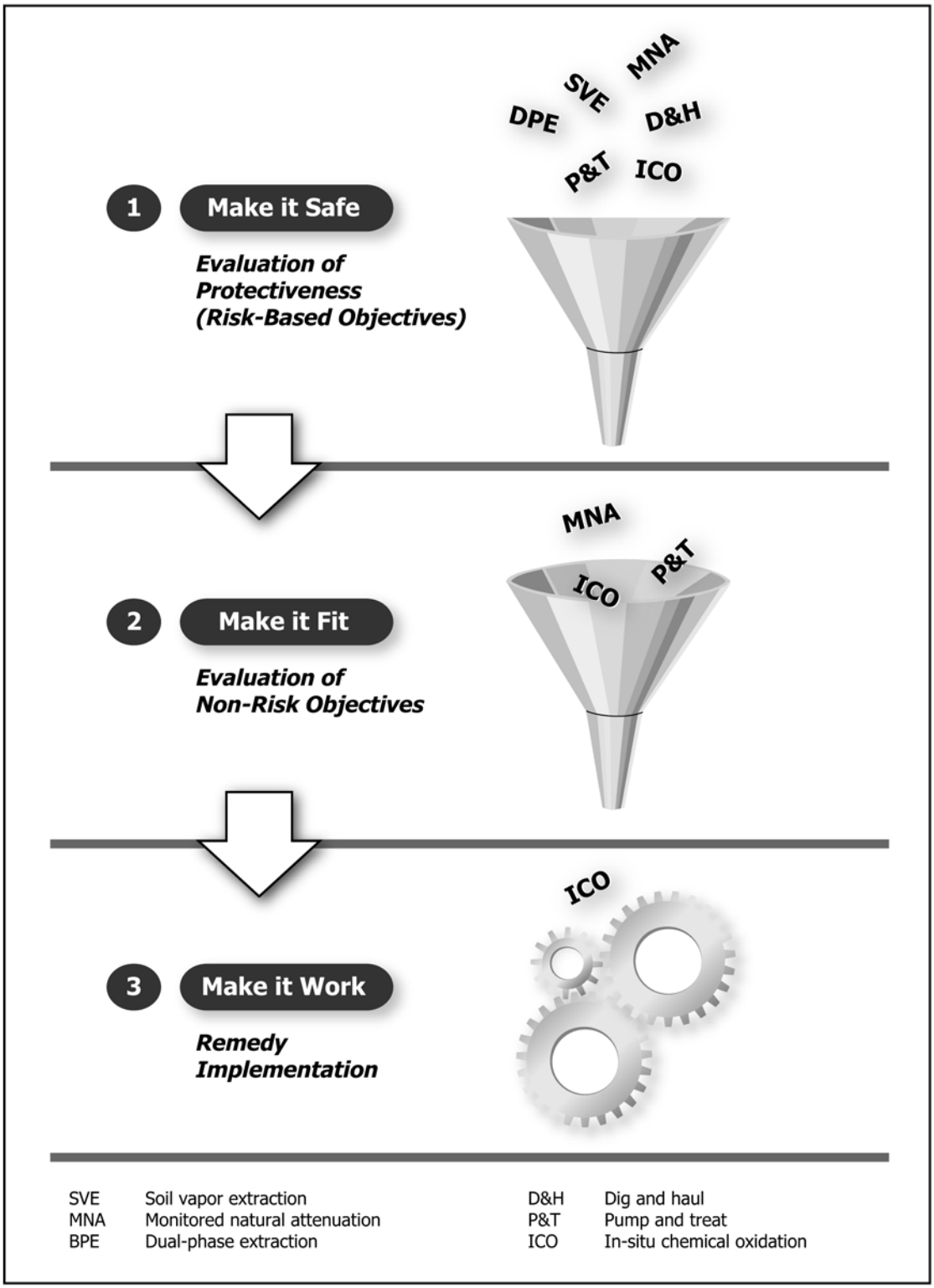
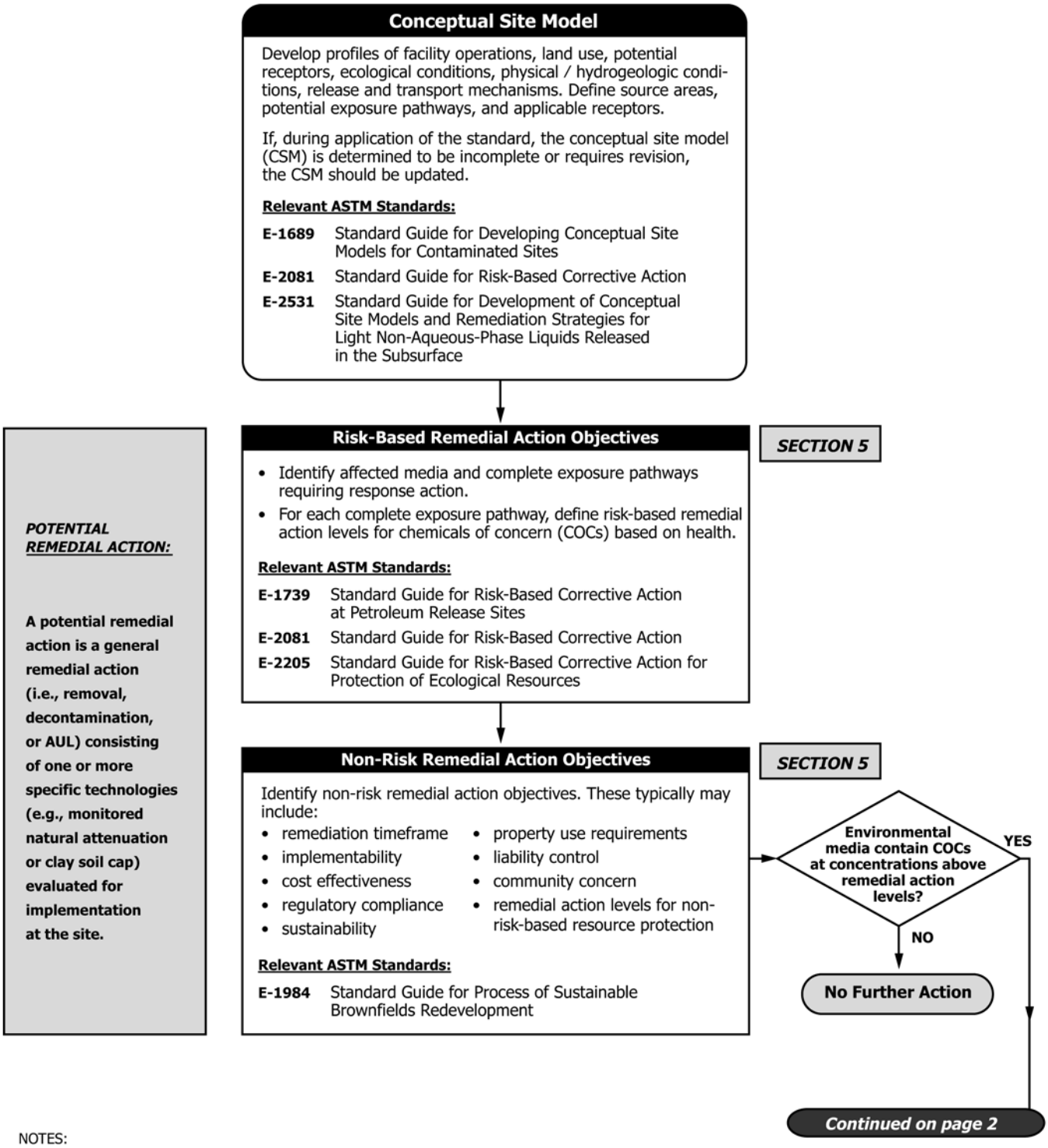


FIG. 1 Remedy Selection Process

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

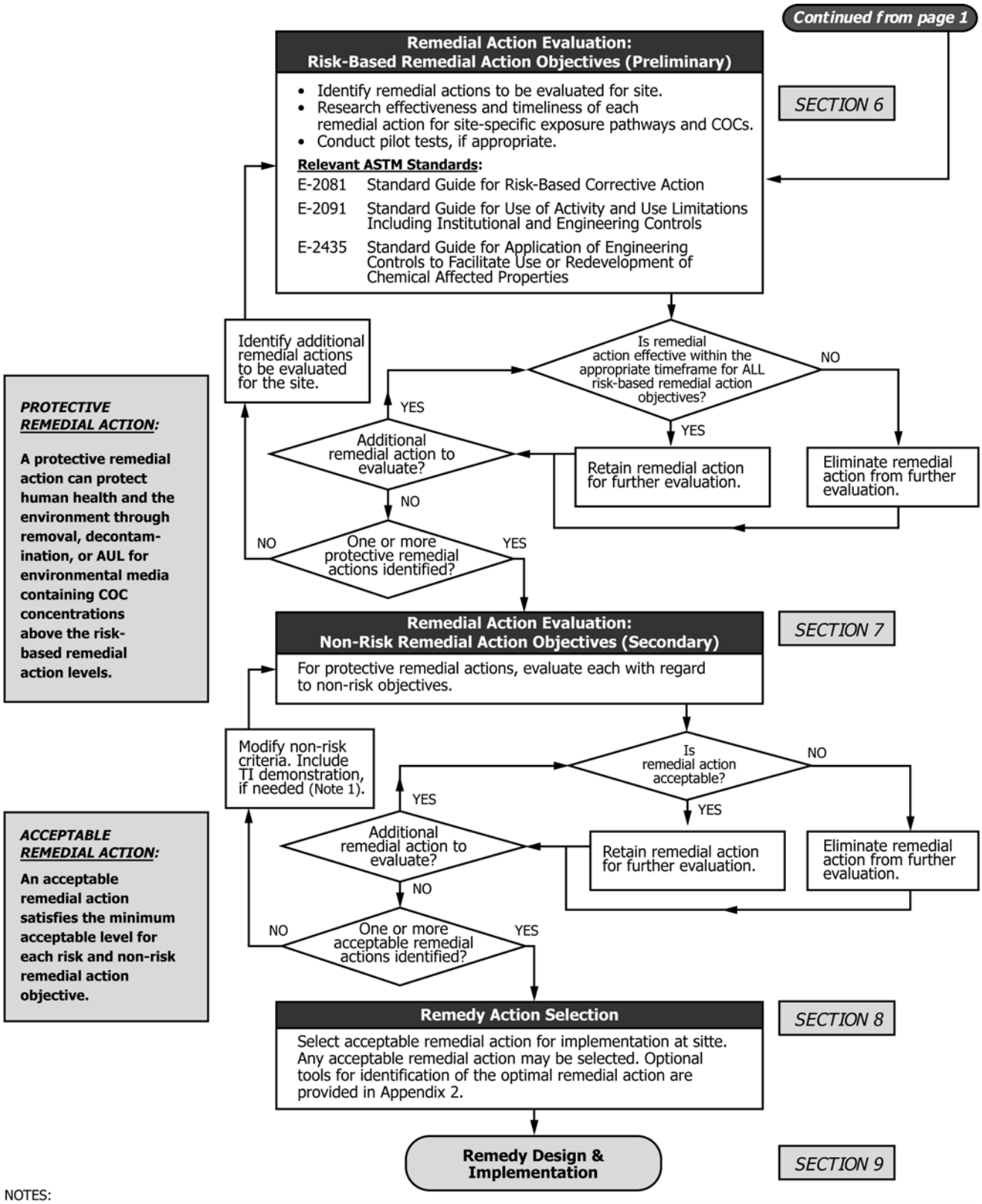
1.8 This guide is not intended to specifically address contractor health and safety issues. It is the responsibility of the user of this guide to ensure that Occupational Safety and



NOTES:

TI = Technical Impracticability
AUL = Activity and Use Limitation

FIG. 2 Remedy Selection Flowchart



NOTES:

1) TI = Technical Impracticability
AUL = Activity and Use Limitation

2) The remedy selection process must identify at least one remedy that addresses all risk-based objectives. If all protective remedies are eliminated based on the evaluation of non-risk objectives, then the user must: i) identify additional potential remedies for evaluation, or ii) modify the non-risk objectives so that one or more protective remedy is considered acceptable.

FIG. 2 Remedy Selection Flowchart *(continued)*

Health Administration (OSHA) regulatory requirements are met,and appropriate industry practices are consulted for guidance.

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

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D6235 Practice for Expedited Site Characterization of Vadose Zone and Groundwater Contamination at Hazardous Waste Contaminated Sites

D7294 Guide for Collecting Treatment Process Design Data at a Contaminated Site—A Site Contaminated With Chemicals of Interest

E1689 Guide for Developing Conceptual Site Models for Contaminated Sites

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

E1912 Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases (Withdrawn 2013)[3]

E1943 Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites

E2081 Guide for Risk-Based Corrective Action

E2091 Guide for Use of Activity and Use Limitations, Including Institutional and Engineering Controls

E2205 Guide for Risk-Based Corrective Action for Protection of Ecological Resources

E2435 Guide for Application of Engineering Controls to Facilitate Use or Redevelopment of Chemical-Affected Properties

E2531 Guide for Development of Conceptual Site Models and Remediation Strategies for Light Nonaqueous-Phase Liquids Released to the Subsurface

3. Terminology

3.1 *Conceptual Model Terms:*

3.1.1 *site*—The area(s) defined by the likely physical distribution of the COCs from a source area. A site could be an entire property or facility, a defined area or portion of a facility or property, or multiple facilities or properties. One facility may contain multiple sites. Multiple sites at one facility may be addressed individually or as a group.

3.1.2 *site assessment*—The characterization of a site to determine whether a release has occurred, the concentrations of the COCs in environmental media, and the distribution of the COCs. The site assessment collects data on soil, groundwater, air, and surface water quality; site characteristics (for example, subsurface geology, geochemistry, soil properties and structures, hydrology and surface characteristics), land and resource use, and potential receptors, and generates information to develop a conceptual site model to support risk-based decision making. The results of the site assessment are used to *(1)* establish remedial action objectives, *(2)* determine whether a remedial action is required to achieve the remedial action objectives, *(3)* identify site areas requiring a remedial action, and *(4)* develop a conceptual site model that reflects the results of the site assessment. The site assessment may be conducted using Practice D6235 or Guide E1912.

3.1.3 *complete exposure pathway*—The route a COC takes from the source area(s) to a human or ecological receptor. A complete exposure pathway describes a mechanism by which an individual or population is or could be exposed to COCs originating from the site. Each exposure pathway is associated with a source, a point of exposure, and an exposure route. If the exposure point is not at the source, a transport/exposure mechanism is included.

3.1.4 *conceptual site model*—The integrated representation of the physical and environmental context, the complete and potentially complete exposure pathways and the potential fate and transport of chemicals(s) of concern at a site. The site conceptual model should include both the current understanding of the site and the understanding of the potential future conditions and uses for the site. It provides a method to conduct the exposure pathway evaluation, inventory the exposure pathways evaluated, and determine the status of the exposure pathways as incomplete, potentially complete, or complete.

3.1.5 *risk-based remedial action objectives*—A set of objectives based on protection of human health and the environment developed for the site that identifies the COCs, affected environmental media, complete exposure pathways, and risk-based remedial action levels.

3.1.6 *non-risk remedial action objectives*—A set of objectives based on non-risk considerations for current and future site management. These objectives may include action levels based on aesthetic criteria or other resource protection standards with non-risk remedial action levels. In addition, these objectives not directly based on COC concentrations such as: remediation timeframe, implementability, cost effectiveness, regulatory compliance, property use requirements, liability control, and community concern.

3.1.7 *remedial action levels*—Concentrations of COCs in the source media and/or receptor media below which remedial actions are not required in order to satisfy the remedial action objectives. Non-risk remedial action levels may include resource protection standards not linked to a complete exposure pathway (that is, the application of drinking water standards to water resources not currently used for drinking water). Non-risk remedial action levels may also include thickness or mobility criteria for NAPL.

3.2 *Types of Remedial Action Technologies:*

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

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

3.2.1 *removal*—A remedial action technology to take environmental media away from the site to another location for storage, processing, or disposal in accordance with all applicable requirements.

3.2.2 *decontamination*—A remedial action technology based on permanent and irreversible treatment processes to an environmental medium so that the threat of release of COCs at concentrations above the remedial action levels is eliminated.

3.2.3 *activity and use limitation (AUL)*—A remedial action technology that relies on institutional controls (ICs) or engineering controls (ECs) (collectively, ICs and ECs are known as "activity and use limitations") to prevent exposure to COCs present in environmental media at concentrations above the remedial action levels. An AUL technology can be used to eliminate a complete or potentially complete exposure pathway by eliminating the receptor or by preventing transport of the COCs to the receptor. AUL measures must be combined with appropriate maintenance, monitoring, and any necessary further remedial action to satisfy the remedial action objectives and be protective of human health and the environment.

3.3 *Remedy Selection:*

3.3.1 *remedial action*—One or more technologies implemented at a site to address environmental media containing COCs at concentrations exceeding the remedial action levels defined for the site. A remedial action for a site may involve removal, decontamination, and/or AUL technologies including monitoring.

3.3.2 *potential remedial action*—A potential remedial action is any remedial action evaluated for implementation at the site as part of the risk-based remedy selection process.

3.3.3 *protective remedial action*—A protective remedial action can achieve all of the risk-based remedial action objectives through timely removal, decontamination, and/or implementation of AULs for environmental media containing COC concentrations above the risk-based remedial action levels.

3.3.4 *acceptable remedial action*—An acceptable remedial action is able to achieve all of the risk-based and non-risk remedial action objectives.

3.4 *Acronyms:*

3.4.1 *AUL*—activity and use limitation

3.4.2 *CMS*—corrective measures study

3.4.3 *COC*—chemical of concern

3.4.4 *EC*—engineering control

3.4.5 *ETCAP*—Environmental Technology Cost Savings Analysis Project

3.4.6 *FRTR*—Federal Remediation Technologies Roundtable

3.4.7 *FS*—feasibility study

3.4.8 *GWRTAC*—Ground Water Remediation Technologies Analysis Center

3.4.9 *IC*—institutional control

3.4.10 *ITRC*—Interstate Technology & Regulatory Council

3.4.11 *NAPL*—non-aqueous phase liquids

3.4.12 *NAVFAC*—Naval Facilities Engineering Command

3.4.13 *OSHA*—Occupational Health and Safety Administration

3.4.14 *RBCA*—risk-based corrective action

4. Significance and Use

4.1 This guide is intended for use within a RBCA process or other risk-based framework for protection of human health and the environment that is based on an evaluation of sources, exposure pathways, and receptors.

4.2 This guide is intended to identify the factors that should be considered in the selection and implementation of an appropriate remedial action to address COCs present in environmental media at the site at concentrations above the remedial action levels. The specific process used to select the remedial action will vary widely from site to site. However, in all cases, the selected remedial action should be both a protective remedial action (that is, achieves the risk-based remedial action objectives) and an acceptable remedial action (that is, satisfies the non-risk remedial action objectives).

5. Remedial Action Objectives

5.1 *Conceptual Model*—A conceptual model is an important tool that is utilized in the risk-based remedy selection process. The conceptual model provides a systematic method for use of site information based on current and potential future site-specific land use considerations. The conceptual model should identify source areas; complete, potentially complete, and incomplete exposure pathways; and human and ecological receptors. In addition, the conceptual model should identify type and concentration of COCs, affected environmental media, and specific areas within the affected environmental media to be addressed by the selected remedial action. Although a conceptual model should be developed prior to initiation of the risk-based remedy selection process, the conceptual model should be considered dynamic and should be updated as needed during the risk-based remedy selection process to reflect any changes in the understanding of the site. A conceptual model may be developed using Guide E1689, Guide E2531, and/or Guide D7294.

5.2 *Identification of Risk-Based Remedial Action Objectives*—Risk-based remedial action objectives are used to identify remedial actions that will be protective of human health and the environment. It is assumed that users of this guide will have developed appropriate risk-based remedial action objectives which are protective of human health and the environment using RBCA or a similar risk-based framework. The risk-based remedial action objectives should include: *(1)* identification of types and concentrations of COCs, *(2)* affected environmental media, *(3)* complete exposure pathways and resource protection requirements, and *(4)* remedial action levels and their basis. Remedial action objectives may be established using Guide E1739, Guide E2081, and/or Guide E2205.

5.3 *Identification of Non-Risk Remedial Action Objectives*—Non-risk remedial action objectives are used to identify remedial actions that will satisfy the current and future non-risk

requirements for the site. While risk-based remedial action objectives ensure long-term protection of human health and the environment, non-risk objectives address all other site remedial action requirements and constraints, including applicable laws and regulatory requirements not already included as risk-based remedial action objectives. The non-risk remedial action objectives should cover all non-risk site constraints that will define an acceptable remedy.

5.3.1 *Example Non-Risk Remedial Action Objectives with Remedial Action Levels*—Resource protection standards are remedial action objectives that include remedial action levels but are not directly tied to human or ecological exposure. Containment or exposure control remedial actions (that is, AULs) may not be considered acceptable for some resource protection objectives. Example non-risk remedial action objectives with remedial active levels include, but are not limited to the following:

5.3.1.1 Action levels to prevent aesthetic or nuisance impacts.

5.3.1.2 Application of drinking water standards to non-drinking water resources: remedial actions levels for drinking water are applied to water resources that will not be used as drinking water in the foreseeable future.

5.3.1.3 NAPL removal requirements: NAPL thickness or mobility criteria for groundwater resources where human exposure will not occur in the foreseeable future.

5.3.2 *Example Non-Risk Remedial Action Objectives without Remedial Action Levels*—Other non-risk remedial action objectives are not directly tied to site COC concentrations and therefore do not include remedial action levels.

5.3.2.1 *Timeliness*—Remedial action will be completed within a timeframe that meets the site-specific requirements.

5.3.2.2 *Implementability*—Remedial action can be implemented and will protect human health and the environment during implementation.

5.3.2.3 *Confidence*—The level of confidence that the remedial action will achieve the remedial action objectives at the site.

5.3.2.4 *Sustainability*—Remedy is sustainable based on evaluation of sustainability metrics such as energy usage, carbon dioxide emissions, natural resource usage/restoration, etc.

5.3.2.5 *Cost*—Remedy cost is acceptable.

5.3.2.6 *Regulatory Compliance*—Remedy satisfies regulatory requirements.

5.3.2.7 *Property Use Compatibility*—Remedy allows for acceptable current and future property use.

5.3.2.8 *Liability Control*—Remedy controls current and future liability associated with site.

5.3.2.9 *Community Acceptance*—Remedy is acceptable to third party stakeholders.

5.3.3 *Acceptance Standards for Non-Risk Remedial Action Objectives*—For each non-risk remedial action objective without remedial action levels, the user must identify an acceptance standard that will be used to determine whether a remedial action satisfies the non-risk objective. For the purpose of identifying acceptable remedial actions, the acceptance standard will generally be absolute (that is, remediation time must not exceed 10 years). Relative acceptance standards (that is, one remedy is more cost effective than an alternative remedy) should not be used for the identification of acceptable remedies. Instead, relative standards should be used to select a remedial action for implementation from among the acceptable remedial actions identified in the screening process (see Section 8).

5.4 *Need for a Remedial Action*—A remedial action is required if environmental media contain COCs at concentrations above the risk-based or non-risk remedial action levels. If all COC concentrations are below the remedial action levels, then no further action is required.

6. Remedial Action Evaluation: Risk-Based Remedial Action Objectives

6.1 *Identification of Potential Remedial Actions*—In risk-based remedial action screening, potential remedial actions are screened to identify protective remedial actions which can achieve all of the risk-based remedial action objectives. A potential remedial action is one or more specific technologies (for example, clay soil cap or monitored natural attenuation) representing one or more classes of remedial action (that is, removal, decontamination, or AULs) evaluated for implementation at the site. Available resources for the identification of potential remedial actions are provided in 6.3.3.

6.2 *Remedial Action Screening Process*—Remedial action screening may be conducted in a staged manner where the simplest and easiest remedial actions are screened first. If no acceptable remedial action is identified in this initial screen, then more complex remedial actions can be identified and screened. As an alternative, a comprehensive list of potential remedial actions may be screened in a single iteration.

6.3 *Evaluation of Potential Remedial Actions*—The user must research the effectiveness and timeliness of each potential remedial action in order to determine whether the potential remedial action is capable of achieving all of the risk-based remedial action objectives.

6.3.1 *Use of the Conceptual Site Model*—The evaluation of effectiveness and timeliness for each remedial action should be made within the context of the conceptual site model (that is, the COCs, physical, geochemical, and hydrogeologic conditions, and other site-specific factors affecting technology effectiveness).

6.3.2 *Performance History*—When evaluating effectiveness and timeliness of a potential remedial action, the user should consider the performance history of the potential remedial action when applied to other sites with similar conceptual site models (that is, similar COCs, site conditions, etc.).

6.3.3 *Available Resources*—A number of resources are available to assist with the evaluation of technical effectiveness of potential remedial actions:

6.3.3.1 Federal Remediation Technologies Roundtable (FRTR): http://www.frtr.gov/

6.3.3.2 USEPA Technology Innovation Program Contaminated Site Clean-Up Information: http://clu-in.org

6.3.3.3 Ground-Water Remediation Technologies Analysis Center (GWRTAC): http://www.gwrtac.org/

6.3.3.4 NAVFAC Environmental Restoration and BRAC Website: https://portal.navfac.navy.mil/portal/page/portal/navfac/navfac_ww_pp/navfac_nfesc_ pp/environmental/erb

6.3.3.5 USEPA Guidance for Evaluating the Technical Impracticability of Ground-Water Restoration. EPA 540-R-93-080: http://www.epa.gov/superfund/health/conmedia/gwdocs/techimp.htm

6.3.3.6 ASTM Guides E1943, E2091, and E2435.

6.4 *Pilot Studies*—Pilot studies may be conducted for one or more potential remedial actions or specific technologies included in potential remedial actions in order to obtain site-specific performance information. Pilot studies are typically conducted to obtain site-specific information concerning the effectiveness for achieving risk-based remedial action objectives and/or to obtain a better understanding of performance with respect to non-risk remedial action objectives such as timeliness, implementability, and cost. If pilot studies have been conducted, the results should be considered in the screening of potential remedial actions.

6.5 *Screening of Potential Remedial Actions*—Each potential remedial action must be evaluated with respect to its ability to achieve each risk-based remedial action objective. Each risk-based remedial action objective may impose different requirements for effectiveness and timeliness. For example, to address vapor intrusion, a remedy must prevent unsafe vapor intrusion impacts within the timeframe for which potentially impacted buildings would be occupied (for example, the remedy must be immediately effective for currently occupied buildings). However, for a remedial action objective applying drinking water standards to a resource not currently used for drinking water, the remedy must be within a timeframe based on the potential future use for the resource. The criteria used to evaluate the effectiveness and timeliness of each potential remedial action may vary depending on the type of technologies used. A remedial action may use one or more different types of technologies.

6.5.1 *Effectiveness Criteria for Removal Technologies*—A protective removal remedial action will be capable of removing all affected environmental media (that is, soil, groundwater, etc.) containing COCs at concentrations exceeding the remedial action levels.

6.5.2 *Effectiveness Criteria for Decontamination Technologies*—A protective decontamination remedial action will be capable of decontaminating all affected environmental media such that the media no longer contain COCs at concentrations exceeding the remedial action levels.

6.5.3 *Effectiveness Criteria for AUL Technologies*—A protective AUL remedial action will be capable of preventing exposure to affected environmental media containing COCs at concentrations exceeding the remedial action levels.

6.5.4 *Remedial Action Timeliness*—A timely remedial action will be effective within the timeframe required to prevent unsafe exposure to the receptors identified for each exposure pathway.

6.6 *Retaining Protective Remedial Actions*—A protective remedial action can achieve the risk-based remedial action objectives through removal, decontamination, and/or implementation of AULs for environmental media containing COC concentrations above the risk-based remedial action levels. To be retained as a protective remedial action, the remedial action must be capable of being safely implemented and capable of achieving the remedial action objectives with an acceptable level of confidence.

6.6.1 *Confidence Criteria for Evaluation of Remedial Action Effectiveness*—At a minimum, to be retained as a protective remedial action, the remedial action must be more likely than not capable of achieving the risk-based remedial action objectives; however, higher confidence criteria may be appropriate at many sites. The level of confidence required to retain a remedial action will depend on the adverse consequences associated with failure of the remedial action. For example, a relatively low level of confidence would be more acceptable at a site where an alternative remedial action could be safely and easily implemented. Potential remedial actions must meet the minimum level of confidence to be retained through the risk-based remedial action screening.

6.6.2 *Remedial Action Screening*—Potential remedial actions that are determined to be protective (that is, able to achieve the risk-based remedial action objectives) with the specified level of confidence are retained for further evaluation using the non-risk remedial action objectives. Potential remedial actions which are not protective are eliminated from further evaluation. One or more protective remedial actions must be identified as part of the risk-based remedial action screening. If all potential remedial actions are eliminated during the risk-based screening, then additional potential remedial actions must be identified and taken through the screening process. At all sites, it should be possible to identify one or more protective remedial actions. For some sites, removal or decontamination technologies alone may not be capable of lowering COC concentrations below remedial action levels. However, at these sites, it should be possible to identify AULs that prevent unsafe exposure to environmental media containing COCs at concentrations above these levels. Remedial action objectives that require consideration of only removal or decontamination technologies (without AULs) are considered non-risk objectives. The situation where no potential remedial action will satisfy all risk-based and non-risk remedial action objectives is addressed in 7.4.

7. Remedial Action Evaluation: Non-risk Remedial Action Objectives

7.1 *Identification of Remedial Actions for Non-Risk Screening*—All remedial actions identified as protective based on the evaluation using risk-based remedial action objectives should be included in the non-risk remedial action screening.

7.2 *Evaluation of Protective Remedial Actions*—The user must research the effectiveness of each protective remedial action with respect to satisfying the non-risk remedial action objectives.

7.2.1 *Use of the Conceptual Site Model*—The evaluation of effectiveness for each remedial action should be made within the context of the conceptual site model (that is, the COCs, physical and hydrogeologic conditions, and other site-specific factors affecting effectiveness).

7.2.2 *Performance History*—When evaluating effectiveness, the user should consider the performance history of the potential technology when applied to other sites with similar conceptual site models (that is, similar COCs, site conditions, etc.).

7.2.3 *Available Resources*—When evaluating the effectiveness of a protective remedial action with respect to non-risk criteria, the user will typically rely on many of the same resources used to evaluate protectiveness (see 6.3.3).

7.3 *Retaining Acceptable Remedial Actions*—An acceptable remedial action achieves the risk-based remedial action objectives and satisfies the minimum acceptable standard for each non-risk remedial action objective. Remedial actions that are determined to be acceptable are retained for potential selection. Remedial actions which are not acceptable are eliminated from further evaluation.

7.4 *Modifying the Non-Risk Remedial Action Objective*—If no potential remedial action will satisfy both the risk-based remedial action objectives and the non-risk remedial action objectives, then the non-risk remedial action objective may need to be modified in order to allow for the identification of an acceptable remedy. Modification of non-risk objectives requires input and consensus from all parties responsible for imposing the non-risk objectives being modified. In addition, when possible, the underlying goal of the non-risk objective being modified should be retained. For example, a non-risk objective requiring removal or decontamination of the source area might be replaced with an objective to contain the source area using AULs, achieving the same overall goal of eliminating ongoing migration of COCs out of the source area.

7.5 *Technical Impracticability*—Technical impracticability exists when no potential remedial action will satisfy both the risk-based remedial action objectives and the non-risk remedial action objectives. If all potential remedial actions are eliminated through remedial action screening, then a determination of technical impracticability may be appropriate. Following a technical impracticability determination, the non-risk remedial action objectives must be modified in order to allow for the selection of a remedial action that will satisfy the modified objectives and will be protective of human health and the environment. When a non-risk objective is modified, the underlying goal of the non-risk objective should be retained, if possible.

8. Remedy Selection

8.1 *Remedy Selection Criteria*—Any acceptable remedial action (that is, any remedial action technology that satisfies the risk-based and non-risk remedial action objectives) may be selected for implementation at the site. A case study illustrating the risk-based remedy selection process is provided in Appendix X1.

8.1.1 *Selection Among Acceptable Remedial Actions*—If more than one acceptable remedial action is identified, the remedial action which does the best job of satisfying the non-risk objectives will typically be selected for implementation (that is, the remedial action with the best combination of cost, timeliness, confidence, and other secondary considerations). However, this standard allows any acceptable remedial action to be selected for implementation and does not require a specific process for the selection of this remedial action.

8.1.2 *Optional Remedy Selection Methods*—Optional remedy selection methods used to select the "best" remedial actions are included in Appendix X2. State and federal regulatory programs may specify that a specific remedy selection process is to be followed such as a feasibility study (FS) or corrective measures study (CMS).

8.2 *Remedy Selection Documentation*—At a minimum, remedy selection documentation must show that the selected remedial action meets the risk-based and non-risk remedial action objectives. Thus, the remedy selection documentation should: *(1)* define the risk-based remedial action objectives, *(2)* define the non-risk remedial action objectives, and *(3)* document the basis for determining that the selected remedial action will satisfy these objectives. In addition, the remedy selection documentation should document the evaluation of non-selected remedial actions indicating which potential remedial actions were evaluated and the basis for eliminating each non-selected remedial action. If more than one acceptable remedial action was identified, the rationale for choosing the selected remedial action should be identified (for example, "the lowest cost acceptable remedy was selected"). In some cases, state or federal regulations establish specific requirements for documentation of the remedy selection process such as a feasibility study (FS) or corrective measures study (CMS).

9. Remedy Implementation Considerations

9.1 *Remedial Action Design*—The selected remedial action should be designed and implemented to achieve the risk-based and non-risk remedial action objectives. Bench scale and/or field pilot testing activities may be performed prior to, or during the remedial action design. Remedial action design includes compliance with local building codes, permitting requirements, and safety requirements. Remedial action design will include remedy monitoring methods to verify remedy effectiveness and/or remedy completion.

9.2 *Remedial Action Monitoring Methods*—Remedial action monitoring may include:

9.2.1 Verification sampling (removal or decontamination technologies).

9.2.2 Point of compliance monitoring (AUL technologies).

9.2.3 Integrity monitoring (AUL technologies).

The type of monitoring method selected depends on the type of remedial action being implemented. The monitoring methods selected should be capable of verifying remedy completion and monitoring remedial action effectiveness during remedy implementation (if needed).

9.3 *Remedial Action Monitoring Criteria*—Remedial action monitoring criteria provide the basis for determining remedy effectiveness and/or completion: *(1)* Remedy completion: Has remedial action achieved the remedial action objectives? *(2)* Remedy effectiveness: Is remedial action progressing towards achieving the remedial action objectives?

These criteria should be identified prior to remedy implementation.

9.3.1 *Remedy Completion Criteria*—Remedy completion is typically demonstrated by comparison of source media or exposure media concentrations to the remedial action levels.

9.3.2 *Remedy Effectiveness Criteria*—Remedy effectiveness criteria are used to determine whether the selected remedial action needs to be modified or replaced in order to achieve the remedial action levels while continuing to satisfy the other objectives (for example, cost, timeliness, etc.). For example, a pump and treat remedy may require modification or replacement if COC concentrations in groundwater plateau prior to achievement of the remedial action levels. In addition, remedy effectiveness monitoring criteria may be used at the time of system start-up in order to optimize system operation.

9.4 *Intermediate Remediation Goals*—The monitoring of remedy effectiveness may include the establishment of intermediate remediation goals that can be achieved prior to achievement of final risk and non-risk remedial action objectives. These goals may be numeric goals such as a 5× reduction in maximum COC concentrations or non-numeric goals such as plume stabilization.

9.5 *Technical Impracticability*—A determination of technical impracticability may be made based on remedy effectiveness monitoring (that is, the selected remedial action is not effective and no alternative acceptable remedial action can be identified). Following a technical impracticability determination, the non-risk remedial action objectives must be modified in order to allow for the selection of a remedial action that will satisfy the modified objectives and will be protective of human health and the environment.

9.6 *Remedy Completion*—The remedy is complete when the remedy monitoring has demonstrated that the remedial action has achieved the remedial action objectives. AUL remedies may require post-response care and monitoring to ensure the continued effectiveness of the remedial action following completion.

9.7 *Post-Response Care*—Post response care involves continued operation and/or maintenance of AUL technologies to ensure continued effectiveness. Monitoring methods and criteria will typically be the same as those used to demonstrate remedy completion. However, lower intensity monitoring will typically be sufficient to provide assurance of continued remedy effectiveness. When monitoring has demonstrated the long-term effectiveness of the remedy, continued monitoring may not be required.

9.8 *Remedy Implementation Documentation*—Documentation of remedy implementation may include:

9.8.1 *Remedial Action Work Plan*—Includes engineering design, bench or pilot tests, compliance with codes and permit requirements, safety considerations, implementation schedule, monitoring methods and criteria.

9.8.2 *Remedy Effectiveness (optional)*—Documents progress towards achievement of remedial action objectives during remedial action implementation.

9.8.3 *Remedy Completion*—Demonstrates achievement of the remedial action objectives. Includes requirements for post-response care, if needed.

9.8.4 *Post-Response Care*—Documents continued effectiveness of AUL technologies.

Applicable regulations may require submittal of some or all of these documents. The user should be aware of regulatory reporting requirements associated with remedy implementation.

APPENDIXES

(Nonmandatory Information)

X1. RISK-BASED REMEDY SELECTION CASE STUDY
(Risk-Based Remedy Selection for Big Bob's AutoHaus)

X1.1 Site Background

X1.1.1 Big Bob's AutoHaus is a small auto repair shop in Utopia, Texas. A release has been discovered from a tank used to store spent solvents. The key contaminant at the site is trichloroethene (TCE).

X1.2 Step 1: Conceptual Site Model

X1.2.1 *Surface Water*—The nearest surface water body is the Sabinal River, located 2 km SE of the property. This river is used for public water supply, recreation, and provides high quality habitat for wildlife.

X1.2.2 *Vapor Impacts*—No subsurface structures (basements, parking garages, etc.) are present within 300 m of the site. No odor complaints or other evidence of vapor impacts have been noted. Concentrations of TCE in outdoor air, indoor air, and sub-slab soil gas samples were found to be below applicable regulatory screening values.

X1.2.3 *Soil Impacts*—Shallow contaminated soils are present at the site in areas covered by pavement or buildings. Contaminated soils do not extend off the property owned by Big Bob's AutoHaus.

X1.2.4 *Groundwater Impacts*—Shallow groundwater in Utopia is NOT used for drinking water. Public water is supplied by the city and is obtained from the Sabinal River. Some groundwater in the area is used for irrigation or other non-consumptive purposes.

X1.2.4.1 *Current Aquifer Use*—Shallow groundwater is not currently used for drinking water. Drinking water, supplied by the city, is taken from a near-by river. A water well used for a car wash is located 60 m east of the site.

X1.2.4.2 *Potential Aquifer Use*—Sustainable well yield for shallow groundwater-bearing unit: 40 L/min (58 000 litres per day). Total dissolved solids: 500 mg/L.

X1.2.4.3 The shallow soils are sedimentary, with layers of fine sand, silt, and clay. Groundwater seepage velocities are generally less than 100 m/yr.

X1.2.4.4 Groundwater contamination is present at the site and extends to the east off the property owned by Big Bob's AutoHaus. A water well is located east of the site at Fred's Service Station. This water well is used for the operation of a car wash, but is not used to supply drinking water.

X1.2.5 *Ecological Habitat*—The site and adjacent properties are fully developed and lack wildlife habitat. In addition, there have been no releases to surface water. As a result, no ecological risk concerns have been identified.

X1.3 Step 2: Risk-Based Remedial Action Objectives

X1.3.1 *Risk-Based Objective*—Prevent unsafe human exposure to environmental media containing contaminant concentrations above the risk-based remedial action levels and prevent impacts to ecological resources.

Summary of Complete and Incomplete Exposure Pathways

Exposure Pathway	Current Exposure?		Potential Future Exposure?	
	On-Site	Off-Site	On-Site	Off-Site
Soil Source Direct Contact With Soils	No	No	**Yes**	No
Soil to Groundwater	No	No	**Yes**	No
Indoor or Outdoor Air Exposure	No	No	No	No
Groundwater Source Actual Drinking Water Resource (i.e., actual or potential impact to existing drinking water well)	No	No	No	No
Potential Drinking Water Resource (i.e., affected aquifer could be utilized as drinking water resource)	N/A	N/A	**Yes**	**Yes**

Summary of Complete and Incomplete Exposure Pathways

Exposure Pathway	Current Exposure?		Potential Future Exposure?	
	On-Site	Off-Site	On-Site	Off-Site
Actual Non-Drinking Water Use (i.e., actual or potential impact to existing non-drinking water well)	No	No	No	**Yes**
Potential Non-Drinking Water Use (i.e., affected aquifer could be utilized as drinking water resource)	N/A	N/A	**Yes**	**Yes**
Indoor or Outdoor Air Exposure	No	No	No	No
Groundwater to Surface Water	No	No	No	No

X1.3.2 *Affected Media:*

Environmental Medium	Remedy Required?	
	On-Site	Off-Site
Soil	**Yes**	No
Groundwater	**Yes**	**Yes**
Surface Water/Sediment	No	No

X1.3.3 *Risk-Based Remedial Action Levels for TCE:*

Exposure Pathway	On-Site		Off-Site	
	Action Level	Exceeded?	Action Level	Exceeded?
Soil Source:				
Direct Contact with Soils	67 mg/kg	No	N/A	N/A
Soil to Groundwater	0.026 mg/kg	Yes	N/A	N/A
Groundwater Source:				
Groundwater Ingestion	0.005 mg/L	Yes	0.005 mg/L	Yes

X1.3.4 *Volume of Affected Soil with TCE Concentration Above Lowest Action Level:*

On-Site: 1400 m^3
Off-Site: None

X1.3.5 *Area of Affected Groundwater with TCE Concentration Above Lowest Action Level:*

On-Site: 700 m^2
Off-Site: 700 m^2

X1.4 Step 3: Non-Risk Remedial Action Objectives

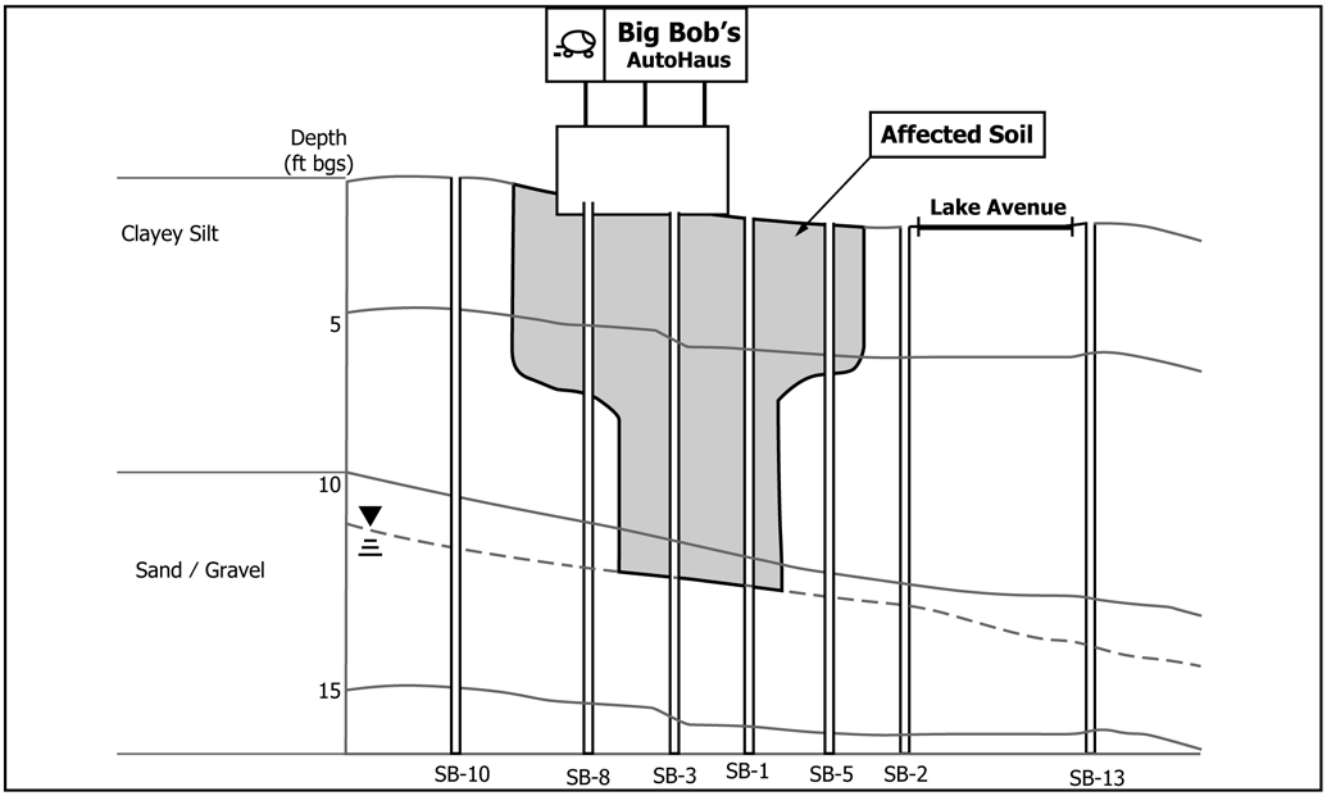


FIG. X1.1 Area of Affected Soil

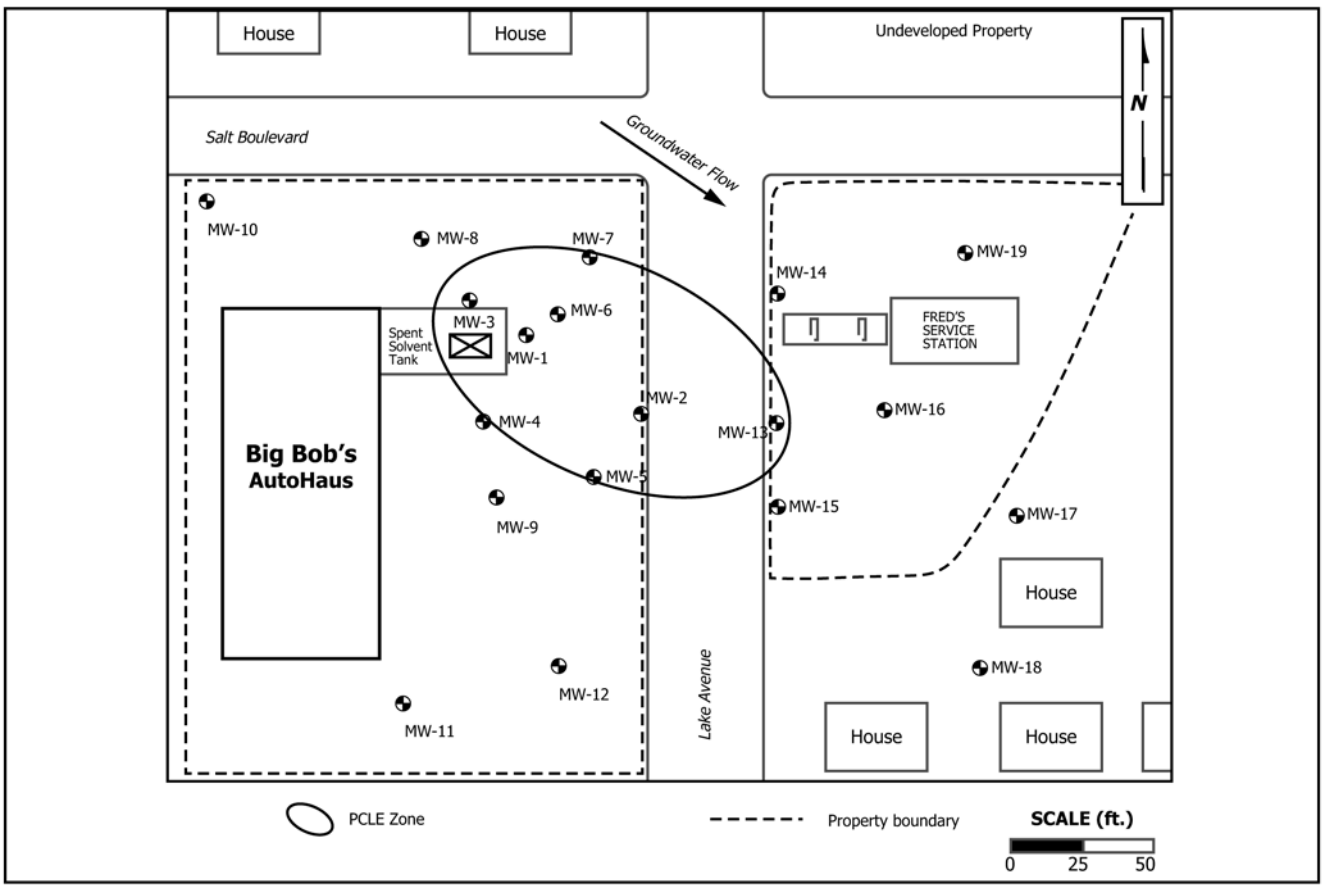


FIG. X1.2 Area of Affected Groundwater

Non-Risk Objective	Source/Basis
Non-Risk Remedial Action Levels:	
None	Not Applicable
Remediation Timeframe:	
On Site: No set timeframe for achieving remedial action levels	Property Owner (Big Bob)
Off-Site: Achieve drinking water standards in groundwater within five years	Property Owner (Fred)
Regulatory Compliance:	
Achieve risk-based remedial action objectives through removal, decontamination, or activity and use limitations (AULs). Apply drinking water standards to potential drinking water resources.	Texas Commission on Environmental Quality
Liability Control:	
Prevent on-site and off-site exposure to contamination	Responsible Party (Big Bob)
Property Use Requirements:	
Maintain current commercial use of on-site and off-site properties following completion of remedy.	Property Owners (Big Bob and Fred)
Cost Effectiveness:	
Total remediation costs < $1,000,000	Responsible Party (Big Bob), based on limits of insurance coverage.

X1.5 Step 4A: Potential Remedial Actions to be Evaluated

Type of Remedy	Technology	Description
Soil Remedies:		
Removal	Excavation	Excavate all soils with TCE concentrations above lowest remedial action level (0.026 mg/kg). Dispose of affected soils in appropriate landfill.
Decontamination	Soil Vapor Extraction	Install 12 vapor recovery points (8 m centers). Use vacuum pump to draw air through unsaturated soils causing volatilization of TCE.
AUL	Groundwater Control Remedy	Rely on groundwater containment remedy to control impacts associated with migration of TCE from soil to groundwater.
Groundwater Remedies: On-Site:		
Decontamination	Pump & Treat	Install one groundwater recovery well adjacent to spent solvent tank. Treat recovered groundwater with activated carbon and discharge to city sewer.
AUL	Natural Attenuation	Monitor three on-site wells annually to verify plume stability.
Groundwater Remedies: Off-Site:		
Decontamination	Pump & Treat	Install one groundwater recovery well at Big Bob's AutoHaus property line, 5 m north of MW-2. Treat recovered groundwater with activate carbon and discharge to city sewer.
AUL	Natural Attenuation	Monitor three off-site well annually to verify plume stability

X1.6 Step 4B: Evaluation of Potential Remedies: Risk-Based Objectives

Soil Remedies

Technology	Likelihood to Achieve Remedial Action Levels	Retain as Protective Remedial Action?
Excavation	High (Technology demonstrated effective in similar settings.)	Yes
Soil Vapor Extraction	Low (Technology has often failed in similar settings due to poor distribution of air flow through fine-grained soils.)	No
Groundwater Control Remedy (AUL)	High (Conditional on adequate control of groundwater exposures.)	Yes

On-Site Groundwater Remedies

Technology	Likelihood to Achieve Remedial Action Levels	Retain as Protective Remedial Action?
Pump & Treat (Decontamination)	Low (Current maximum TCE concentration is >300× remedial action level. Based on experience from other sites, contaminant concentrations in groundwater is likely to stabilize prior to achieving drinking water standards. However, source area pump and treat may facilitate achievement of remedial action levels at off-site locations.)	No
Natural Attenuation (AUL)	High (Technology demonstrated effective in similar settings. Institutional control needed to prevent exposure to groundwater containing TCE concentrations above the remedial action level.)	Yes

Off-Site Groundwater Remedies

Technology	Likelihood to Achieve Remedial Action Levels	Retain as Protective Remedial Action?
Pump & Treat (Decontamination)	Medium (Current maximum TCE concentration is 10× remedial action level. Based on experience from other sites, pump & treat is likely to achieve drinking water standards off-site. If implemented without on-site source treatment, long-term operation may be required.)	Yes
Natural Attenuation (AUL)	High (Technology demonstrated effective in similar settings. Institutional control needed to prevent exposure to groundwater containing TCE concentrations above the remedial action level.)	Yes

X1.7 Step 4C: Summary of Protective Remedial Actions based on Evaluation of Risk-Based Objectives

Type of Remedy	Technology	Description
Soil Remedies:		
Removal	Excavation	Excavate all soils with TCE concentrations above lowest remedial action level (0.026 mg/kg). Dispose of affected soils in appropriate landfill.
AUL	Groundwater Control Remedy	Rely on groundwater containment remedy to control impacts associated with migration of TCE from soil to groundwater.
Groundwater Remedies: On-Site:		
AUL	Natural Attenuation	Monitor three on-site well annually to verify plume stability.
Groundwater Remedies: Off-Site:		
Decontamination	Pump & Treat	Install one groundwater recovery well at Big Bob's AutoHaus property line, 5 m north of MW-2. Treat recovered groundwater with activated carbon and discharge to city sewer.
AUL	Natural Attenuation	Monitor three off-site wells annually to verify plume stability.

X1.8 Step 5A: Evaluation of Potential Remedies: Non-Risk Objectives

Soil: Excavation

Non-Risk Objective	Achieved by Remedy?	Comment
Remediation Timeframe: None	Yes	
Regulatory Compliance: Achieve risk-based objectives	Yes	Remedy removes contamination
Liability Control: Prevent exposure	Yes	Remedy removes contamination
Property Use: Maintain current commercial use following remedy completion.	Yes	No use restrictions following remedy completion
Cost effectiveness: <$1,000,000 total cost (including GW remedy)	Yes	Estimated Cost = $200/$m^3$ × 1400 m^3 = $280 000 (Soil remedy cost only)
Remedy Acceptable?	Yes	

Soil: Groundwater AUL

Non-Risk Objective	Achieved by Remedy?	Comment
Remediation Timeframe: None	Yes	
Regulatory Compliance: Achieve risk-based objectives	Yes	Institutional control required to prevent exposure to affected groundwater
Liability Control: Prevent exposure	Yes	Institutional control required to prevent exposure to affected groundwater
Property Use: Maintain current commercial use following remedy completion.	Yes	Consistent with current use of property
Cost effectiveness: <$1,000,000 total cost (including GW remedy)	Yes	Estimated Cost = $0 (Soil remedy cost only)
Remedy Acceptable?	Yes	

On-Site Groundwater: Natural Attenuation (AUL)

Non-Risk Objective	Achieved by Remedy?	Comment
Remediation Timeframe: None	Yes	
Regulatory Compliance: Achieve risk-based objectives	Yes	Institutional control required to prevent exposure to affected groundwater
Liability Control: Prevent exposure	Yes	Institutional control required to prevent exposure to affected groundwater
Property Use: Maintain current commercial use following remedy completion.	Yes	Consistent with current use of property

On-Site Groundwater: Natural Attenuation (AUL)

Non-Risk Objective	Achieved by Remedy?	Comment
Cost effectiveness:<$1 000 000 total cost (including soil remedy)	Yes	Estimated Cost = $5000/yr for 5 years = $25 000 (On-site groundwater remedy only)
Remedy Acceptable?	Yes	

Off-Site Groundwater: Pump and Treat

Non-Risk Objective	Achieved by Remedy?	Comment
Remediation Timeframe: 5 years	Yes	Pump and Treat likely to achieve required 10x concentration reduction to meet drinking water standards within 5 years.
Regulatory Compliance: Achieve risk-based objectives	Yes	No AULs needed following remedy completion
Liability Control: Prevent exposure	Yes	No AULs needed following remedy completion.
Property Use: Maintain current commercial use following remedy completion.	Yes	Consistent with current use of property
Cost effectiveness: <$1,000,000 total cost (including soil remedy)	Yes	Estimated Cost = Capital cost = $50 000 O&M Cost = $15 000/year for five years Total = $125 000 (Off-site GW remedy only)
Remedy Acceptable?	Yes	

Off-Site Groundwater: Natural Attenuation

Non-Risk Objective	Achieved by Remedy?	Comment
Remediation Timeframe: 5 years	No	Natural attenuation unlikely to achieve required 10× concentration reduction to meet drinking water standards within 5 years.
Regulatory Compliance: Achieve risk-based objectives	Yes	No AULs needed following remedy completion
Liability Control: Prevent exposure	Yes	No AULs needed following remedy completion.
Property Use: Maintain current commercial use following remedy completion.	Yes	Consistent with current use of property
Cost effectiveness: <$1,000,000 total cost (including soil remedy)	Yes	Estimated Cost = $5000/yr for 5 years = $25 000 (Off-site groundwater remedy only)
Remedy Acceptable?	No	Remedy not likely to achieve remediation timeframe imposed by off-site landowner

X1.9 Step 5B: Summary of Acceptable Remedies

Environmental Medium	Remedy	Estimated Cost
Soil	Excavation	$280 000
Soil	Groundwater Control Remedy (AUL)	$0
On-Site Groundwater	Natural Attenuation (AUL)	$25 000
Off-Site Groundwater	Pump & Treat	$125 000

X1.10 Step 6: Selected Remedy

Environmental Medium	Selected Remedy	Justification
Soil	Groundwater Control Remedy (AUL)	Selected over soil excavation based on cost considerations.
On-Site Groundwater	Natural Attenuation (AUL)	Only retained remedy.
Off-Site Groundwater	Pump & Treat	Only retained remedy.

X2. EXAMPLE TOOL FOR IDENTIFICATION OF THE OPTIMAL REMEDIAL ACTION

X2.1 Table X2.1 illustrates a remedial action scoring tool that can be used to select the optimal remedial action from the acceptable remedial actions identified in the remedy selection process.

X2.2 *Example Application*: For the Remedy Selection case study in Appendix X1, two acceptable remedies were identified for affected soils: *(1)* excavation and *(2)* groundwater control. This example illustrates the use of a scoring tool to select one of these two remedies for implementation. See Table X2.2.

X2.3 *Potential Soil Remedies*:

X2.3.1 *Groundwater Control*—Rely on groundwater containment remedy to control impacts associated with migration of benzene from soil to groundwater.

X2.3.2 *Excavation*—Excavate all soils with benzene concentrations above lowest remedial action level (0.026 mg/kg). Dispose of affected soils in appropriate landfill.

X2.4 *Conclusion*—Groundwater control selected for management of affected soils.

TABLE X2.1 Remedial Action Scoring Tool

Remedial Action	Acceptability of Technology		Applicability to Site		Effectiveness		Remediation Time		Cost		Total Score	Comments
	Discussion	Score	Discussion	Score	Discussion	Score	Discussion	Score	Discussion	Score		

Scoring Criteria:
Acceptability of Technology— Score technology based on compatibility with current site use, community concern, and other acceptability criteria.
Very acceptable (4 pts), acceptable (3 pts), somewhat acceptable (2 pts), marginally acceptable (1 pt)
Applicability to Site—Score technology based on implementability and reliability based on consideration of site setting. Has technology been implemented at similar sites?
Very applicable (4 pts), applicable (3 pts), somewhat applicable (2 pts), marginally applicable (1 pt)
Effectiveness—Score technology based on effectiveness at similar sites.
Very effective (4 pts), effective (3 pts), somewhat effective (2 pts), marginally effective (1 pt)
Remediation Time—Score technology based on expected remediation time.
Short (4 pts), intermediate (3 pts), long (2 pts), very long (1 pt)
Cost—Score technology based on expected lifecycle cost.
Low (4 pts), medium (3 pts), high (2 pts), very high (1 pt)

TABLE X2.2 Sample Remedial Action Scoring Tool

Remedial Action	Acceptability of Technology		Applicability to Site		Effectiveness		Remediation Time		Cost		Total Score	Comments
	Discussion	Score	Discussion	Score	Discussion	Score	Discussion	Score	Discussion	Score		
Groundwater Control	Containment technology relies on natural attenuation	2	No logistic constraints	4	Proven technology for petroleum impacts	3	Construction: None O&M: 3 yrs	3	$0K	4	16	
Excavation	Removal technology	4	Likely to impact existing structures and utilities	1	Proven technology for most COCs	3	Construction: 6 months O&M: None	4	$280K	1	13	

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