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Standard Guide for Risk-Based Corrective Action[1]

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INTRODUCTION

This guide provides guidance for the development of a Risk-Based Corrective Action (RBCA) program that integrates the sciences of ecological and human health risk-based decision making into the corrective action process. The RBCA provides a flexible, technically defensible framework for corrective action that is applicable to a wide range of sites and chemical(s) of concern. The framework incorporates a tiered analytical approach, applying increasingly complex levels of data collection and analysis as the user proceeds through the process. It provides a starting point for the integration of multiple regulatory programs into a site-wide corrective action activity and a technically defensible process for achieving "No Further Action." The successful implementation of the RBCA framework is dependent on an understanding by the user of the technical policy decisions that are critical to the risk management process and the identification and determination of these technical policy decisions prior to beginning the process (see 3.2.60). There are numerous technical policy decisions that must be made to implement the RBCA process, for example, defining data quality objectives, determining target risk levels and addressing resource protection. It is not the intent of this guide to define appropriate technical policy decisions. The RBCA process is not intended to replace existing regulatory programs, but rather to complement these programs. Regardless of whether a corrective action is specifically governed by a regulatory program, the user should consult the regulatory agency requirements to identify the appropriate technical policy decisions prior to implementing the RBCA process. The RBCA process encourages user-led initiatives and stakeholder involvement in both the development of the technical policy decisions and the RBCA program. It recognizes the diversity of sites and provides appendixes for possible applications and examples. The appendixes are provided for additional information and are not mandatory sections of this standard guide. ASTM standards are not federal or state regulations; they are consensus standards that can voluntarily be followed.

1. Scope

1.1 This is a guide for conducting risk-based corrective action (RBCA) at chemical release sites based on protecting human health and the environment. The RBCA is a consistent decision-making process for the assessment and response to chemical releases. Chemical release sites vary greatly in terms of complexity, physical and chemical characteristics, and in the risk that they may pose to human health and the environment. The RBCA process recognizes this diversity by using a tiered approach that integrates site assessment and response actions with human health and ecological risk assessment to determine the need for remedial action and to tailor corrective action activities to site-specific conditions and risks. The evaluations and methods used in the RBCA process begin with simple analyses in Tier 1 and move to more complex evaluations in either Tier 2 or Tier 3, as applicable. The process of gathering and evaluating data is conducted in a scaled fashion. Consequently, only the data that are necessary for a particular tier's decision-making are collected at that tier.

1.2 This guide describes an approach for risk-based corrective action. It is intended to help direct and streamline the corrective action process and to complement but not to supersede federal, state and local regulations. It can be employed at sites where corrective action is being conducted including sites where there may not be a regulatory framework for corrective action, or where the user wishes to conduct corrective action such as sites in voluntary cleanup programs or under Brownfields initiatives. In addition, it can also be used as a unifying framework when several different agency programs affect the site. Furthermore, the user should be aware of the federal, state and local corrective action programs that are applicable for the site and, regardless of the program, federal, state and local agency approvals may be required to implement

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the processes outlined in this guide. Finally, regardless of whether a corrective action is specifically governed by a regulatory program, the user should consult the regulatory agency requirements to identify the appropriate technical policy decisions prior to implementing the RBCA process.

1.3 There are numerous technical policy decisions that must be made to implement the RBCA process, for example, defining data quality objectives, determining target risk levels, specifying the appropriate statistics and sample sizes for calculating exposure concentrations, selection of exposure assumptions, determining when and how to account for cumulative risks and additive effects among chemical(s) of concern and addressing resource protection. It is not the intent of this guide to define appropriate technical policy decisions. The user must identify the appropriate technical policy decisions.

1.4 The general performance standard for this guide requires that:

1.4.1 Technical policy decisions be identified before beginning the process,

1.4.2 Data and information collected during the RBCA process, including historical data as well as new data collected during the site assessment, will be relevant to and of sufficient quantity and quality to answer the questions posed by and the decisions to be made in the RBCA process,

1.4.3 Actions taken during the risk-based decision process will be protective of human health and the environment,

1.4.4 Applicable federal, state and local regulations will be followed (for example, waste management requirements, ground water designations, worker protection) and,

1.4.5 Remedial actions implemented will not result in higher risk levels than existed before taking actions.

1.5 ASTM standards are not federal or state regulations, they are consensus standards that can voluntarily be followed.

1.6 The RBCA process is not limited to a particular class of compounds. This guide is intended to be a companion to Guide E 1739, and does not supersede that document for petroleum releases. If a release site contains a mixture of releases of petroleum and other chemicals, this guide should be followed.

1.7 The United States Environmental Protection Agency (USEPA) has developed guidance for human health risk evaluation (see Appendix X8 for other resources). Many of the components of this guidance have been integrated into the RBCA framework. The science of ecological evaluation and the process by which the science is applied, however, are not as well defined and agreed upon as human health risk assessment. Therefore, the information provided in this guide for each tier evaluation for relevant ecological receptors and habitats is general. The user is referred to Appendix X5, which provides additional information regarding the development of a RBCA framework for protection of ecological resources.

1.8 The decision process described in this guide integrates exposure and risk assessment practices with site assessment activities and remedial action selection to ensure that the chosen actions are protective of human health and the environment. The following general sequence of events is prescribed in RBCA:

1.8.1 Perform an initial site assessment and develop the first iteration of the site conceptual model. If the information is sufficient to demonstrate that there are no complete or potentially complete exposure pathways, then no further action is warranted,

1.8.2 Evaluate the site (see definition of site 3.2.50) for response actions (multiple sites at a single facility may require different response actions and times),

1.8.3 Implement a response action that is appropriate for conditions found at the site during the site response action evaluation,

1.8.4 Define data requirements, develop data quality objectives, and perform a site assessment for the Tier 1 evaluation if the site conceptual model indicates that the tiered evaluation is appropriate,

1.8.5 Conduct an exposure pathway analysis to determine if relevant ecological receptors and habitats are present and if complete and potentially complete exposure pathways are present. If no relevant ecological receptors or habitats or complete and potentially complete exposure pathways exist, then no further action for relevant ecological receptors and habitats is warranted,

1.8.6 For potential human exposure pathways, identify the applicable Risk Based Screening Levels (RBSL) and for potential ecological exposure pathways, identify the applicable Relevant Ecological Screening Criteria (RESC). In addition, identify any Other Relevant Measurable Criteria (ORMC), as applicable. Collectively these are the Tier 1 corrective action goals for the site;

1.8.7 Compare site conditions to the Tier 1 corrective action goals determined to be applicable to the site;

1.8.8 If site conditions meet the corrective action goals for chemical(s) of concern then, no further action is warranted,

1.8.9 If site conditions do not meet corrective action goals for chemical(s) of concern then, one or more of the following actions is appropriate:

1.8.9.1 Further tier evaluation;

1.8.9.2 Implement interim remedial action;

1.8.9.3 Design and implement remedial action to achieve the corrective action goals.

1.8.10 Define Tier 2 data requirements, data quality objectives, collect additional site-specific information and update the site conceptual model, as necessary, if further tier evaluation is warranted,

1.8.11 Develop point(s) of demonstration and Tier 2 corrective action goals based on Site-Specific Target Levels (SSTL), Site-Specific Ecological Criteria (SSEC) or ORMC, where appropriate, for complete and potentially complete exposure pathways, including exposure pathways for which no RBSL, RESC or ORMC, as applicable, were determined;

1.8.12 Compare site conditions to the Tier 2 corrective action goals determined to be applicable to the site;

1.8.13 If site conditions meet corrective action goals for chemical(s) of concern, then no further action is warranted,

1.8.14 If site conditions do not meet corrective action goals for chemical(s) of concern then, one or more of the following actions is appropriate:

1.8.14.1 Further tier evaluation;

1.8.14.2 Implement interim remedial action;

1.8.14.3 Design and implement remedial action to achieve the corrective action goals.

1.8.15 Define Tier 3 data requirements, data quality objectives and collect additional site-specific information and update the site conceptual model, as necessary, if further tier evaluation is warranted,

1.8.16 Develop point(s) of demonstration and Tier 3 corrective action goals based on SSTL, SSEC, or ORMC, where appropriate;

1.8.17 Compare site conditions to the Tier 3 corrective action goals,

1.8.18 If site conditions meet corrective action goals for chemical(s) of concern, then no further action is warranted,

1.8.19 If site conditions do not meet corrective action goals for chemical(s) of concern, then one of the following actions is appropriate:

1.8.19.1 Implement interim remedial action to facilitate reassessment of the tier evaluation;

1.8.19.2 Design and implement remedial action to achieve the corrective action goals.

1.8.20 Develop and implement a monitoring plan based on the corrective action goals to validate the assumptions used for the tier evaluation and to demonstrate effectiveness of the remedial action, as applicable.

1.9 For chemical release sites currently in corrective action, the user should review information and data available for the site and determine the most appropriate entry point into the RBCA framework consistent with the general performance standards and sequence of events outlined in this guide.

1.10 *This Guide is Organized as Follows*— Section 2 lists referenced documents, Section 3 defines terminology used in this guide, Section 4 describes the significance and use of this guide, Section 5 is a summary of the tiered approach, and Section 6 presents the RBCA procedures in a step-by-step process. Appendix X1 provides guidance on developing technical policy decisions and building a RBCA program, Appendix X2 provides examples of chemical properties and effects data that may be useful for a RBCA evaluation, Appendix X3 provides EXAMPLE development of RBSL, Appendix X4 describes the use of predictive modeling, Appendix X5 provides an outline of the process of the ecological evaluation, Appendix X6 provides information about activity and use limitations, Appendix X7 includes illustrative examples of the application of the RBCA framework, and Appendix X8 includes references that may be helpful to the user. The Appendixes are provided for additional information and are NOT included as mandatory sections of this guide.

2. Referenced Documents

2.1 *ASTM Standards:*

D 5447 Guide for Application of a Ground-Water Flow Model to a Site-Specific Problem[2]

D 5490 Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information[2]

D 5610 Guide for Defining Initial Conditions in Ground-Water Flow Modeling[2]

D 5611 Guide for Conducting a Sensitivity Analysis for a Ground Water Flow Model Application[2]

D 5612 Guide for Quality lanning and Field Implementation of a Water Quality Measurement Program[3]

D 5718 Guide for Documenting a Ground-Water Flow Model Application[2]

D 5880 Guide for Subsurface Flow and Transport Modeling[2]

D 6235 Practice for Expedited Site Characterization of Vadose Zone and Ground Water Contamination at Hazardous Waste Contaminated Sites[2]

E 978 Practice for Evaluating Mathematical Models for the Environmental Fate of Chemicals

E 1527 Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process[4]

E 1599 Guide for Corrective Action for Petroleum Releases[4]

E 1689 Guide for Developing Conceptual Site Models for Contaminated Sites[5]

E 1739 Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites[4]

E 1903 Guide for Environmental Site Assessments: Phase II Environmental Site Assessment Process[4]

E 1912 Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases[4]

E 1943 Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites[4]

3. Terminology

3.1 The reader should review the definitions presented here prior to reviewing the guide, as many of the terms included in this guide may have different meanings than the specific regulatory definitions within existing federal, state or local programs. The following terms are being defined to reflect their specific use in this guide. The user should not assume that these definitions replace existing regulatory definitions. Where the definition or use of a term in this guide differs from an existing regulatory definition or use, the user should address these differences prior to proceeding with the RBCA process.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *activity and use limitations*—Legal or physical restrictions or limitations on the use of, or access to, a site or facility to eliminate or minimize potential exposures to chemical(s) of concern, or to prevent activities that could interfere with the effectiveness of a remedial action, to ensure maintenance of site conditions that meet the corrective goals for chemical(s) of concern. These legal or physical restrictions are intended to prevent adverse impacts to receptors and relevant ecological receptors and habitats that may be exposed to chemical(s) of concern. Activity and use limitations include both engineering and institutional controls.

3.2.2 *additive effects*—refers to combined non-cancer effects of chemical(s) of concern with the same mechanism of action in a receptor.

[2] *Annual Book of ASTM Standards*, Vol 04.09.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 11.04.

[5] *Annual Book of ASTM Standards*, Vol 11.05.

3.2.3 *bio-availability*—a measure of the chemical(s) of concern in environmental media that is accessible to an organism for absorption.

3.2.4 *biodegradation*—Natural plant, animal, or microbial metabolism that results in the reduction of mass of a chemical(s) of concern.

3.2.5 *chemical release*—Any spill or leak or detection of concentrations of chemical(s) of concern in environmental media.

3.2.6 *chemical(s) of concern*—The specific compounds and their breakdown products that are identified for evaluation in the RBCA process. Identification can be based on their historical and current use at a site, detected concentrations in environmental media and their mobility, toxicity, and persistence in the environment. Because chemical(s) of concern may be identified at many points in the RBCA process, including before any determination that they pose an unacceptable risk to human health or the environment, the term should not automatically be construed to be associated with increased or unacceptable risk.

3.2.7 *corrective action*—The sequence of actions that include site assessment and investigation, risk assessment, response actions, interim remedial action, remedial action, operation and maintenance of equipment, monitoring of progress, making no further action determinations and termination of the remedial action.

3.2.8 *corrective action goals*—concentration or other numeric values, physical condition or remedial action performance criteria that demonstrate that no further action is necessary to protect human health and the environment. For example, these goals may include one or a combination of RBSL, SSTL, RESC, SSEC and ORMC chosen for source area(s), point(s) of demonstration and point(s) of exposure. The corrective action goals are specific to each Tier in the evaluation.

3.2.9 *cumulative risks*—refers to the combined carcinogenic risks from all exposure pathways for all chemicals for a receptor.

3.2.10 *direct exposure pathways*—An exposure pathway where the point of exposure is at the source, without a release to any other medium and without an intermediate biological transfer step.

3.2.11 *ecological evaluation*—A process for organizing and analyzing data, information, assumptions and uncertainties to evaluate the likelihood that adverse effects to relevant ecological receptors or habitats may occur or are occurring as a result of exposure to chemical(s) of concern.

3.2.12 *engineering controls*—Physical modifications to a site or facility to reduce or eliminate the potential for exposure to chemical(s) of concern (for example, slurry walls, capping, hydraulic controls for ground water, or point-of-use water treatment).

3.2.13 *exposure assessment*—The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration and route of exposure between a source area and a receptor.

3.2.14 *exposure pathway*—The course a chemical of concern takes from the source area(s) to a receptor or relevant ecological receptor and habitat. An exposure pathway describes the mechanism by which an individual or population is exposed to a chemical of concern originating from a site. Each exposure pathway includes a source or release from a source of a chemical of concern, a point of exposure, an exposure route and the potential receptors or relevant ecological receptors and habitats. If the exposure point is not at the source, a transport or exposure medium, or both, (for example, air or water) are also included.

3.2.15 *exposure route*—The manner in which a chemical(s) of concern comes in contact with a receptor (for example, ingestion, inhalation, dermal contact).

3.2.16 *exposure scenario*—The description of the circumstances, including site properties and chemical properties, or the potential circumstances under which a receptor or a relevant ecological receptor or habitat could be in contact with chemical(s) of concern;

3.2.17 *facility*—The property containing the source of the chemical(s) of concern where a release has occurred. A facility may include multiple sources and therefore, multiple sites.

3.2.18 *guide*—a series of options or instructions that do not recommend a specific course of action.

3.2.19 *hazard index*—The sum of two or more hazard quotients for chemical(s) of concern or multiple exposure pathways to a particular receptor, or both.

3.2.20 *hazard quotient*—The ratio of the level of exposure of a chemical of concern over a specified time period to a reference dose for that chemical of concern derived for a similar exposure period.

3.2.21 *incremental carcinogenic risk levels*—The potential for incremental human carcinogenic effects, over background cancer occurrence levels, due to exposure to the chemical(s) of concern. This is the individual lifetime excess cancer risk.

3.2.22 *indirect exposure pathways*—An exposure pathway with at least one intermediate release to any media, or an intermediate biological transfer step, between the source and the point(s) of exposure (for example, chemical(s) of concern from soil through ground water to the point(s) of exposure).

3.2.23 *institutional controls*—A legal or administrative restriction on the use of, or access to a site or facility to eliminate or minimize potential exposure to a chemical(s) of concern (for example, restrictive covenants, restrictive zoning).

3.2.24 *interim remedial action*—The course of action taken to reduce migration of a chemical(s) of concern in its vapor, dissolved, or liquid phase, or to reduce the concentration of a chemical(s) of concern at a source area(s).

3.2.25 *maximum contaminant level (MCL)*—A standard for drinking water established by USEPA under the Safe Drinking Water Act which is the maximum permissible level of a chemical(s) of concern in water which is delivered to any user of a public water supply.

3.2.26 *natural attenuation*—The reduction in the concentration(s) of chemicals of concern in environmental media due to naturally occurring physical, chemical and biological processes (for example, diffusion, dispersion, adsorption, chemical degradation and biodegradation).

3.2.27 *non-aqueous phase liquids (NAPL)*—Chemicals that are insoluble or only slightly soluble in water that exist as a

separate liquid phase in environmental media. They can be less dense or more dense than water.

3.2.28 *other relevant measurable criteria (ORMC)*—Parameters used to define corrective action goals for chemical(s) of concern. The ORMC are concentration values, other numeric values, physical condition or performance criteria other than RBSL, RESC, SSTL or SSEC. Examples of ORMC are regulatory standards, consensus criteria, aesthetic criteria, and ground water protection criteria. Technical policy decisions regarding ORMC may exist, or may need to be made to determine the appropriate values, conditions or performance criteria that are used for the corrective action goals.

3.2.29 *petroleum*—Includes crude oil or any fraction thereof that is liquid at standard conditions of temperature and pressure (60 °F (15.6°C) and 14.7 lb/in.^{2} absolute (10 340 kg/m^2)). The term includes petroleum-based substances comprised of a complex blend of hydrocarbons derived from crude oil through processes of separation, conversion, upgrading, and finishing, (for example, motor fuels, jet fuels, lubricants, petroleum solvents, used oils).

3.2.30 *point(s) of demonstration*—A location(s) selected between the source area(s) and the potential point(s) of exposure where corrective action goals are met.

3.2.31 *point(s) of exposure*—The point(s) at which an individual or population may come in contact with a chemical(s) of concern originating from a site.

3.2.32 *potentially complete exposure pathway*—A situation with a reasonably likely chance of occurrence in which a receptor or relevant ecological receptor or habitat may become directly or indirectly exposed to the chemical(s) of concern.

3.2.33 *practice*—a definitive procedure for performing one or more specific operations or functions that does not produce a test result.

3.2.34 *probabilistic evaluation*—A modeling procedure used to evaluate the uncertainty surrounding a probability distribution when the result depends on a number of factors, each of which has its own variability and uncertainty.

3.2.35 *qualitative ecological screening evaluation*—A process conducted as part of the Tier 1 evaluation wherein relevant ecological receptors and habitats and exposure pathways are identified. The necessary information can be collected as part of the data gathering activities during the initial site assessment or the Tier 1 site assessment (6.3.2 and 6.3.3). Within Tier 1, this screening-level information, which is typically qualitative, may be used to evaluate potential exposure pathways to relevant ecological receptors and habitats and to identify potential chemical(s) of concern. If available, generic, non-site-specific ecological criteria and guidelines (3.2.42) may be used to further evaluate complete and potentially complete exposure pathways.

3.2.36 *qualitative risk analysis*—A non-quantitative evaluation of the potential risks at a site as determined by the potential exposure pathways and receptors based on known or reasonably available information.

3.2.37 *reasonable maximum exposure (RME)*—The highest exposure that is reasonably expected to occur at a site. RME's are estimated for individual exposure pathways or a combination of exposure pathways.

3.2.38 *reasonably anticipated future use*—Future use of a site or facility which can be predicted with a reasonably high degree of certainty given historical use, current use, and local government planning and zoning.

3.2.39 *receptors*—The persons that are or may be affected by a release. (see relevant ecological receptors and habitats, 3.2.41, for non-human receptor definition).

3.2.40 *reference dose*—A toxicity value for evaluating potential non-carcinogenic effects in humans resulting from exposure to a chemical(s) of concern.

3.2.41 *relevant ecological receptors and habitats*—The ecological resources that are valued at the site. Because of the variety of ecological resources that may be present, focusing upon those relevant to a site is an important part of the problem formulation phase of ecological evaluation. Identification of relevant ecological receptors and habitats is dependent upon site-specific factors and technical policy decisions. Examples may include species or communities afforded special protection by law or regulation; recreationally, commercially or culturally important resources; regionally or nationally rare communities; communities with high aesthetic quality; and habitats, species or communities that are important in maintaining the integrity and bio-diversity of the environment.

3.2.42 *relevant ecological screening criteria (RESC)*—Generic, non-site specific ecological criteria or guidelines that are determined to be applicable to relevant ecological receptors and habitats, exposure pathways and site conditions utilized during the Tier 1 evaluation. These may include chemical concentrations, biological measures or other relevant generic criteria consistent with the technical policy decisions.

3.2.43 *remedial action*—Activities conducted to reduce or eliminate current or potential future exposures to receptors or relevant ecological receptors and habitats. These activities include monitoring, implementing activity and use limitations and designing and operating clean-up equipment. Remedial action includes activities that are conducted to reduce sources of exposures to meet corrective action goals, or sever exposure pathways to meet corrective action goals.

3.2.44 *response action*—An immediate course of action, including monitoring, abatement or containment measures to mitigate known or potential hazards to human health, safety and the environment, taken before interim remedial action or remedial action.

3.2.45 *response action evaluation*—A qualitative analysis of a site, based on known or readily available information, to identify the need for and urgency of response actions and the need for further information gathering. The analysis is also used to identify appropriate early risk reduction steps.

3.2.46 *risk*—The potential for, or probability of, an adverse effect. These may be expressed qualitatively or quantitatively.

3.2.47 *risk assessment*—An analysis of the potential for adverse effects on receptors and relevant ecological receptors and habitats caused by a chemical(s) of concern from a site. The risk assessment activities are the basis for the development of corrective action goals and determination of where interim remedial actions, remedial action or a combination of actions are required.

3.2.48 *risk reduction*—The lowering or elimination of the level of risk posed to human health or the environment through, response actions, interim remedial actions, remedial action or a combination of actions.

3.2.49 *risk-based screening level/screening levels (RBSL)*—Non-site-specific human health risk-based values for chemical(s) of concern that are protective of human health for specified exposure pathways utilized during the Tier 1 evaluation.

3.2.50 *site*—The area(s) defined by the likely physical distribution of the chemical(s) of concern 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.

3.2.51 *site assessment*—A characterization of a site through an evaluation of its physical and environmental context (for example, subsurface geology, soil properties and structures, hydrology, and surface characteristics) to determine if a release has occurred, the levels of the chemical(s) of concern in environmental media, and the likely physical distribution of the chemical(s) of concern. As an example, the site assessment collects data on soil, ground water and surface water quality, land and resource use, potential receptors, and potential relevant ecological receptors and habitats, and generates information to develop a site conceptual model and to support risk-based decision-making. The user is referred to Guides E 1912 and D 6235 and other references in Appendix X8 for more information.

3.2.52 *site conceptual model*—The integrated representation of the physical and environmental context, the complete and potentially complete exposure pathways and the potential fate and transport of chemical(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.

3.2.53 *site conditions*—A general description of a site's chemical, physical or biological characteristics that relate to potential exposures to receptors or relevant ecological receptors and habitats.

3.2.54 *site-specific*—Activities, information and data unique to a particular site.

3.2.55 *site-specific ecological criteria (SSEC)*—Risk-based qualitative or quantitative criteria for relevant ecological receptors and habitats identified for a particular site under the Tier 2 or Tier 3 evaluations. These may include chemical concentrations, biological measures or other relevant generic criteria consistent with the technical policy decisions. SSEC may be revised as data are obtained that better describe the conditions and the relevant ecological receptors and habitats.

3.2.56 *site-specific target levels (SSTL)*—Risk-based values for chemical(s) of concern that are protective of human health for specified exposure pathways developed for a particular site under the Tier 2 or Tier 3 evaluations.

3.2.57 *source area(s)*—The source area(s) is defined as the location of non-aqueous phase liquid (NAPL) chemical, the locations of highest soil or ground water concentrations of the chemical(s) of concern or the location releasing the chemical(s) of concern.

3.2.58 *stakeholders*—Individuals, organizations or other entities that directly affect or are directly affected by the corrective action. Stakeholders include, but are not limited to, owners, buyers, developers, lenders, insurers, government agencies and community members and groups.

3.2.59 *standard*—As used in ASTM, a document that has been developed and established within the consensus principles of the Society and that meets the approval requirements of ASTM procedures and regulations.

3.2.60 *technical policy decisions*—The choices specific to the user that are necessary to implement the Risk-Based Corrective Action framework described in this guide at a particular site. The decisions involve regulatory policies, value judgments, different stakeholder decisions and using professional judgment to evaluate available information, therefore, there may be more than one scientifically supportable answer for any particular technical policy decision. The choices represent different approaches. The user should consult the regulatory agency requirements to identify the appropriate technical policy decisions prior to implementing the RBCA process. Examples of technical policy decisions are, data quality objectives, target risk levels, land use, ground water use, natural resource protection, relevant ecological receptors and habitats, stakeholder notification and involvement and exposure factors.

3.2.61 *Tier 1 Evaluation*—A risk-based analysis utilizing non-site-specific corrective action goals for complete and potentially complete direct and indirect human exposure pathways and qualitative ecological screening evaluation for complete and potentially complete exposure pathways for relevant ecological receptors and habitats. The non-site-specific corrective action goals developed for human exposure pathways are based on conservative assumptions (for example, exposure factors, fate and transport parameters) and methodologies (for example, algorithms, analytical models) to estimate the non-site-specific values. The Tier 1 exposure pathways for human receptors assume that the receptor and the source are located in the same location. A qualitative ecological screening evaluation is conducted that may be combined with RESC to evaluate the potential exposures to relevant ecological receptors and habitats. The Tier 1 evaluation for some chemical(s) of concern or exposure pathways may also be based on comparison of site conditions to ORMC. The non-site-specific corrective action goals for complete and potentially complete exposure pathways are compared to site conditions to determine if further corrective action is warranted.

3.2.62 *Tier 2 Evaluation*—A risk-based analysis that involves an incremental refinement of the Tier 1 methodology to develop site-specific corrective action goals. The Tier 2 evaluation for human exposure pathways may include developing statistically representative concentrations of chemical(s) of concern for comparison to the Tier 1 corrective action goals, back-calculating SSTL by applying the direct exposure pathway corrective action goals established under a Tier 1 evaluation at site-specific determined point(s) of exposure, developing SSTL for potential indirect exposure pathways at point(s) of exposure using site-specific conditions and the Tier 1 methodology, or developing SSTL for complete or potentially complete exposure pathways using site-specific conditions for which no RBSL were developed in Tier 1, or the evaluation may employ a combination of alternatives. For relevant ecological receptors and habitats, the Tier 2 evaluation may involve additional qualitative or quantitative analyses. The Tier 2 evaluation for some chemical(s) of concern and exposure pathways may also be based on comparison of site conditions to ORMC. The corrective action goals for complete and potentially complete exposure pathways are compared to site conditions to determine if further corrective action is warranted.

3.2.63 *Tier 3 Evaluation*—A risk-based analysis that involves a significant incremental effort over the Tier 2 evaluation to develop site-specific corrective action goals. The Tier 3 evaluation for human exposure pathways typically uses advanced exposure assessment, toxicity and risk assessment techniques (for example, probabilistic exposure assessment methods, use of bio-availability data, use of advanced fate and transport modeling) allowing maximum flexibility to develop SSTL for potential direct and indirect exposure pathways at the point(s) of exposure based on site-specific conditions. A Tier 3 evaluation for relevant ecological receptors and habitats is typically more quantitative in nature and uses more site-specific data than previous tiers. The Tier 3 evaluation for some chemical(s) of concern and exposure pathways may also be based on comparison of site conditions to ORMC. The corrective action goals for complete and potentially complete exposure pathways are compared to site conditions to determine if further corrective action is warranted.

3.2.64 *user*—An individual or group involved in the RBCA process including owners, operators, regulators, UST fund managers, federal government case managers, attorneys, consultants, legislators and other stakeholders. Two specific cases of users are envisioned. The first is the individual or group addressing a site or sites under the circumstances where there is no specific agency program or there are multiple agency programs applicable to their project. The second is a regulatory agency that is developing a comprehensive corrective action program.

4. Significance and Use

4.1 The risk-based corrective action (RBCA) process presented in this guide is a consistent, streamlined decision process for selecting corrective actions at chemical release sites.

4.2 Risk assessment is a developing science. The scientific approach used to develop the RBSL and SSTL may vary by regulatory agency and by user due to regulatory requirements, guidance and use of alternative scientifically-based methods.

4.3 Activities described in this guide should be conducted by persons familiar with current site characterization techniques, remedial action science and technology, current human health risk and exposure assessment methodologies, toxicology, and current ecological evaluation methodologies.

4.4 In order to properly apply the RBCA process, the user should **AVOID** the following:

4.4.1 Prescribing Tier 1 RBSL or RESC as remedial action standards for all sites rather than screening levels,

4.4.2 Limiting use of the RBCA process to Tier 1 evaluation only and not continuing with Tier 2 or Tier 3 analyses for sites where further tier evaluation is appropriate,

4.4.3 Placing arbitrary time constraints on the corrective action process; for example, requiring that Tiers 1, 2, and 3 be completed within time periods that do not reflect the actual urgency of and risks posed by the site,

4.4.4 Using the RBCA process only when active remedial action is not technically feasible, rather than as a process that is applicable during all phases of corrective action,

4.4.5 Conducting active remedial action to achieve only technology-based remedial limits (for example, asymptotic levels) prior to determining applicable corrective action goals,

4.4.6 Using predictive modeling that is not supported by available data or knowledge of site conditions,

4.4.7 Limiting remedial action options to a single class of remedial actions for all sites,

4.4.8 Using unjustified or inappropriate exposure factors,

4.4.9 Using unjustified or inappropriate toxicity parameters,

4.4.10 Failing to consider cumulative risks and additive effects when evaluating multiple chemicals,

4.4.11 Excluding the evaluation of options for activity and use limitations, point(s) of exposure, point(s) of demonstration, sequencing remedial action activities at multiple sites on the same facility, or risk levels,

4.4.12 Excluding the maintenance and monitoring of activity and use limitations,

4.4.13 Failing to consider the long-term effectiveness and reliability of potential remedial action options,

4.4.14 Failing to evaluate potential risks to the public, to workers and to relevant ecological receptors and habitats that may be created by proposed remedial actions or assessment methods and

4.4.15 Continuing monitoring or remedial action at sites that have achieved the corrective action goals (unless monitoring is specifically required for an activity and use limitation or another regulatory requirement). Achievement of corrective action goals is predicated on sufficient monitoring to substantiate the site conditions.

4.5 The RBCA process described in this guide includes several features that are only examples of standardized approaches to addressing the objectives of the particular activity, for example, the response action evaluation table and the exposure scenario evaluation flowchart. These elements should be customized by the user based on the constraints of the site

or group of sites being addressed and the appropriate technical policy decisions. The objectives of the analyses are identified in this guide.

5. A Tiered Approach to Risk-Based Corrective Action (RBCA)

5.1 Risk-based corrective action is the integration of site assessment, remedial action selection, and monitoring with appropriate risk and exposure assessment practices. This creates a process by which corrective action decisions are made in a consistent manner that is protective of human health and the environment. Prior to implementing the RBCA process, the user must identify the relevant technical policy decisions appropriate for the site (see 1.2, 1.3 and Appendix X1). The user should also identify the appropriate stakeholder notification and involvement process to provide information and to collect input during the implementation of the RBCA process.

5.2 The RBCA process is implemented in a tiered approach, involving increasingly sophisticated levels of data collection and analysis as the user proceeds through the tiers. At each further tier of evaluation, the assumptions of earlier tiers are replaced with additional site-specific data and information.

5.3 There is some degree of uncertainty associated with all risk estimates and site assessments. In the RBCA process it is necessary for the user to address uncertainty through the level of conservatism applied to each tier. As the user moves through the tier evaluation process, the level of conservatism should decrease as the uncertainty decreases. The uncertainty should be clearly articulated during each tier of evaluation. The analysis of uncertainty allows the user to determine if the information obtained is adequate to make a decision. As the user proceeds to higher tiers, the knowledge gained about the site is used to tailor the degree of investigation needed, as explained in the following sections. In some cases, after completion of the Tier 1 evaluation, the user may find it appropriate for some exposure pathways to proceed directly to a Tier 3 evaluation. As contemplated here, the results of all of the completed tiers of analyses would be compiled into one RBCA report at the end of the evaluation. Reporting requirements and approvals must be determined based on the particular federal, state and local programs that apply to the site.

6. Risk-Based Corrective Action (RBCA) Procedures

6.1 The sequence of principal tasks and decisions associated with the RBCA process are outlined on the flowcharts shown in Fig. 1 and Fig. 2. Each of these actions and decisions is discussed as follows. Prior to implementing these actions, the user should identify the appropriate stakeholder notification and involvement process to provide information and to collect input during the implementation of the RBCA process. Information is gathered in the initial site assessment to develop the site conceptual model.

6.2 *Initial Site Assessment*—The initial site assessment is a planning and scoping activity to develop the site conceptual model, (for example, identifying potential transport pathways and potential receptors) based on the initial understanding of the site. The planning and scoping activity is a critical part of implementing the technical policy decisions due to the potential complexity of human and ecological exposure pathways. This is especially important for ecological issues due to the variety of relevant ecological receptors and habitats. Information collected during the initial site assessment may identify incomplete exposure pathways that may eliminate the need for any further evaluation of one or more exposure pathways or the site. For example, some regulatory agencies specify processes to define incomplete exposure pathways or define minimum criteria, threshold quantities or concentrations of a chemical release as an exclusion from or entry to a further RBCA analysis for a site. If the information is sufficient to demonstrate that there are no complete or potentially complete exposure pathways, then no further action is warranted. If minimum criteria, threshold quantities or concentrations that define exclusion from a RBCA analysis are available and site conditions meet these criteria, thresholds or concentrations, as applicable, then no further action is warranted for the site.

6.2.1 The initial site assessment should include a review of known or reasonably available information on:

6.2.1.1 Appropriate regulatory requirements;

6.2.1.2 Historical site activities, past releases and prior site assessment information to identify potential chemical(s) of concern, sources of the chemical(s) of concern, source area(s), human receptors and relevant ecological receptors and habitats, and fate and transport mechanisms;

6.2.1.3 Potential current and reasonably anticipated future use of the site and surrounding land;

6.2.1.4 Potential ground water and surface water use; and

6.2.1.5 Regional hydrogeologic and geologic characteristics, (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units and ground water quality).

6.3 *Site Conceptual Model*—The site conceptual model is developed to provide an overall understanding of the site and includes the hypotheses that form the basis of the RBCA evaluation. It is also used to communicate the understanding of the site to the stakeholders. Through the site conceptual model the user identifies the complete and potentially complete exposure pathways. The site conceptual model provides a template 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. It also provides a means to identify potential Response Actions (see 6.6). The site conceptual model is developed as part of the initial site assessment and is updated as additional data are gathered throughout the RBCA process. Subsequent site assessment activities are conducted to refine the site conceptual model and conduct the tier analyses.

6.3.1 *Exposure Pathway Evaluation—The user is responsible for identifying the complete and potentially complete exposure pathways for a site.* An EXAMPLE exposure pathway evaluation flowchart is presented in Fig. 3, and it may be used as a tool to guide the user in selecting appropriate exposure scenarios based on site assessment information. *This figure is only presented as an example of the kind of visual representation that may be useful in the evaluation of exposure pathways.* Other types or forms of charts or tables may also be used in the evaluation.

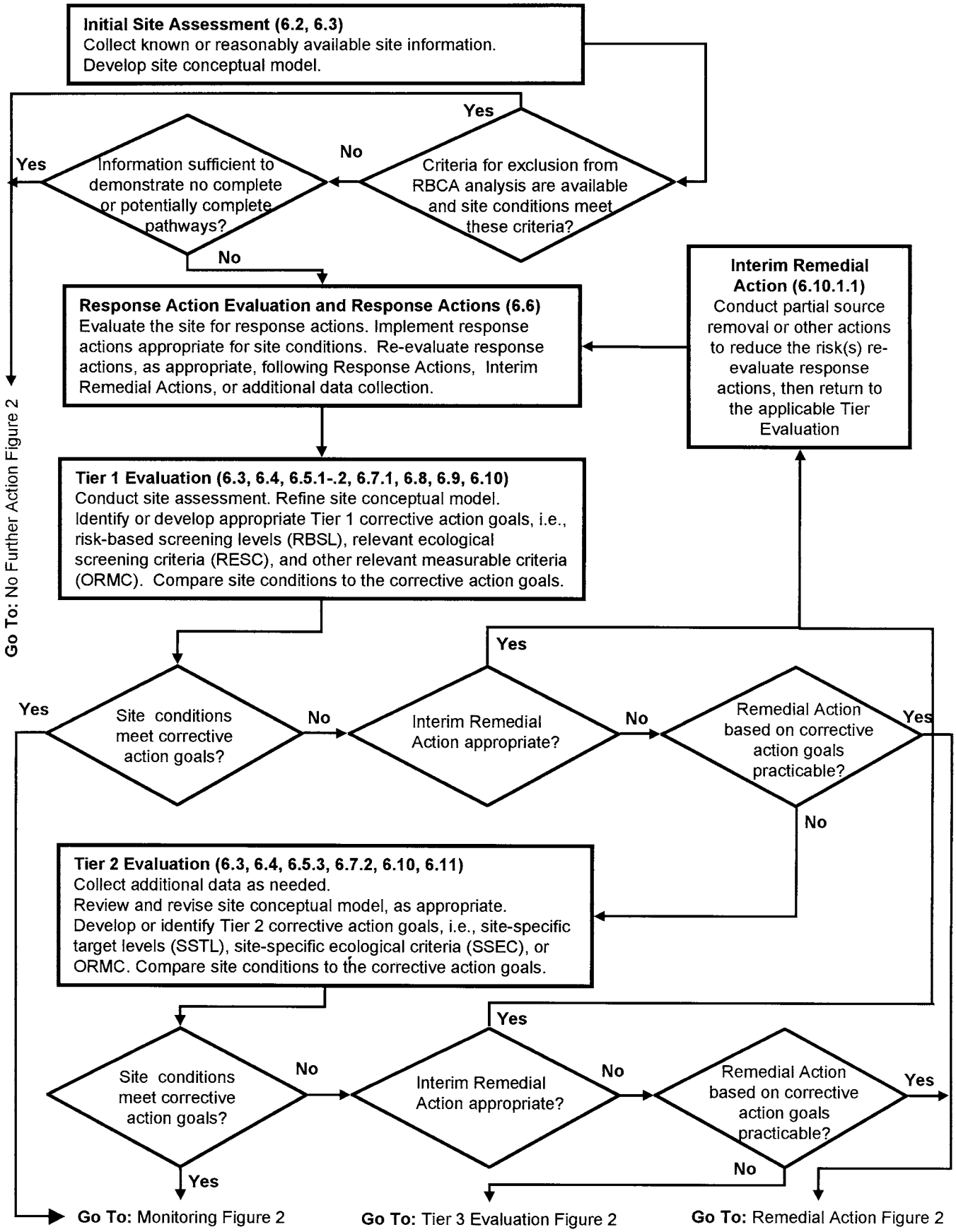


FIG. 1 RBCA Flowchart (After E 1739-95)

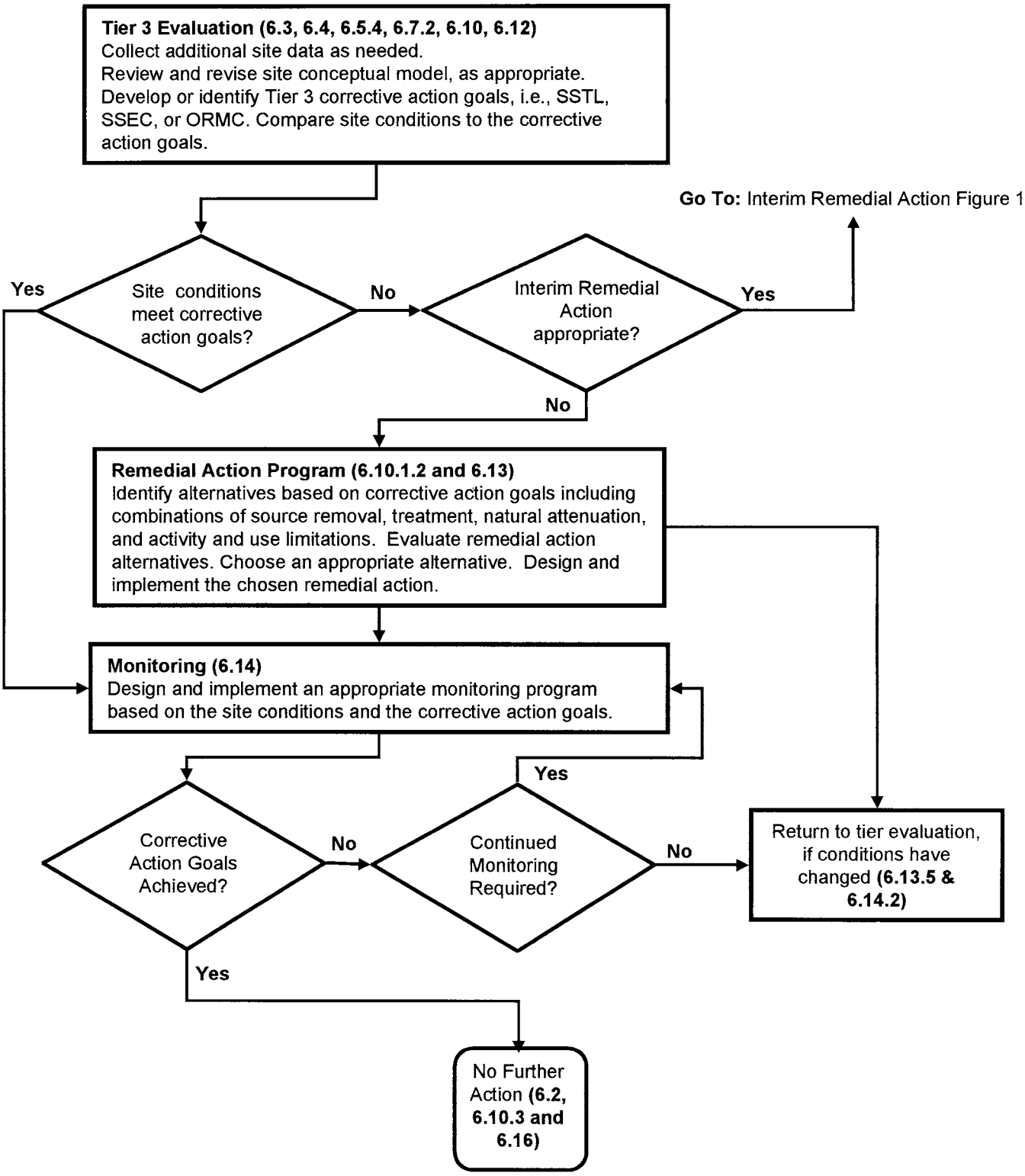
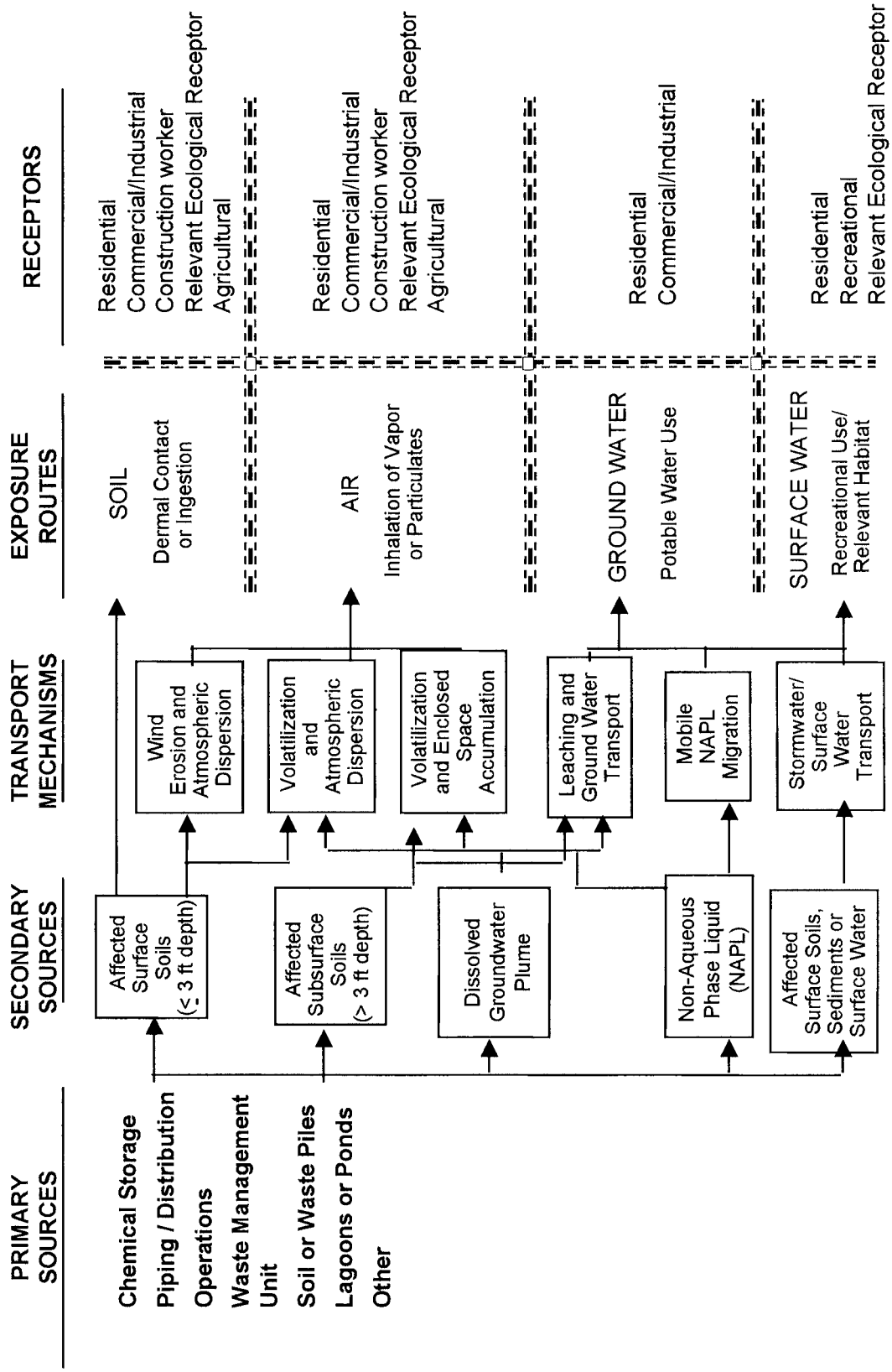


FIG. 2 RBCA Flowchart (Continued) (After E 1739-95)

6.3.1.1 *Identify Receptors*—To identify receptors and relevant ecological receptors and habitats, consider current and reasonably anticipated future site and surrounding land use.

6.3.1.2 *Characterize Site Sources and Exposure Pathways*—Use the data and information collected throughout the RBCA process to identify relevant sources, transport



The current and reasonably anticipated future land use must be considered in completing this flowchart evaluation. (After E1739-95)

FIG. 3 Example Exposure Scenario Evaluation Flowchart

mechanisms, and exposure pathways. More than one flow chart may be needed to correspond to multiple sources with different exposure pathways.

6.3.2 In each successive tier of evaluation the complete and potentially complete exposure pathways are re-evaluated in light of the additional data collected. Further evaluations are not conducted for exposure pathways determined to be incomplete.

6.4 *Data Quality Objectives*—Throughout the RBCA process, appropriate data quality objectives should be determined for the task that is being conducted. These objectives integrate the site specificity of data needed for each task and applicable regulatory requirements. The user may generate site-specific data and information or estimate reasonable values for key physical characteristics using soil survey data and other reasonably available information. Sufficient quantity and quality of data should be collected during the RBCA process to meet the data quality objectives for any aspect of the RBCA evaluation. In addition, the quality and quantity of data collected must be consistent with the objectives of the particular task within the RBCA evaluation. The user is referred to Guide E 1912 and Ref **(1)**[6] and other references for more information.

6.5 *Site Assessment*—In general, the site assessment gathers the information necessary to implement the RBCA analyses. Among the tasks for which site assessment data are used are: refining the site conceptual model, determining appropriate response actions, performing human health and ecological risk evaluations and making decisions for further tier evaluation, no further action, interim remedial action or remedial action for the complete and potentially complete exposure pathways. State and local government and local community sources should be consulted, as appropriate, in the collection of the site assessment information. Adequate site assessment is critical to the RBCA process to identify sources of chemical(s) of concern that may exist at the site. The site assessment data should be summarized in a clear and concise format (for example, using Fig. 3 or Guide E 1689). The site assessment is limited to gathering only the information necessary at each tier to evaluate the complete or potentially complete exposure pathways identified in the site conceptual model.

6.5.1 If complete or potentially complete exposure pathways are identified during the site conceptual model development indicating that the tiered evaluation is appropriate, then a site assessment for the Tier 1 evaluation should be conducted. The purpose of the site assessment is to gather information relevant to the evaluation of the complete and potentially complete exposure pathways defined by the site conceptual model. The information collected should also be used to improve the understanding of the site through refinements to the site conceptual model. The site assessment for Tier 1 should include information to:

6.5.1.1 Identify chemical(s) of concern;

6.5.1.2 Locate sources of the chemical(s) of concern and source area(s), to the extent practicable;

6.5.1.3 Locate maximum concentrations of chemical(s) of concern in different media (for example, air, soil, soil gas, surface water, sediments, ground water);

6.5.1.4 Locate human receptors and relevant ecological receptors and habitats that could be impacted;

6.5.1.5 Identify potentially significant transport and human and ecological exposure pathways (for example, ground water transport, vapor migration through soils and utilities);

6.5.1.6 Identify current and reasonably anticipated future use of the site and surrounding land. This identification should include an evaluation of ground water resources, surface water and relevant ecological receptors and habitats;

6.5.1.7 Identify state or local ground water classifications, options for alternative classifications or designations applicable to the site; and

6.5.1.8 Determine regional and site-specific hydrogeologic and geologic characteristics, (for example, depth to ground water, aquifer thickness, flow direction, gradient, description of confining units and ground water quality).

6.5.2 The site assessment for Tier 1 may also collect information to:

6.5.2.1 Calculate an appropriate upper confidence limit on concentration data for chemical(s) of concern, if sufficient data are available;

6.5.2.2 Determine background concentrations of chemical(s) of concern in environmental media (see Appendix X1);

6.5.3 The purpose of the site assessment under Tier 2 is to gather information relevant to the complete and potentially complete exposure pathways defined by the site conceptual model and determined, based on the Tier 1 results, to require further tier evaluation. The information collected should also be used to improve the understanding of the site through refinements to the site conceptual model. In addition to the information gathered under 6.2, 6.5.1 and 6.5.2 and updates to that information, if the Tier 2 evaluation is appropriate, the site assessment should collect information to:

6.5.3.1 Determine site-specific hydrogeologic and geologic characteristics (for example, depth to ground water, aquifer thickness, hydraulic conductivity, flow direction and velocity, gradient, description of lithology and confining units and ground water quality);

6.5.3.2 Determine concentrations of chemical(s) of concern in environmental media, and site conditions relative to the corrective action goals;

6.5.3.3 Determine changes in concentrations of chemical(s) of concern over time (for example, stable, increasing, decreasing);

6.5.3.4 Determine concentrations of chemical(s) of concern measured at point(s) of exposure (for example, concentrations in nearby drinking water wells, concentrations in surface water or vapor concentrations in nearby conduits or sewers);

6.5.3.5 Evaluate complete and potentially complete exposure pathways for human receptors and relevant ecological receptors and habitats to refine the list of complete and potentially complete exposure pathways and determine those that are incomplete exposure pathways, and;

6.5.3.6 Determine point(s) of demonstration (see 3.2.30).

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

6.5.4 The purpose of the site assessment under Tier 3 is to gather information relevant to the complete and potentially complete exposure pathways defined by the site conceptual model and determined, based on the Tier 2 results, to require further tier evaluation. The information collected should also be used to improve the understanding of the site through refinements to the site conceptual model. In addition to the information gathered under 6.2, 6.5.1, 6.5.2 and 6.5.3, if the Tier 3 evaluation is appropriate, the site assessment may include significant additional information collection required for site-specific modeling efforts.

6.6 *Response Action Evaluations and Response Actions*—As the user gathers data, site conditions should be evaluated and a response action should be implemented, consistent with site conditions and simultaneously with the tiered evaluation process to mitigate known or potential hazards. Sites are first evaluated by the need and urgency for response action based on information collected during the initial site assessment. This process is repeated when new data indicate a significant change in site conditions, as additional data affords a more detailed characterization of the site, or after interim remedial actions. Table 1 presents EXAMPLE site conditions and potential responses.

NOTE 1—The response actions given in Table 1 are only examples. The user should select options that best address the short-term human health, safety and environmental concerns of the site while implementing the RBCA process.

TABLE 1 Example Site Conditions and Response Actions

Site Conditions	Example Response Actions
Immediate threat to human health, safety, or relevant ecological receptors and habitats	Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
• Explosive levels of vapors present in a building	• Evacuate occupants, begin abatement measures
• An active public water supply is impacted by chemicals of concern	• Provide alternate water supply
• Threatened and endangered species are impacted	• Implement containment measures and habitat management to minimize extent of impact
Short Term (0-2 years) threat to human health, safety, or relevant ecological receptors and habitats.	Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
• Chronic concentrations of chemical(s) of concern have been measured in shallow surface soils that are open to public access	• Remove soils, cover soils, or restrict access.
• Impacted surface water, storm water, or ground water discharges to a habitat, or surface water body used for human drinking water or contact recreation.	• Institute containment measures, restrict access to areas near discharge, and evaluate the magnitude and impact of the discharge.
Long-term (>2 years) threat to human health, safety, or relevant ecological receptors and habitats.	Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
• Ground water is impacted and potable water supply wells producing from the impacted interval are located >2 years ground water travel time from the dissolved plume.	• Monitor the dissolved plume and evaluate the potential for natural attenuation and the need for hydraulic control.
• Impacted surface water, storm water, or ground water discharges within 1500 feet of a habitat, or surface water body used for human drinking water or contact recreation.	• Investigate current impact on habitat or surface water body, restrict access to area of discharge (if necessary) and evaluate the need for containment/control measures.

6.6.1 The site conditions and response actions given in Table 1 are examples. The user should base the response actions for a site on the current and potential degree of hazard to human health, safety and the environment. For example, sites may pose an immediate, short-term (0-2 years) or longer-term (greater than 2 years) threat to human health, safety and the environment.

6.6.2 Associated with each site condition in Table 1 is a response action; the response actions are implemented to eliminate potential for future impacts that may occur as the user proceeds with the RBCA process. Note that response actions do not always require active remedial action; in many cases the response action is to monitor or further assess site conditions to ensure that risks posed by the site do not increase above acceptable levels over time.

6.6.3 The site should be re-evaluated when additional site information is collected which indicates a significant change (including an improvement) in site conditions or when implementation of a response action or an interim remedial action causes a significant change in site conditions.

6.7 *Development of Corrective Action Goals*—At each tier the user identifies or develops the applicable corrective action goals based on the current or potential exposure pathways. These will be a combination of RBSL, RESC, SSTL, SSEC and ORMC. Technical policy decisions regarding ORMC may exist, or may need to be made to determine the levels or performance criteria that are used for the corrective action goals. The user should recognize that the specific combination of RBSL, RESC, SSTL, SSEC and ORMC to be used as corrective action goals for a particular site is determined based on the technical policy decisions.

6.7.1 *Tier 1 Corrective Action Goals*—The corrective action goals in Tier 1 are the RBSL, RESC or ORMC, as applicable. If an RBSL, RESC or ORMC is not available, the user may develop an RBSL, RESC or ORMC. If RBSL are available, the user is responsible for determining that the RBSL are based on currently acceptable methodologies and parameters and are appropriate for the site(s). If there is no applicable RBSL, RESC, or ORMC for a specific exposure scenario, then the exposure pathway cannot be evaluated in Tier 1 and it is carried to a Tier 2 evaluation. In Tier 1, the point(s) of exposure and point(s) of demonstration are assumed to be located proximal to the source area(s), regardless of the actual, or potential future, location of the receptor.

6.7.1.1 The RBSL are concentration values for each chemical of concern in environmental media (for example, soil, water and air), based on the technical policy decisions for incremental carcinogenic risk levels and hazard quotients and on the potential exposure scenarios for human receptors (for example, residential, commercial, industrial, agricultural).

6.7.1.2 The RBSL are determined utilizing typical, non-site specific values for exposure parameters and physical parameters for media. For each exposure scenario the RBSL are based on current human health parameters (for example, USEPA RME), and current human toxicological information such as in the USEPA Integrated Risk Information System (IRIS) Database, Health Effects Assessment Summary Tables

(HEAST), State sources, peer-reviewed source(s), agency approved toxicity data for proprietary chemicals or the best available toxicity data. Consequently, the RBSL are updated when new methodologies and parameters are developed.

6.7.1.3 When developing Tier 1 RBSL, cumulative risks and additive effects should be considered.

6.7.1.4 If RBSL or RESC are not developed or ORMC are not appropriate for complete or potentially complete exposure pathways, then further evaluation for those exposure pathways is conducted in Tier 2.

6.7.1.5 For indirect exposure pathways, fate and transport models can be used to predict RBSL at a source area that correspond to exposure point concentrations.

6.7.1.6 *The user should always review the assumptions, technical policy decisions and methodology used to derive values the RBSL to make sure that they are consistent with reasonable maximum exposure scenarios for the site being considered as well as currently accepted methodologies.*

6.7.1.7 Appendix X3 provides examples of the derivation of RBSL for a range of compound types. The assumptions and methodology used in deriving the examples are discussed in Appendix X3. Note that not all of the possible exposure pathways are considered in the derivation of the examples. *Appendix X3 is presented solely for the purpose of providing examples of the development of the RBSL. The values and methodologies should not be viewed as proposed RBSL.*

6.7.2 *Tier 2 and 3 Corrective Action Goals*—The corrective action goals in Tier 2 and Tier 3 are the SSTL, SSEC or ORMC, as applicable. Tier 2 and Tier 3 provide the user with options for human exposures to determine SSTL and point(s) of exposure. Corrective action goals are based on SSTL, SSEC and ORMC that are protective of human health and the environment. It is important to note that Tier 1 RBSL, Tier 2 SSTL and Tier 3 SSTL are based on achieving similar levels of protection of human health. Similar levels of protection are defined by the technical policy decisions on risk targets, methods for addressing cumulative risks and additive effects and methods for addressing uncertainty. Tier 2 and Tier 3 provide the user options to determine SSEC for relevant ecological receptors and habitats. Tier 2 and Tier 3 also provide the user with the option to develop or refine ORMC, where applicable, consistent with the technical policy decisions. In Tier 2 and Tier 3 the corrective action goals for the source area(s), point(s) of demonstration and point(s) of exposure may be different values or criteria, for example, different concentrations of chemical(s) of concern in environmental media based on the fate and transport relationships between the various locations.

6.7.2.1 For human exposure pathways, the Tier 2 SSTL can be derived from the same equations used to calculate Tier 1 RBSL, except that site-specific parameters are used in the calculations. The additional site-specific data may support alternate fate and transport analyses. The Tier 2 analysis may involve applying Tier 1 RBSL at more probable point(s) of exposure. The SSTL may also be needed for potential exposure pathways using site-specific conditions for which no RBSL were developed or ORMC were appropriate in Tier 1. The development of SSTL may also consider a combination of these methods.

6.7.2.2 For relevant ecological receptors and habitats, the Tier 2 evaluation may involve the development of SSEC and the comparison of site conditions to SSEC. Other qualitative or quantitative analyses may also be appropriate for a Tier 2 evaluation.

6.7.2.3 For human exposure pathways, Tier 3 provides the user with an option to determine SSTL for both direct and indirect human exposure pathways using site-specific parameters and point(s) of exposure and point(s) of demonstration when it is judged that Tier 2 SSTL should not be used to determine corrective action goals.

6.7.2.4 Cumulative risks and additive effects should be considered when developing Tier 2 and Tier 3 SSTL.

6.7.2.5 For relevant ecological receptors and habitats, a Tier 3 evaluation is typically quantitative in nature and involves more site-specific data than previous tiers. Determination of SSEC may involve a more extensive site-specific analysis. In developing the SSEC, the user should consult current federal, state and other information.

6.7.3 *Use of Multi-Component Measurements*—Various multi-component measurement chemical analyses are often used in site assessments. These methods include, total petroleum hydrocarbons (TPH), total organic carbon (TOC) and total organic volatiles (TOV), and usually determine the total amount of a class of compounds. Some of these multi-component measurements are general measures and as such may provide insufficient information about the amounts of individual chemical(s) of concern present to calculate risk. However, new methods for the evaluation of multi-component measurements in terms of risk and exposure are being developed. If multi-component measurements are used as corrective action goals in any tier evaluation, the user is responsible for determining that the evaluations are based on currently acceptable methodologies and parameters that are applicable to risk-based calculations.

6.8 *Tier 1 Evaluation*—Tier 1 provides the user the option to identify or develop the corrective action goals (see section 6.7.1). If there is no corrective action goal for a specific exposure scenario, then the exposure pathway cannot be evaluated in Tier 1 and it is carried to a Tier 2 evaluation. In Tier 1, the point(s) of exposure and point(s) of demonstration are assumed to be located proximal to the source area(s), regardless of the actual or potential future location of the point(s) of exposure. The site conditions as determined through the initial site assessment and the site assessment for Tier 1 are compared to the corrective action goals based on the complete and potentially complete exposure pathways defined by the site conceptual model. In Tier 1, the quantity of assessment data are typically limited, therefore conservative assumptions about site conditions are used for the comparison. For example the maximum concentrations of chemical(s) of concern are compared to the RBSL or ORMC. If there are sufficient site assessment data, the user may choose to use a statistically derived value rather than a conservative value. Background conditions should also be considered in the Tier 1 comparisons.

In Tier 1, the evaluation for relevant ecological receptors and habitats should take the form of qualitative analyses, as discussed in 6.9.

6.9 *Ecological Evaluation*—Utilize a qualitative ecological screening evaluation to support the identification of relevant ecological receptors and habitats, to select relevant ecological exposure pathways and to identify potential chemical(s) of concern (see Appendix X5). Due to the complexity of ecological systems, if exposure pathways are complete or potentially complete, then a refinement of the exposure pathway analysis should occur in Tier 1 to focus the assessment as early in the process as practicable or appropriate. Selection of RESC or development of RESC should occur, and a comparison to site conditions made. If after this refinement, complete or potentially complete ecological exposure pathways still exist for relevant ecological receptors and habitats on or near the site, then a site-specific assessment should be conducted. The site-specific assessment may involve selection of RESC or the development of SSEC, as applicable. This may include literature values, determining the toxicity of media to test organisms, biological surveys or multiple lines of evidence.

6.10 *Evaluation of Tier Results*—Within each tier evaluation the user compares the site conditions to the corrective action goals.

6.10.1 If site conditions meet corrective action goals for chemical(s) of concern, then no further action may be appropriate (see 6.10.3). If site conditions do not meet the corrective action goals, then interim remedial action, remedial action, or further tier evaluation must be conducted.

6.10.1.1 *Interim Remedial Action*—An interim remedial action may be more practical than attempting to implement a comprehensive remedial action (for example, when the desired risk reduction is infeasible due to technology or resource limitations). Furthermore, if interim remedial actions can reduce or eliminate a short-term threat, then interim remedial action steps should be employed before proceeding to further tier evaluation. If an interim remedial action is selected in the evaluation under 6.10.1 as the most appropriate option, then a design is implemented to address the most significant concerns in an expedited fashion. The interim remedial action may include removal or treatment of source area(s) with complete or potentially complete exposure pathways, or another method to address the most significant exposure concerns, to reduce migration, and facilitate reassessment of the tier evaluation. Interim remedial actions may also lead to further evaluation of response actions.

6.10.1.2 *Remedial Action*—If remedial action is selected in the evaluation under 6.10.1 as the most appropriate option, then a remedial action is designed and implemented to reduce concentrations at the point(s) of exposure, to eliminate an exposure pathway, or to address a potentially unacceptable risk to relevant ecological receptors and habitats. The remedial action may include some combination of source removal, treatment, and containment technologies, exposure pathway elimination as well as activity and use limitations (for additional discussion see 6.13). Examples of these include soil removal, soil venting, bioventing, air sparging, pumping for hydraulic control, chemical fixation, capping, industrial workplace protective practices and natural attenuation. When site conditions meet corrective action goals, then the user may elect to move to 6.10.3. Additionally, remedial action may be used to reduce concentration(s) of chemical(s) of concern, reduce exposures and facilitate a re-evaluation of the tier analysis.

6.10.1.3 *Further Tier Evaluation*—If further tier evaluation is warranted, additional site assessment information should be collected to develop or identify corrective action goals under a Tier 2 or Tier 3 evaluation (see 6.7.2). Further tier evaluations are conducted only for the complete and potentially complete exposure pathways. Further tier evaluation is warranted when:

(1) The basis for the Tier 1 or Tier 2 corrective action goals, as applicable, (for example, hydrogeology, exposure parameters, point(s) of exposure, reasonable land use options) are not representative of the site-specific conditions; or,

(2) The Tier 1 or Tier 2 corrective action goals, as applicable, do not exist for a complete and potentially complete exposure pathway; or,

(3) The corrective action goals developed under further tier evaluation will be significantly different than the Tier 1 or Tier 2 corrective action goals, as applicable, or will significantly modify the remedial action activities; or,

(4) The cost of remedial action to achieve Tier 1 or Tier 2 corrective action goals, as applicable, will likely be greater than the cost of further tier evaluation and subsequent remedial action.

6.10.2 If site conditions meet corrective action goals, but the user is not confident that data support the conclusion that the site conditions will meet the corrective action goals in the future, then the user institutes a monitoring plan to collect data sufficient to confidently conclude that site conditions will meet corrective action goals in the future (see 6.14). After these data are collected, no further action may be appropriate (see 6.10.3). If site conditions will not meet corrective action goals in the future, then initial remedial action, remedial action or further tier evaluation is appropriate (see 6.10.1).

6.10.3 If site conditions meet corrective action goals and the user is confident that data support the conclusion that site conditions will meet corrective action goals in the future, then no additional corrective action activities are necessary, and the user has completed the RBCA process. In practice, this is often accompanied by the issuing of a No Further Action letter, or its equivalent, by the applicable regulatory agency (see Appendix X1).

6.11 *Tier 2 Evaluation*—Tier 2 provides the user with an option to determine the site-specific point(s) of exposure and point(s) of demonstration and corresponding corrective action goals for the chemical(s) of concern applicable at the point(s) of demonstration and source area(s) as well as corrective action goals for relevant ecological receptors and habitats (see 6.7.2). Additional site assessment data may be required; however, the incremental effort may be minimal relative to Tier 1. In most cases, only a limited number of exposure pathways, exposure scenarios, and chemical(s) of concern are considered in the Tier 2 evaluation since many are eliminated from consideration during the Tier 1 evaluation. In Tier 2, the evaluation for relevant ecological receptors and habitats can take the form of additional qualitative or quantitative analyses.

6.11.1 In Tier 2 for human health the user identifies the direct and indirect complete and potentially complete exposure pathways. The Tier 2 evaluation may include:

6.11.1.1 For the complete and potentially complete indirect exposure scenarios, identification of the appropriate site-specific point(s) of exposure and point(s) of demonstration. A combination of assessment data and predictive modeling results are used to determine the SSTL at the source area(s) or the point(s) of demonstration, or both, or

6.11.1.2 Application of the RBSL, or ORMC, for the direct exposure scenarios at site-specific point(s) of exposure (as opposed to the source area(s) as is done in Tier 1). The SSTL for source area(s) and point(s) of demonstration can be determined based on the demonstrated and predicted attenuation (that is, reduction in concentration with distance) of compounds that migrate away from the source area(s), or

6.11.1.3 Application of a statistical data handling method, when appropriate data exist, to the source area(s) data and comparison of the representative source area(s) concentration to the RBSL, or

6.11.1.4 Application of the site-specific exposure and site condition values to the Tier 1 RBSL calculations to determine SSTL for the source area(s), or

6.11.1.5 Implementation of alternate fate and transport algorithms to determine SSTL, or

6.11.1.6 Development of SSTL may consider a combination of these methods.

6.11.1.7 The SSTL may also be needed for potential exposure pathways using site-specific conditions for which no RBSL were developed or ORMC identified in Tier 1.

6.11.1.8 An example of Tier 2 application is illustrated in Appendix X7.

6.11.2 The Tier 2 evaluation of the RBCA process involves the development of SSTL based on the measured and predicted attenuation of the chemical(s) of concern away from the source area(s) using relatively simplistic mathematical models. The SSTL for the source area(s) are generally not equal to the SSTL for the point(s) of demonstration. The predictive models are:

6.11.2.1 Relatively simplistic, and are often algebraic or semi-analytical expressions,

6.11.2.2 Limited to practicably attainable site-specific data, or easily estimated quantities (for example, total porosity, fraction organic carbon, depth to ground water) for input parameters, and

6.11.2.3 Based on descriptions of relevant physical and chemical phenomena. The models are relatively simple, (that is, certain complex mechanisms are neglected) which results in predicted concentrations that are greater than those likely to occur (for example, assuming constant concentrations in source area(s)). Appendix X4 discusses the use of predictive models and presents models that might be considered for Tier 2 evaluation.

6.11.3 For relevant ecological receptors and habitats the Tier 2 evaluation may involve further site-specific evaluation utilizing additional qualitative or quantitative analyses.

6.11.4 Compare the site conditions to the Tier 2 corrective action goals. Identify the exposure scenarios where the site conditions do not meet the corrective action goals and evaluate these scenarios in accordance with 6.10.

6.12 *Tier 3 Evaluation*—In a Tier 3 evaluation for both human health and relevant ecological receptors and habitats, corrective action goals are developed on the basis of more sophisticated statistical evaluations and chemical fate and transport analyses, using site-specific input parameters for both direct and indirect exposure scenarios, as well as alternative toxicity data, exposure factors and bio-availability information, (see 6.7.2). Tier 3 evaluations could involve collection of significant additional site information, statistical evaluation of that data and completion of more extensive modeling efforts than required for either a Tier 1 or Tier 2 evaluations. Cumulative risks and additive effects are important considerations in Tier 3 analyses.

6.12.1 Tier 3 analyses may include the following:

6.12.1.1 The use of numerical ground water modeling codes that predict time-dependent dissolved chemical transport and account for spatially varying permeability fields to predict exposure point(s) concentrations,

6.12.1.2 The use of site-specific data, mathematical models, alternative toxicity data, bio-availability information and

6.12.1.3 Implementation of probabilistic exposure analysis methods to quantify the uncertainties in the exposures for a given site (see Appendix X2 and Appendix X4), and

6.12.1.4 The gathering of sufficient data to refine site-specific parameter estimates (for example, biodegradation rates, desorption factors) and improve the accuracy of the model predictions.

6.12.2 In a Tier 3 evaluation for relevant ecological receptors and habitats, activities to identify applicable SSEC are quantitative in nature. Where appropriate, these assessments may be conducted in accordance with current federal or state acceptable methods for relevant ecological receptors and habitats.

6.12.3 Compare the site conditions to the Tier 3 corrective action goals. Identify the exposure scenarios where the site conditions do not meet the corrective action goals and evaluate these scenarios in accordance with 6.10, except that a tier upgrade (6.10.1.3) is not available.

6.13 *Implementing the Selected Remedial Action Program*—When it is judged by the user that no further tier evaluation is necessary, or practicable, or applicable, a remedial alternatives evaluation should be conducted to determine the appropriate remedial actions necessary to achieve the corrective action goals determined for the site. Because remedial action itself can create new risks, including imposing significant physical, biological and chemical stresses on relevant ecological receptors and habitats, the remedial action should be balanced against the short and long term risks consistent with the technical policy decisions.

6.13.1 The remedial alternative evaluation should consider the applicable technical policy decisions and the following for each remedial action:

6.13.1.1 Effectiveness of the remedial action in protecting human health and the environment,

6.13.1.2 Long-term reliability and probable success in meeting the corrective action goals now and in the future,

6.13.1.3 Short-term risks posed by the implementation of the remedial action,

6.13.1.4 Amenability of the remedial action to integration with property redevelopment plans,

6.13.1.5 Acceptability of the remedial action to the stakeholders,

6.13.1.6 Implementability and technical practicability of the remedial action, and

6.13.1.7 The cost-effectiveness of the options to meet the corrective action goals.

6.13.2 Based on the alternative evaluation conducted under 6.13.1, a remedial action(s) is selected. The detailed design and specification of the selected alternative(s) are then developed for installation and operation.

6.13.3 The remedial action is implemented in accordance with the design and specification developed under 6.13.2. Following implementation, monitoring should be conducted to ensure that the design conditions are being met by the remedial action (see 6.13.4 and 6.14).

6.13.4 The remedial action must continue until such time as monitoring indicates that the corrective action goals have been met for a statistically significant number of monitoring periods, at the point(s) of demonstration or source area(s), or both, as appropriate.

6.13.5 At any time during the remedial action:

6.13.5.1 If site conditions change (for example, property use changes from residential to commercial and this was not anticipated in the future use of the property) or new data becomes available (for example, more refined aquifer parameters, site-specific biodegradation rates, new toxicity data for the chemical(s) of concern, or site-specific exposure factors are better defined) that would impact the corrective action goals, the user should return to the tier evaluation.

6.13.5.2 If the remedial action was initiated with Tier 1 or Tier 2 corrective action goals, the user may choose to return to the next higher tier evaluation.

6.13.5.3 If concentrations of chemical(s) of concern decrease to an asymptotic level that is above the corrective action goals, at the point(s) of demonstration, the user must choose to either conduct further tier evaluation (unless Tier 3 has already been completed), modify the remedial action system or further reduce or eliminate exposures through activity and use limitations.

6.13.6 Similar remedial actions can be implemented at different sites with different design objectives depending on the chemical(s) of concern, the hydrogeological setting and the corrective action goals. For example at one site ground water pumping may be implemented for hydraulic control while at another the ground water pumping may be used for source removal. In addition, the reliability of different designs for different objectives will be different. Further, the reliability of different remedial action options will vary depending on the site setting and potentially on the regulatory and legal structure of the jurisdiction in which the site is located (for example, the reliability of activity and use limitations varies depending on the structure of the limitation and the jurisdiction in which it is implemented, see Appendix X6).

6.14 *Implementing a Monitoring Program*—In many cases monitoring is appropriate. Upon completion of this monitoring effort (if required), no further action is required.

6.14.1 Monitoring is necessary to:

6.14.1.1 Demonstrate the effectiveness of the implemented remedial action, or

6.14.1.2 Confirm that current conditions persist or improve with time, or

6.14.1.3 Verify model assumptions and conditions.

6.14.2 If monitoring does not demonstrate the effectiveness of the implemented remedial action the user should reevaluate the remedial action (see 6.13). If the monitoring does not confirm that current conditions persist or improve with time or verify model assumptions and conditions then the user should return to the applicable tier evaluation (see 6.11 and 6.12).

6.15 *Site Maintenance*—In addition to monitoring, some remedial actions (for example, physical barriers - capping, hydraulic control, or activity and use limitations) require maintenance to ensure integrity and continued performance. The required maintenance should be conducted until corrective action goals have been demonstrated. In the case of some activity and use limitations site maintenance may be needed beyond the remedial action closure (see 6.16).

6.16 *No Further Action and Remedial Action Closure*—No further action is necessary when corrective action goals have been demonstrated (as required in 6.10.3) to be achieved. Under these circumstances, if monitoring and site maintenance are no longer required to ensure that conditions persist, then no further action is necessary, except to ensure that activity and use limitations (if any) remain in place. If these conditions are met, the closure should be documented. Example closure instruments are discussed in Appendix X1.

6.17 *RBCA Report*—After completion of the final tier evaluation, a RBCA report should be prepared. The report must include all of the data collected to support the RBCA decisions that were made. The report content will depend on the specific site, the tier evaluation and the requirements of the regulatory agency, however the RBCA report will typically include the following:

6.17.1 An executive summary,

6.17.2 A site description,

6.17.3 A summary of the site ownership and use,

6.17.4 A summary of past releases or potential source areas,

6.17.5 A summary of the current and completed site activities,

6.17.6 A description of regional hydrogeologic conditions,

6.17.7 A description of site-specific hydrogeologic conditions,

6.17.8 A summary of reasonably anticipated use,

6.17.9 A summary and discussion of the site conceptual model, the exposure pathway analysis and the qualitative ecological screening evaluation,

6.17.10 A summary of the tier evaluations conducted, including the methods and assumptions used to derive the corrective action goals,

6.17.11 A summary of the analytical data and the appropriate corrective action goals used,

6.17.12 A site map of the location,

6.17.13 An extended site map to include significant features (for example local land use and ground water supply wells),

6.17.14 Site plan view showing location of facility or site structures (for example, aboveground storage tanks, underground storage tanks, waste management areas, buried utilities and conduits, suspected/confirmed sources),

6.17.15 Site photos, if available,

6.17.16 A ground water elevation map,

6.17.17 Geologic cross-section(s),

6.17.18 Concentration maps for chemical(s) of concern in the appropriate environmental media,

6.17.19 A section that contains an outcome statement defining the corrective action goals and completion conditions, and

6.17.20 A summary of the technical policy decisions.

APPENDIXES

(Nonmandatory Information)

X1. CONSIDERATIONS FOR DEVELOPMENT OF A RBCA PROGRAM

X1.1 *Introduction*:

X1.1.1 The agencies responsible for developing and implementing a RBCA program and interested stakeholders are the focus of this appendix. Agencies empowered to enforce statutes, promulgate and enforce regulations and implement policy guidance governing cleanup must make key decisions in order to blend the existing program with the risk-based approach. Such decisions are typically made, either formally or informally, with the involvement of stakeholders. In this context a risk-based corrective action (RBCA) program provides regulatory agencies, the regulated community, and the stakeholders with clear, practical guidelines for assessment and control of risks posed to human health and the environment by chemical releases. The RBCA framework provides an opportunity and a focus for agencies working toward the development of a unified and consistent set of policies and procedures for risk-based corrective actions. While no single procedure is mandatory, a clear understanding of the RBCA planning process for both regulatory agency personnel and the regulated community can streamline the site review process by the regulatory agency and expedite implementation of appropriate corrective action. Toward this end, development of a RBCA regulatory program involves considerable discussion by the regulatory authority and other concerned stakeholders regarding legal and regulatory issues, technical policy decisions, and program documentation and communication.

X1.1.2 This appendix is intended to serve as an outline of suggestions to assist in the development process and identify relevant information resources. Although in some cases specific examples are discussed in this appendix for ease of understanding, there is no intention to advocate specific positions regarding regulatory policies. Instead, a list of key actions and issues to be considered by the RBCA development team are provided. An effective development team includes all major stakeholder groups. In some programs there are statutory or regulatory authorities that require interested parties to be brought together before rules regarding clean-up programs are promulgated. There may be requirements to appoint and convene a multidisciplinary advisory board to provide advice before rules are promulgated. The composition of such advisory boards may be detailed in regulation or a matter of policy in a particular jurisdiction.

X1.2 *Overview of RBCA Development Process*:

X1.2.1 The RBCA program development process involves the following principal steps:

X1.2.1.1 *Selecting the Framework*—Deciding to use the RBCA framework.

X1.2.1.2 *Administrative Actions*—Coordination with concerned stakeholders and evaluation and/or revision of existing laws and regulations. A key element is the Stakeholders' Meeting.

X1.2.1.3 *Technical Policy Decisions*—Specification of technical criteria required for calculation of risk-based corrective action goals, performance standards for modeling, exposure pathway analysis and data collection.

X1.2.1.4 *Program Documentation*—Development of written guidance and other tools to assist the agency and the user. (for example, standardized report forms and software tools for application of the RBCA process.)

X1.2.1.5 *Specialized Program Elements*—The development team may wish to consider specialized mechanisms for voluntary cleanup programs (VCPs), such as completion letters, no further action statements or liability covenants. Many state programs, for example, have specific or general statutory provision governing the issuance of liability covenants.

X1.2.1.6 *Education/Outreach*—Training or communication or both with regulatory staff, the regulated community, environmental consultants and contractors, stakeholder organizations, and the general stakeholders.

X1.2.1.7 *Stakeholder Involvement*—The development team may consider use of standard policies and techniques for communication with stakeholders on a site-by-site basis and/or for program development and implementation.

X1.2.2 In general, these development tasks may be undertaken in a sequential manner. However, some degree of overlap or iteration may be required to establish a workable and efficient risk-based program for assessment, remediation, and closure of affected sites. Detailed discussion of each program development step is provided below.

X1.3 *Selecting the Framework*—The threshold decision for a regulatory agency is whether to develop or modify an existing cleanup program around the RBCA framework. This decision may require some underlying assumptions to be

modified in fundamental ways. Many traditional cleanup programs require the collection of large amounts of information and a complete and detailed profile of the site, before an evaluation of the risks, risk reduction measures or the remedy selection process is ever initiated. In contrast, the basic principle of RBCA is to allow the user to gather just enough information to make a risk-based decision at the lowest tier of analysis. This facilitates timely decisions, based on risk, most efficiently, and with the least amount of information possible. At lower tiers, uncertainty is compensated by more conservative assumptions. In other words, at lower tiers, a complete detailed profile of the site is not needed because the agency builds in a reasonable worst-case set of assumptions in the corrective action goals, as appropriate. At higher tiers, uncertainty is reduced through collection and analysis of more site-specific information. The agency responsible for decision making should consider the level of understanding and acceptance of this underlying philosophy by the people who must implement it, prior to embarking on program development using RBCA.

X1.4 *Administrative Actions*:

X1.4.1 This guide provides a risk management framework that can be customized to address the concerns of local stakeholders and integrated with the legal and regulatory framework. For this reason, it is important to involve key stakeholders (defined below) early in the program development process. In addition, the development team (defined below) may review existing laws and regulations to identify possible roadblocks to RBCA implementation and any statutory or regulatory actions that may be required. While specific provisions for stakeholder involvement are beyond the scope of this guide, it is recommended that stakeholder involvement and outreach activities be integrated into the RBCA development process. Stakeholder involvement activities may or may not be appropriate at every site in a RBCA program. Key considerations are outlined below.

X1.4.2 *Advisory Committee Acts and Stakeholders Meetings*—Many state and federal programs develop regulations, policies and guidelines with specific consensus building requirements and formal or informal requirements for representation by balanced stakeholder groups. It is extremely important for the program development process to consider the use of such representation to reach consensus on some of the widely debated issues which could impact the application and implementation of the RBCA process. During the development process, Stakeholders Meetings among the following potential participants may be critical: the regulatory agency and other users; industry; real estate interests; financing interests; local governments and redevelopment authorities; citizen groups and environmental groups. The purpose of such meetings is to reach consensus on a common approach for the critical technical policy decisions discussed below, especially in the area of risk management.

X1.4.3 *Development Team*—To assist in producing an efficient and workable RBCA program, an effective development team can serve a key role. The team may include representatives from the principal regulatory agency, the regulated community, environmental groups, citizens and other parties likely to be affected by a new or revised regulatory program. Other such stakeholders may include, but are not limited to: local government; representatives from the real estate, banking, or insurance industries; environmental professional or technical organizations; citizens' groups; and environmental and public health advocates. Consideration of these diverse perspectives can greatly facilitate the ultimate success of the RBCA program. Stakeholders may be involved either as a working group (that is, the development team) or as an oversight or advisory committee. In most cases, to provide for meaningful discussion and input, preliminary training or orientation of stakeholder representatives regarding RBCA concepts and key policy issues will be required.

X1.4.4 *Statutory Review*—The development team should review existing environmental laws and identify how the RBCA program should be crafted to comport with existing statutes and to identify possible constraints on RBCA implementation. Examples include state drinking water quality criteria, non-degradation standards and policies, wellhead protection programs, legally mandated soil and ground water remediation standards, or full site delineation requirements. A distinction should be made to differentiate between ground water restoration standards and those for ground water protection, since they may have different purposes. The development team may evaluate existing laws to customize the risk-based approach, recommend statutory modification to facilitate RBCA, or a combination of both. Key elements in the statutory review include consideration of natural resource protection and conservation requirements. Many programs have, for example, explicit ground water protection and future use statutes.

X1.4.5 *Regulatory Action*—In some cases, current regulations mandate uniform concentration limits for soil and ground water affected by a chemical release (for example, background levels, practical quantitation limits, or other maximum allowable limits), regardless of location, land use, or exposure scenario. In some cases this situation may require careful crafting of the RBCA framework to accommodate current regulations. In other cases incorporation of risk-based corrective action goals may require redrafting portions of the existing rules. As a practical matter, many programs have employed some combination of regulatory accommodation and modification. The outcome of any debate to replace or modify existing programs depends on active, successful of stakeholder involvement activities. In addition, depending on the scope of the existing regulations, accommodations or modifications may also be required to those sections addressing: site assessment requirements; response action evaluation procedures; remediation options; requirements for treatment; permanent solutions; use of activity and use limitations; use of natural attenuation; point of compliance; and compliance monitoring specifications. The regulations may consist of language defining key policy elements of the RBCA program and authorizing agency promulgation of detailed written guidance. In some jurisdictions, detailed procedural guidelines will need to be incorporated in the rules due to legal constraints on the use of guidance documents.

X1.4.6 *Policy and Guidance Development*—As an alternative to statutory or regulatory mandates, agencies may elect to implement the RBCA program in the form of policy guidelines and/or technical guidance materials. As noted below, clearly documented policies and administrative procedures are critical to proper understanding and implementation of a RBCA program by the regulated community. Having technical decisions promulgated through policy and/or guidance enhances the flexibility of the program, allowing for routine updates as the leading edge of environmental science evolves. Many states, for example, rely on policy and guidance for certain aspects of the cleanup program.

X1.5 *Technical Policy Decisions*:

X1.5.1 *Reaching Consensus*—Virtually all cleanup programs demonstrate differences of opinion among stakeholders on some of the key policy issues which confront remedy selection and the development of a RBCA program. There is a natural tension which exists, for example, between groups which believe allowable risk-levels should be set conservatively and those which would recommend more relaxed standards. The use of activity and use limitations, the requirement for treatment and point(s) of compliance are other controversial issues which will inevitably confront the regulatory agency responsible for such policy decisions. An important principle to use in this part of the development process is to engage in the debate, through adequate stakeholder involvement, and to achieve as much consensus as possible among differing views. Technical policy decisions can then be incorporated into the RBCA framework. Although the agency must clearly and decisively exercise its regulatory responsibility and make the key decisions needed to implement the cleanup program the experience from many programs has shown that continued stakeholder involvement in the regulatory process has been very beneficial.

X1.5.2 *Risk Decisions:*

X1.5.2.1 For a release to enter into the RBCA analysis, the regulatory agency or user should establish criteria to determine whether or not further evaluation or action is needed for human health or ecological concerns. This is a threshold technical policy decision. Some agencies may establish notification thresholds, based on reportable quantities or concentrations of chemical releases. In some programs, if no exposure pathway is complete no further risk analysis is required. In this manner, regulations or policy show whether or not the application of RBCA is needed.

X1.5.2.2 The regulatory agency has the prerogative to make key policy decisions during program development. The RBCA program development team should consider detailed guidance on a comprehensive range of policy issues such as the calculation and application of risk-based corrective action goals. A summary list of the key issues to be addressed is provided in Table X1.1. These policy decisions serve to flesh out the ASTM RBCA framework, providing a consistent basis for determining whether remediation is necessary and, if so, "how clean is clean" for a wide variety of site conditions. To design the RBCA program, the development team may attempt to build consensus in the following areas: cumulative risks and additive effects; the conservatism applied to risk calculations; minimum data requirements for site assessment and closure; variables affecting the selection of target risk levels and exposure factors; and the applicability of ASTM, state, or Environmental Protection Agency (EPA) calculation protocols (see Table X1.1).

TABLE X1.1 Example Technical Policy Decisions to be made by the Regulatory Agency

How to Reach Consensus
Risk Decisions
How to Deal with Cumulative Risk and Additive Effects
Appropriate Sources of Toxicity Information
Use of a Risk Range
Other Relevant Measurable Criteria
How to Record Consensus Decisions
Site Assessment
Ecological Risk Assessment
Land Use
Future Uses and Exposure Pathway Analysis
How to Use Activity and Use Limitations
When to Use Activity and Use Limitations
Resource Protection
Remedy Selection Criteria
Balancing the criteria
Treatment Versus Activity and Use Limitations
Remedial Action Effectiveness
Long-term Reliability
Short-term risks
Property Redevelopment Plans
Acceptability to Stakeholders
Implementability
Cost-effectiveness

X1.5.2.3 *Cumulative Risk and Additive Effects*—The responsible regulatory agency should consider how to handle additive effects or cumulative risk. Some agencies may create Tier 1 RBSL with sufficiently conservative assumptions to account for cumulative risks and additive effects and therefore establish screening levels within an allowable risk range. Other agencies may require Tier 1 screening to use conservative single endpoint screening values and not a range. For example, in Massachusetts, screening numbers (the equivalent of RBSLS) are set at a single number based on a $1*10^{-6}$ cancer risk endpoint or 20 % of the non-cancer Reference Dose, which ever is lower. The rationale here is that the screening numbers using the conservative risk endpoints for a single number will be protective for almost all sites. For higher Tier analysis the total site risk must not exceed a $1*10^{-5}$ cancer risk endpoint or a non-cancer Hazard Index of 1.0 .(Massachusetts Contingency Plan, 1997, 310CMR 40.0983). For some chemicals, non-cancer effects may be considered for RBSL because they may have an additive effect on the same target organ. EPA guidance recommends that the potential for additive effects must be carefully evaluated at every site by considering the Hazard Index for chemicals with References Doses or Concentrations are based on the same endpoint of toxicity such as a target organ or system. For example, EPA Soil Screening guidance recognizes at least eleven chemicals, including several pesticides, whose non-carcinogenic effects may be specific to the human liver (Ref **(2)**, pp. 9-15)

X1.5.2.4 States may also develop their own sources of information on chemical toxicity. Among other things, the regulatory agency must decide on the level of scientific research, reliability and uncertainty which is appropriate in a particular program for a particular use. This is especially true for toxicity information. Regulatory agencies may also wish to evaluate the applicability of occupational, ambient exposure values for workers at operating industrial sites within their RBCA program. In addition to chemical toxicity, an agency developing a RBCA program may wish to consider alternative data sources and methods to address exposure and bioavailability. The alternative data sources and methods consulted and used should be reasonably accessible and clearly communicated to the user.

X1.5.2.5 *The Risk Range*—Many programs allow the flexibility of decision making within an acceptable risk range. For example, the Federal Superfund Program has established an acceptable range for lifetime excess cancer risks of 10^{-4} to 10^{-6}.[7] Corrective action goals are based on achieving similar levels of protection for human health that are within the acceptable range of risks and the protection of environmental receptors as determined by the implementing agency. Thus the levels of protection may vary from site to site as well as across the tiers at the same site as long as it will result in achieving levels of protection within the defined acceptable range of risks. In some programs, however, a single number for total site risk has been selected by the regulatory agency or set by statute for all sites and tiers of analysis. While such programs lack the flexibility of a risk range, some stakeholders feel this approach affords a level of fairness and cleanup consistency.

X1.5.2.6 The regulatory agency may also consider development of Other Relevant Measurable Criteria in the program which are not directly related to human health or ecological risks. In planning risk based programs, noise, odors, taste and visual appearance may be important considerations in evaluating chemical releases.

X1.5.3 Upon completion of the planning session(s), the consensus decisions of the development team may be recorded in a variety of ways. Development of a RBCA program should avoid arbitrary decisions, which are isolated from stakeholder involvement. Based on this process and sufficient training, a knowledgeable person should be able to complete a RBCA evaluation in accordance with the established program. Specialized documentation may be required for RBCA implementation to reach site completion as outlined below.

X1.5.4 *Site Assessment:*

X1.5.4.1 *Initial Site Assessment*—The purpose of the initial site assessment is to form the first conceptual model of a release at a site based on rudimentary information. This model may change over time, as more information becomes available. For simple releases at sites incomplete pathways may eliminate the need for any further evaluation. Some regulatory agencies, for example, define threshold quantities or concentrations of a chemical release as exclusion from or entry to a further RBCA analysis.

X1.5.4.2 One of the key technical decision frameworks in a risk based corrective action program is the type and degree of assessment needed to provide the level of information necessary to make cleanup decisions. The identification of chemicals of concern in the soil, ground water and other media in relationship to exposure pathways must be sufficient to support the decision being made, while minimizing the amount of data collected which is of limited use. The objective is to optimize the site assessment using the "just-in-time" process of least information for lower tiers. While site assessments for the RBCA process attempt to determine all significant sources of chemical releases, performance standards to define the extent of the release may differ, according to the requirements developed by the regulatory agency. For example, some agencies require definition of the full horizontal and vertical extent of all releases to below the most conservative risk-based screening values. Other agencies outline how to define data quality objectives and then use those to determine the extent of site assessment. Still others may select conservative assumptions in lower RBCA Tiers as a substitute for the definition of all levels of chemical releases.

X1.5.4.3 There is a wealth of information from both government and industry on appropriate levels and techniques for assessment. These include Guide E 1912 Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases and Guide E 1527, as well as numerous EPA guidance documents, including Ref (**1**). In building a program, the development team should consider appropriate guidance for site assessment.

X1.5.5 *Ecological Risk Assessment*—The development team should consider carefully the issues that will arise during the development of a tiered framework for ecological risk assessment. This includes any boundary parameters, which may be selected during the qualitative ecological exposure assessment described in Appendix X5. For example, some regulatory agencies may decide that size or distance thresholds such as acreage or distance from resources may be useful screening tools for ecological assessment to determine if further, detailed assessment of the ecosystem is or is not required. Other regulatory agencies, on the other hand, may decide that this approach is too limited and that exclusion of some habitats and selection of receptors is too subjective to be useful. Ecological boundary parameters may depend on both regulatory and policy issues that apply to the geographic area to be covered by the standards being developed under the RBCA framework. Ecological screening criteria may include chemical concentrations, biological measures or other relevant generic criteria. The regulatory agency should exercise great care in selecting the appropriate decision points for ecological screening and assessment, especially in the selection of relevant ecological receptors and habitats. Appendix X5 contains a suggested qualitative ecological exposure assessment and describes the conceptual tiered framework for ecological risk assessment.

X1.5.6 *Land and Resource Use:*

[7] EPA uses a 10^{-6} level as a point of departure for preliminary remediation goals for cancer risks. While the 10^{-6} starting point expresses EPA's preference for setting clean up levels at the more protective end of the risk range, these levels may be revised within the acceptable risk range based on consideration of appropriate factors, including exposure factors, uncertainty factors and technical factors.

X1.5.6.1 Current and reasonably anticipated future uses of land and water, including ecological considerations, are important in the RBCA process. This is because the exposure scenarios for human health and relevant ecological receptors depend on the population potentially exposed and the frequency and intensity of exposure to the media where chemicals have been released. Exposure pathway analysis may also be known as the conceptual site model.

X1.5.6.2 For a number of reasons, the restriction of future activities, access, or land use through various activity and use limitations may or may not be acceptable to the implementing agency as part of a cleanup remedy. As with other technical and policy issues, this decision requires consideration by stakeholder groups for a particular program in order to decide how effective such controls may be in reducing risks. For some programs, for example, the financial and other assurances required of an operating industrial facility may be totally acceptable to the regulatory agency to ensure exposure pathways which are limited to future industrial use. On the other hand, in a mixed-use urban area, a regulatory agency may decide that no particular activity and use limitation is acceptable to eliminate a potential residential exposure pathway.

X1.5.6.3 In the United States, the current and future allowable or planned uses of real property and other resources, such as water, are controlled by a complex combination of municipal, county, state and federal rules and processes. Each local jurisdiction may have unique land use controls. For this reason, the development team should consider decisions carefully on how and when to use restrictions on access, land use and human activities as part of available corrective actions for the site. While program developers should exercise care in using zoning regulations to rule out exposure pathways for on-site chemical releases, specifically targeted activity and use limitations may be effective tools in cutting off or preventing the completion of potential exposure pathways to chemical releases. Various types of activity and use limitations are described in Appendix X6.

X1.5.7 *Ground Water Restoration and Protection:*

X1.5.7.1 *Restoration*—The RBCA program development team should address critical issues regarding ground water restoration. Decisions on how to address ground water restoration are manifested in the RBCA program in determining the applicability of various ground water exposure pathways, point of demonstration requirements (where does the standard have to be met), and remedial objectives (restoration versus exposure prevention) for ground water. Existing state statutes, regulations, or policies must be accommodated during RBCA program development, but sufficient discretion may be afforded in deciding how the requirements apply in terms of degree and time to the various ground water resources. The USEPA policies that promote restoration of ground water for maximum beneficial use also recognize that all ground waters do not represent the same maximum beneficial use and therefore may not warrant an equivalent level of restoration. Because ground water restoration issues are sensitive and controversial, a wide stakeholder representation in the decision-making process may enhance the acceptance of decisions made by the RBCA development team. The National Contingency Plan, and Regional EPA Guidance such as the 1996 EPA Region 1 Ground water Use and Value Determination Guidance provide important and applicable concepts, principles, and criteria regarding ground water restoration.

X1.5.7.2 *Protection*—In order to address issues of non-degradation, and protection of ground water, many states have developed ground water classification systems which define beneficial and non-beneficial use ground waters. The classification systems may have been developed separately from restoration issues. They typically consider such factors as ground water quality and quantity, proximity to public and private ground water users, nature of the ground water use, presence of alternate or superior water supplies, susceptibility to impacts by releases of chemicals of concern, and location. Some state ground water classification systems which have been established through the USEPA's Comprehensive State Ground Water Protection Program (CSGWPP) may set ground water classifications at a state or regional scale, while other classification systems which are not established through a CSGWPP are applied as a set of criteria at individual release sites. Ground water classification systems provide a convenient context in which to establish policies regarding ground water for RBCA program development. Once a ground water classification system is established, the RBCA development team can make decisions about how the ground water protection scheme relates to restoration issues such as ground water exposure pathways, points of demonstration, and remedial objectives for the various ground water classes. Sources of information on ground water protection include 1986 draft Federal Ground Water Classification Guidelines and the 1992 EPA Final Comprehensive State Ground Water Protection Program Guidance,

X1.5.7.3 *Example Approaches:*

(1) The Massachusetts Department of Environmental Protection's (DEP) Massachusetts Contingency Plan establishes three classes of ground water, which factors in different risk considerations. GW-1 class ground waters are current and potential drinking water sources. GW-2 class ground waters are shallow ground waters where vapor migration pathways may be of concern. Both class GW-1 and GW-3 ground waters can also be class GW-2 ground waters. GW-3 class ground waters are non-drinking water ground waters where protection of surface waters from ground water discharges is of concern. Massachusetts DEP also has an EPA-endorsed CSGWPP, and a Ground Water Use and Value Memorandum of Agreement (MOA) with the US EPA designed to enhance consistency in ground water classification between Massachusetts DEP and EPA Region 1. The MOA is applicable to National Priority List sites and is structured in terms of high and medium use and value ground waters which is generally represented by GW-1, and low use and value ground waters (GW-3).

(2) The Pennsylvania Department of Environmental Protection Land Recycling Program sets a ground water classification system in terms of Used and Non-Use Aquifers. The point of compliance is established at the property boundary that existed at the time impacts were discovered, but the standard to be met at the point of compliance varies depending on the aquifer classification, properties of the chemical, and other site-specific

considerations. Flexibility is provided to document lack of current and planned use of ground water within 1000 ft of the property boundary and within the impacted area in order to provide some consideration of special considerations in urbanized areas.

(3) The Ohio Environmental Protection Agency Voluntary Action Program sets an elaborate ground water classification system defined in terms of Critical Resource Ground Water/Non-Urban Setting, Critical Resource Ground Water/Urban Setting, Class A Ground Water/Non-Urban Setting, Class A Ground Water/Urban Setting, and Class B Ground Water. For each ground water class, different performance-based ground water response objectives are established for on-site and off-site ground water exposure pathways depending on if the source area is on-site, off-site, or both on-site and off-site.

(4) The Texas Natural Resource Conservation Commission's proposed Texas Risk Reduction Program would set a ground water classification system defined in terms of primary ground water resources (Class 1), other current and potential use ground waters (Class 2), and no potential use ground waters (Class 3). Class 1 ground water resources must be fully restored to drinking water standards, while exposure prevention strategies may be established for Class 2 and 3 ground waters.

(5) The Louisiana Department of Environmental Quality's proposed Risk Evaluation/Corrective Action Program also sets three classes of ground water. Class 1 ground waters must be fully restored to drinking water standards, whereas drinking water criteria may be applied at the property line or closest reasonable off-site point of exposure for Class 2 ground water. Class 3 ground water requirements are based on the protection of any surface waters receiving discharge from the impacted ground water. Each of these example ground water classification systems have a common recognition that all ground water resources do not represent the same beneficial use, and accordingly provide the context for RBCA program development in the state.

X1.5.7.4 *Non-Attainment Zones*—Some states have developed ground water protection programs that include the designation of areas of ground water to be "non-attainment" zones. These zones could be located in urbanized areas where there are multiple impacts to ground water from releases of chemicals of concern. For example, Illinois recognizes ordinances established by units of local government that effectively prohibit the installation and use of potable supply wells as an effective activity and use limitation for the elimination of the ground water ingestion exposure pathway. When the ordinance does not apply to the local unit of government, then the local unit of government must enter into a Memorandum of Understanding with the state and maintain a registry of release sites within the ordinance area. Provisions are also set forth regarding notification of affected landowners, criteria for voidance of the ordinance, deed recordation, presence of existing potable wells, and ground water response objectives. Such non-attainment provisions recognize situations where units of local government may not place a high value on ground water resources within urbanized areas due to economic considerations, or due to the existence of regional historical ground water impacts that render the ground water unfit for use. The non-attainment zones may be re-evaluated as remediation by natural attenuation and individual user response actions improve the regional ground water conditions. These zones also provide a convenient context in which to establish policies regarding ground water restoration and protection for RBCA program development. Further, non-attainment zones may be of particular benefit in Brownfields redevelopment areas where ground water ingestion is not an otherwise relevant exposure pathway.

X1.5.8 *Natural Resource Values:*

X1.5.8.1 Many natural resources may have intrinsic value to the public, regardless of actual current or planned future use of the resource. For example, while the ground water underneath a National Park may not have an actual use, its value in pristine condition may outweigh considerations of actual use. Such large public policy issues may play a role in technical policy decisions for actions under a RBCA program, even though they are not related to risk, per se.

X1.5.9 *Remedy Selection Criteria*—Programs developing remedy selection should consider a wide array of factors such as treatment types, permanence versus institutional based remedies as well as the use of innovative technologies. Both risk reduction and long term risk management activities should consider remedy effectiveness against cost. Given limited resources for either publicly or privately funded corrective actions, the program development team may consider various schemes to balance selected risk criteria against the cost of corrective actions. Cost and effectiveness as balancing criteria are common elements of risk-based decision-making programs for corrective action. During the initial development of the program, in balancing these factors, the user should consider that no single factor will predominate over the others. As with other difficult risk management issues, such factors will require a careful balancing act among differing stakeholder opinions and focused decision-making on the part of the regulatory agency. In the end, however, it is the responsibility of the regulatory agency to determine how best to balance the criteria for a particular program.

X1.5.9.1 *Treatment versus Activity and Use Limitations*—While it is beyond the scope of this guide to suggest specific preferences for treatment or for activity and use limitations, these are issues which are critical to this technical policy decision which a regulatory agency must make. For example, the speed, frequency and short term cost-effectiveness of risk reduction through cutting off exposure pathways is generally of great interest to a regulatory program. These are benefits of using activity and use limitations. Also of interest to the regulatory agency are issues such as: returning potentially useable ground water to beneficial use, increasing land values, and lowering long term operation, maintenance and monitoring costs. These are some of the benefits of treatment and the reduction of toxicity, mobility, and volume of chemical releases. Categories of remedy selection criteria include:

X1.5.9.2 Effectiveness of the remedial action in protecting human health and the environment;

X1.5.9.3 Long-term reliability and probable success in meeting the corrective action goals;

X1.5.9.4 Short-term risks posed by the implementation of the remedial action;

X1.5.9.5 Amenability of the remedial action to integration with property redevelopment plans;

X1.5.9.6 Acceptability of the remedial action to the stakeholders;

X1.5.9.7 Implementability and technical practicability of the remedial action; and

X1.5.9.8 The cost-effectiveness of the options to meet the corrective action goals.

X1.6 *RBCA Program Documentation*:

X1.6.1 In order to ensure uniform application of the RBCA program, agencies should consider providing guidance documents and standardized tools for the regulated community and stakeholders. This documentation may consist of guidance manuals, standardized report forms and software tools. Such documentation may include the following:

X1.6.2 *RBCA Process Overview*—A RBCA guidance manual should outline the RBCA process and provide detailed step-by-step instructions for implementation of the program. The manual may include flowcharts outlining the program and a description of potential exposure pathways and transport mechanisms, including any assumptions regarding land use patterns, activity and use limitations, and remedy selection criteria.

X1.6.3 *Response Action Evaluation*—As the user gathers data, site conditions should be evaluated and a response action should be implemented, consistent with site conditions. This process may be repeated as additional data affords a more detailed characterization of the site. Some programs place sites in risk reduction categories, and when actions are performed, the category automatically changes to a less urgent status. In these programs the user selects a category and action which best addresses the short-term health (human and ecological) and safety concerns of the site while implementing the RBCA process. While some programs also have risk reduction categories to generate fees or for other statutory purposes, other programs avoid long term categorization schemes to avoid attaching a stigma to a property which could affect later transactions. As with many program development elements, the regulatory agency must resolve such issues, following the stakeholder involvement process.

X1.6.4 *Tier 1 Evaluation Guidance*—Tier 1 guidance may include the algorithms used to develop look-up tables, as well as an example look-up table or tables and detailed instructions on how to use the look-up tables. The RBCA framework refers to such look-up tables as Risk-Based Screening Levels or RBSL. Table X1.1 gives a suggested outline for the technical policy decisions that define the look-up table. These decisions can be made by all stakeholders and documented by the development team. The development team may decide to avoid creating RBSL and other look-up tables as "bright-line," stand-alone targets for clean up.

X1.6.5 *Tier 2 Evaluation Guidance*—Tier 2 guidance may include detailed instructions on selection of appropriate modeling procedures, target risks, exposure scenarios, and policies regarding off-site migration of chemicals of concern, performance and compliance monitoring. The guidance may also include the criteria for evaluating Tier 2 results, conditions for tier upgrade, criteria and location of the point of compliance, corrective action alternatives, and closure options.

X1.6.6 *Tier 3 Evaluation Guidance*—The guidance for Tier 3 may simply define the tier and explain its use. In order to remain flexible, specific procedures may not be recommended, however, it may be desirable for some limits to be placed on performance standards acceptable to the agency. Evaluations at the Tier 3 level may include alternative risk and exposure assessment protocols. As with the other tiers, Tier 3 guidance may also include criteria for evaluating Tier 3 results, and explain what alternatives exist for sites to meet Tier 3 criteria, such as corrective action, monitoring programs, variance procedures, more complex fate and transport modeling and engineering controls.

X1.6.7 *Administrative Procedures*—Administrative procedures for the RBCA application submittal and review process should be clearly outlined. To the degree feasible, separate steps of the RBCA planning program (for example, site assessment, response action evaluation, and Tier 1 evaluation) may be consolidated into single submittals to minimize the number of separate reviews requested by agency personnel for each site. As the user proceeds to higher Tiers of the RBCA process, the knowledge gained about the site is used to tailor the degree of investigation needed. Approval to move from one tier to the next may not be necessary. In some cases, after completion of the Tier 1 evaluation, the program may direct the user to proceed directly to a Tier 3 evaluation. The results of all completed tiers of analysis will typically be submitted to the overseeing agency for final documentation. Upon receipt, submittals may be checked for completeness. This may be facilitated with an administrative checklist prior to in-depth evaluation. Standard site completion letters (see X1.6) issued to volunteers may also be reviewed to ensure consistency with the RBCA program. Depending on the tier and the complexity of a site, an agency may phase its involvement (that is, for some programs, little oversight may be necessary for a Tier 1 evaluation, while a Tier 3 evaluation may require significant input from the agency).

X1.6.8 *Standardized Report Forms*—Standardized report forms can be very helpful in the RBCA process, aiding in the collection of site data and in both the preparation and review of site reports. Properly designed standardized report forms may guide the user in the collection of the appropriate type and amount of data. These forms can be of the "fill-in-the-blank" or "cross reference" variety, or both, for Tiers 1 and 2, and may outline general procedures to be used in Tier 3.

X1.6.9 *Tier 1/Tier 2 Software Tools*—A helpful element in a successful RBCA program may be computer software that assists both the regulatory agency and the regulated community in understanding and performing the multitude of necessary calculations. With the increasing use and power of personal desktop computers and the availability of common spreadsheet programs, user-friendly software tools can be developed for use by technical staff with minimal training in computer applications. These tools can be customized to include specific exposure pathways and algorithms, and can be programmed to

report results in a standardized format, suitable for inclusion into site assessment reports.

X1.7 *Specialized Program Elements*:

X1.7.1 *Introduction*—This section of the appendix provides a review of program elements currently being used by regulatory agencies including those with licensed or certified private contractors. The items described include those used in state voluntary cleanup programs (VCPs) and a variety of other programs to provide site closure or completion, as well as comparable assurances available from the Federal government. The term *completion letters* includes letters and other types of documents, including covenants, certificates and agreements, being used to provide interested parties with assurances that a voluntary corrective action has adequately identified the chemicals of concern from releases into the environment, has adequately identified exposure pathways and any unacceptable risks posed by those chemicals of concern to human health or the environment, and has achieved an appropriate target level. This section of the appendix gives examples of the types of completion documents currently being used by various states or the Federal government,or both, and describes some of the advantages and disadvantages of each type of completion method.

X1.7.2 Program elements vary in form and content. Some consist of completion letters and are very formal, while others are very informal. The interested party must petition for or request a completion letter in some states, whereas in other states the completion document is granted automatically upon the completion of certain activities.

X1.7.3 For further information about a particular state's program, contact the Association of State and Territorial Solid Waste Management Officials (ASTSWMO) or the Regional office of the Environmental Protection Agency (EPA).

X1.7.4 Example Program Elements.

X1.7.4.1 *Application Process*—Many states require an application for interested parties to participate in the VCPs. Some states require the volunteer to sign a formal agreement, such as a consent agreement.

X1.7.4.2 *Submission of Reports*—Some states require submission of reports once remediation has been completed.

X1.7.4.3 *State-Certified or Licensed Contractors*—Some states require the use of state-certified professionals, or laboratories, or both to conduct a cleanup.

X1.7.4.4 *Environmental Professional*—Some states require submission of a statement, opinion or certification from a qualified environmental professional that the voluntary cleanup plan has been fully implemented or completed and that the remediation meets applicable standards.

X1.7.4.5 *Letter Agreement or Formal Consent Order*—Some states require a memorandum/letter of agreement or consent order before the volunteer can participate in the VCP.

X1.7.4.6 *Prior Approval*—Some states require prior approval of work plans, or reports, or both.

X1.7.4.7 *Reopeners*—Many states have explicit reopener provisions in their completion letters for changed conditions, new information, or failure to comply with the voluntary cleanup plan.

X1.7.4.8 *Consideration of Future Land Use*—Many states take future land use into consideration in making risk-based decisions and have developed (by policy or statute) activity and use limitations to address future land use changes.

X1.7.4.9 *Reimbursement of State Oversight Costs*—Many states require reimbursement of their oversight or laboratory or other costs.

X1.7.5 *Examples of Completion Documents*—The types of completion documents currently being used by the states include, but are not necessarily limited to, the following: statements or certificates of completion; no further action opinions/letters; no action letters; private contractor statements of completion; off-site source determination letters; covenants not to sue; releases; contribution protection; no association determination letters; and prospective purchaser agreements. The terminology for a specific type of completion letter in one state may not mean the same thing in another state, and the descriptions given below are very general in nature.

X1.7.5.1 *Statements or Certificates of Completion of Response Action*—In some states, Statements or Certificates of Completion of Response Action are relatively straight-forward to obtain from regulatory agencies. They provide some certainty that the regulatory agency is satisfied that no further corrective action is required at the site. Legally, however, they generally are not as binding as other types of completion letters, such as covenants not to sue. Accordingly, in these states, Certificates of Completion may be viewed by some interested parties as not providing sufficient comfort against further liability. However, in other states, a Statement or Certificate of Completion is a complete release of state superfund liability and runs with the land; as such, it provides liability assurances to successors and assigns as well. A Statement or Certificate of Completion in these states is likely to be viewed quite favorably by interested parties, but it may be more time-consuming to obtain. Some state programs tie the certificate of completion to specific exposure pathway assumptions, such as land use.

X1.7.5.2 *No Further Action Opinions/Letters/Assurance Letters*—As a general rule, no further action opinions or letters are relatively straight-forward to obtain from regulatory agencies. They provide some certainty that the regulatory agency is satisfied that no further corrective action is required at the site. EPA, for example, has developed generic ways to encourage redevelopment including a designation of No Further Remedial Action Planned for sites listed in the CERCLIS inventory. No Further Action Opinions or Letters generally do not constitute a release from further liability at the site. Legally, therefore, they do not provide the same level of comfort as, for example, a covenant not to sue. Accordingly, No Further Action Opinions or Letters may be viewed by some interested parties as not providing sufficient comfort against further liability.

X1.7.5.3 No Further Action Opinions or Letters can also be written as Limited No Further Action Opinions or Letters. Limited No Further Action Opinions or Letters pertain to only a portion of the property or to only some of the known releases at a site. For example, they might address and document releases to the soil, but not potential ground water releases. They are helpful when a discrete issue is slowing down a real

estate transaction because they can generally be obtained fairly quickly and easily. However, they are limited in nature and do not provide the same degree of comfort that most other types of completion letters offer.

X1.7.5.4 *No Action Letter*—A No Action Letter is essentially a no further action letter, except that it includes additional language indicating that the state will not take any enforcement/administrative actions once the regulatory agency is satisfied with the volunteer's technical conclusions. A No Action Letter will often say that the release (site) will not be referred to the Superfund program and will not be added to CERCLIS or the state Superfund list.

X1.7.5.5 Private Contractor Statements of Completion or No Further Action Letters provide an alternative where the state does not have sufficient resources to review every site investigation and remediation to determine its adequacy. In the states with this type of program, the private contractor must be state-licensed or certified, so there is indirect state oversight over the process. Private Contractor Statements of Completion/No Further Action Letters are generally available more quickly and readily than other types of completion letters. Legally, however, they are not as binding as other types of completion letters, such as covenants not to sue. Accordingly, Private Contractor Statements of Completion/No Further Action Letters may be viewed by some interested parties as not providing sufficient comfort against further liability.

X1.7.5.6 *Off-Site Source Determination Letters*—Some states, as well as the Federal government, have taken the position that they will not exercise their enforcement discretion under certain circumstances where chemicals of concern originating off-site in the ground water have affected an "innocent," downgradient property. Many of these states issue letters providing that they will not hold the impacted property liable for any chemical releases originating off-site. The Federal government's position is available in the form of guidance, issued May 24, 1995, and entitled "Final Policy Toward Owners of Property Containing Contaminated Aquifers." A state Off-Site Determination Letter has the same types of advantages and disadvantages as a No Further Action Opinion or Letter.

X1.7.5.7 *Covenants Not to Sue*—Covenants Not to Sue are legally binding agreements between a state or the Federal government and an interested party. They provide assurances that the interested party will not be pursued in the future for additional remediation work or targeted in an enforcement action. At the same time, because they are more binding than most other types of completion letters discussed above, they are generally more difficult and time-consuming to obtain. They generally must be negotiated on a case-by-case basis.

X1.7.5.8 *Releases*—Some states use releases to absolve volunteers from further responsibility for corrective action. Releases tend to be a qualitative determination that the remediation has been successfully completed; they generally do not absolve the volunteer from joint, strict and several liability. In this regard, releases have the same types of advantages and disadvantages as No Further Action Letters.

X1.7.5.9 *Contribution Protection*—A few states are providing, by statute, contribution protection to parties that voluntarily remediate a site. This protection is generally embodied in an administrative or judicial order or consent decree or a settlement agreement. Contribution protection protects the volunteer from contribution actions by other responsible parties and, in some instances, protection against citizen suits as well.

X1.7.5.10 *No Association Determination Letters*—No Association Determination Letters are being used to offer lenders, prospective purchasers, and other "innocent" parties assurances that they will not be the subject of future remediation orders or other types of enforcement actions. Similar types of protection are being offered automatically by statute (that is, without the need for a formal letter) in some states to interested persons such as lenders, municipalities, utilities, etc.

X1.7.5.11 *Prospective Purchaser Agreements*—Prospective Purchaser Agreements provide protection from liability for innocent buyers who perform remediation in accordance with a plan approved by the state or the Federal government. These agreements can be obtained from either a state offering such an mechanism, or EPA (if its an NPL site), or both. The Federal government has offered guidance, dated May 24, 1995, entitled "Guidance on Agreements With Prospective Purchasers of Contaminated Property," describing what types of sites are eligible for the Federal program. A variety of policies may be pursued which arise from EPA guidance, such as government statements of no further interest at this time.

X1.7.5.12 Other Mechanisms:

X1.7.5.13 *Review and Evaluation Services*—Many states provide review and evaluation services to determine the adequacy of any site investigations or remediation plans.

X1.7.5.14 *Reclassification of the Site or Redefinition of Site Boundaries*—Many states reclassify sites that have been remediated or deemed not to require remediation as "inactive" or redefine a site's boundaries.

X1.7.5.15 *Agreement Not to List on Federal CERCLIS*—Many states have agreed to refrain from listing sites participating in the state VCP on the Federal CERCLIS or the state Superfund list. This agreement often comes in the form of a No Action Letter or is incorporated into another type of completion letter.

X1.7.5.16 *Immunity from Enforcement Actions*—In some states, the completion letter constitutes immunity to a state enforcement action.

X1.7.5.17 *No Release*—A few states explicitly provide that current or prior owners or operators who are considered to be potentially responsible parties will *NOT* be released from liability at the site.

X1.7.6 Eligibility for Program

X1.7.6.1 *Current Owner Only*—Some states allow current owners only to participate in the VCP.

X1.7.6.2 *Lenders/Fiduciaries*—Some states allow lenders, fiduciaries, and/or other parties providing financing to participate in the VCP and thereby enjoy its benefits. In addition, some states provide liability protection automatically by statute without the need for the lender or fiduciary to obtain a completion letter from the VCP.

X1.7.6.3 *Prospective Purchasers*—Some states allow prospective purchasers the benefits from the VCP.

X1.7.6.4 *Non-Responsible Parties Only*—Some states allow only non-responsible or non-liable parties to participate in their VCPs.

X1.7.6.5 *Successors and Assigns*—Some states allow successors and assigns to enjoy the benefits from the VCP.

X1.7.6.6 *Third Party Claims*—Some states provide broad-based releases that protect the volunteer from third party claims as well.

X1.7.7 *Other Issues*:

X1.7.7.1 *Recordation*—Some states require recordation of the completion letter in local land records.

X1.7.7.2 *Audits*—Some states reserve the right to audit properties undergoing voluntary remediation.

X1.7.7.3 *Stakeholder Involvement*—Some states mandate stakeholder involvement for some or all of the sites moving through the VCP.

X1.7.7.4 *Affidavits*—Some states require that all documents relating to the VCP be submitted by affidavit.

X1.7.7.5 *Audit Privilege*—Some states provide that any information or data generated during the remediation is not admissible in any administrative or judicial action.

X1.7.7.6 *Access to Records/Records Retention*—Some states require that volunteers provide them access to remediation records and require retention of those records for a specific length of time.

X1.7.7.7 *Waiver or Consolidation of Permitting Requirements*—Some states waive or consolidate state and local permitting requirements in an effort to facilitate voluntary remediation.

X1.8 *Education/Outreach*:

X1.8.1 To ensure the success of the RBCA program, both regulatory agencies and the regulated community should be given adequate training opportunities regarding program objectives and procedural requirements. In addition, outreach efforts may be undertaken to promote understanding and acceptance of the risk-based process by other involved parties, such as community or citizen's groups and the real estate, development, banking, or insurance industries. Key considerations are summarized below.

X1.8.2 *Agency Personnel Training*—Regulatory agency personnel should receive training commensurate with their responsibilities regarding RBCA evaluations, corrective actions, and completion reports. Such training may include an overview of the RBCA process, review of key policy decisions, guidance regarding evaluation of site assessment data and selection of representative site parameters, calculation of risk-based corrective action goals, and determination of appropriate corrective actions. In general, such training will build upon the prior knowledge and experience of the agency staff, focusing on those areas in which RBCA policies may modify or expand existing procedures.

X1.8.3 *Regulated Community and Contractor Training*—The regulated community and the professional consultants and contractors involved in the RBCA program implementation should also receive a formal orientation comparable to that received by agency personnel. An effective training technique may be to train agency personnel, the regulated community and consultants simultaneously. Emphasis may be placed on available standardized tools for calculations and reporting. The regulatory agency may choose to conduct these orientation sessions and/or authorize certified trainers to conduct in-depth training workshops. Written guidance and practical case study examples will greatly improve the ability of the applicant to "get it right" the first time.

X1.8.4 *Outreach Programs*—Efforts should be considered to communicate the objectives and significance of the RBCA program to stakeholders, including members of the general public, environmental groups businesses, real estate interests, banking establishments, the insurance industry and all those potentially involved in the sale and transfer of affected properties. Key issues to address include: the significance of risk-based corrective action goals and the level of protection provided to current and future property users; the general process required to achieve site closure; and the optional mechanisms for activity and use limitations that may be applied in some cases. These outreach initiatives may take the form of printed information booklets, stakeholder forums, trade association presentations, or all of these.

X1.9 *Stakeholder Involvement Activities*:

X1.9.1 *Introduction*:

X1.9.1.1 One of the purposes of this appendix is to provide a review of generally accepted principles in successful stakeholder involvement, including risk communication. For purposes of this appendix, stakeholder involvement activities are those activities that can be used by volunteers and regulatory agencies in corrective action programs to ensure that the stakeholder is both informed of and, if interested, involved in planning for corrective actions. This incorporates the concept that risk communication activities must be designed to allow the stakeholder an opportunity to understand what the risks from chemical releases are and how they can be mitigated. In VCPs, the opportunity for stakeholder involvement activities may be provided by the state or the private sector, or both, and the opportunity may be provided during either the development of the program, on a site-specific basis, or both.

X1.9.1.2 Methods to provide the opportunity for stakeholder involvement in RBCA and risk communication programs may occur during the following steps of regulatory development:

X1.9.1.3 Initial program development;

X1.9.1.4 Policies and guidance;

X1.9.1.5 Regulation development/Implementation;

X1.9.1.6 Informal Methods;

X1.9.1.7 Risk Communication Techniques;

X1.9.1.8 Stakeholder involvement opportunities for environmental programs vary in the level of effort, form and content. Agencies can establish various regulatory requirements for the regulated community or they can fashion guidance stating the general policy of the state agency to provide maximum opportunities for stakeholder involvement in decision making. Stakeholder involvement may be program-wide and site-specific.

X1.9.1.9 The scope of stakeholder involvement for different activities is quite varied among cleanup programs. While some programs require and engage in stakeholder involvement only during the guidance or regulatory development stage, others

may require local, site-specific stakeholder involvement opportunities for each stage in the cleanup process. Three examples will illustrate this phenomenon. During private corrective actions, which may use the RBCA framework, there may be no specific regulatory approval or required stakeholder involvement activities. Insurance companies, for example, may use RBCA to determine "prudent to do" actions for their clients, without requiring site-specific stakeholder involvement. In the second example, Pennsylvania developed its Act 2, Land Recycling Program using stakeholder participation. Specific sites, however, which use the background or statewide health standards, require notification only and do not require any further stakeholder involvement to complete cleanup. The rationale here is that stakeholder input on the basis of cleanup was provided at once in developing the program. Finally, Massachusetts developed its RBCA program and required milestone public notification requirements for each site in the program. Furthermore, with a citizen petition, responsible parties are required to formulate and implement a Public Participation Plan for an individual site, including public meetings at each milestone of the cleanup process. Clearly these examples represent the spectrum as to the scope and level of effort of stakeholder involvement in RBCA programs.

X1.9.2 *Risk Communication*—The use of the RBCA guide, as with all technical materials, will require a sincere attempt to communicate with stakeholders. Some basic principles of risk communication are articulated in this appendix.

X1.9.3 *Program Development*—Many state VCPs and other cleanup programs have either required or voluntarily included stakeholder involvement during development. The use of advisory committees, surveys of potential stakeholders, and workgroups from the regulated community are all techniques that have been employed to develop a VCP. These methods are in addition to any statutory public hearing requirements, and generally reflect the unique nature of VCPs. During this process, the scientific underpinnings supporting RBCA methods should be clearly explained to stakeholders.

X1.9.4 *Policies and Guidance*:

X1.9.4.1 Many VCPs are built on policies and guidance written by the regulatory agency. Such documents may recommend general or specific opportunities for stakeholder involvement opportunities.

X1.9.4.2 At sites where the stakeholders indicate an interest in participating in response action planning and implementation, policy and guidance may recommend that opportunities be established in a stakeholder involvement plan that is prepared in response to petition or more informal request or a request by local officials. Such a plan may: provide background about the site, response actions already conducted, and the history of stakeholder involvement at the site; identify the specific opportunities for stakeholder involvement in cleanup decisions that will take place; and describe activities that will be undertaken to address and incorporate concerns in the remediation. Stakeholders may also be involved in risk reduction measures and/or remediation done as part of a state VCP. In addition to its utility at the overall program development phase, the stakeholders meeting may be an effective communication technique at an individual site. Site-specific stakeholder meetings may be used to discuss the identified regulatory approach, identify critical data gaps such as fundamental information on exposure pathways and receptors, and ultimately to communicate the selected risk-based corrective actions for the chemical release.

X1.9.4.3 Specific techniques recognized in agency guidance may also include the regular publication and distribution of site fact sheets and conducting community interviews.

X1.9.5 *Regulations*—Many regulatory agencies have promulgated specific regulations which require formal, documented opportunities for stakeholder involvement. Public meetings or hearings, either formal or informal, may be required at certain stages of corrective action decision making such as the selection of remedy. Other requirements may include activities that inform stakeholders about the status of response actions. These activities include, among others, notifications to local officials and publication of legal notices in newspapers at key milestones in the response action process. In addition, because future use of a site is a major determinant of remediation goals, regulations may require consideration of local land use planning activities to determine current and potentially feasible future site uses.

X1.9.6 *Informal Methods*—The use of the RBCA guidance includes site assessment activities that by their very nature require close contact with stakeholders and the local government. Everything from site access to sampling, to the review of town records, requires interaction with people who live and work in the community where the site is located. Informal stakeholder involvement requires tact, honesty and a willingness on the part of the user of the guide to communicate with many different people about the site. Sometimes, the understanding of site conditions and remediation challenges are more effected by such informal interactions than they are by public hearings or meetings.

X1.9.7 *Risk Communication Techniques*:

X1.9.7.1 People in the community should be well informed about the true risks presented by a site and the decision-making process regarding assessment and cleanup activities at a site. It is important to communicate with residents as often as possible and at a level that can be easily understood.

X1.9.7.2 The use of jargon and acronyms should be strictly limited during interactions with stakeholders. Written and oral presentations should consider material at the 9th or 10th grade reading level for ease of understanding among adults who are not technically trained. Long involved sentences with multiple clauses may be avoided by substituting simple direct statements and familiar terms.

X1.9.7.3 Comparative risks from chemicals and from everyday activities may be a tool for consideration in communication of risks. The risks of getting struck by lightning, for example, might be compared with the risks of cancer from an individual chemical at an individual site. The cumulative risks of driving an automobile might be compared with cumulative risks from a site. In addition there is a need to compare actual, expected risk with calculated or theoretical risk which may be based on upper bound, conservative estimates.

X1.9.7.4 Caution in the use of comparative examples must be exercised because of the perception of risks by individuals

and communities, as well as understandable sensitivity to the comparison of voluntary versus involuntary risks. Risks that are natural, not man-made and that are part of a community's everyday experience may not be perceived as very high risks. In rural communities, for example, while the risk of contracting Lyme disease transmitted from ticks may be quite high, the perceived risk is surprisingly low. While the risks of injury from motor vehicles are quite high, because riding in a car or on the bus is more or less voluntary, the perceived risks and level of outrage generated by cars in the community may be much lower than the perceived risk and level of outrage generated by the presence of chemical releases in the neighborhood. Regardless of the use of comparative risk tools, stakeholder involvement in decision making will eventually lower both the level of outrage and the perceived risks from a site, because it gives communities and individuals a greater sense of control over the risks.

X1.10 *RBCA Program Evaluation*:

X1.10.1 Evaluation of the proposed RBCA process may assess the impact of critical policy decisions and optimize program efficiency. This evaluation can be conducted before, during, or after development and implementation. It may be a cooperative effort among various organizations representing industry, government and other stakeholders. Such program evaluations may include one or more administrative reviews of technical investigations described below.

X1.10.2 *Administrative Review*—Administrative process flowcharts of the proposed RBCA program and the existing corrective action rules may be developed and compared to characterize the scope and timing of principal steps involved in the site evaluation, remediation, and closure process. Key issues in this assessment will be the clarity and completeness of the site management process, as well as the number of review and approval steps imposed upon the regulatory authority. Consistent with the goals of RBCA, the administrative process should serve to expedite action at higher risk sites.

X1.10.3 *Demonstration Projects*—A demonstration project involves processing a limited number of sites (for example, less than ten) through the RBCA program in as much detail as possible. The objective of the demonstration effort is to check the completeness of the proposed RBCA guidelines, identify possible conflicts or constraints on implementation, and predict general effects on remediation requirements or costs.

X1.10.4 *Planning Level Studies*—A planning level study involves processing a large number of sites (that is, all of one company's sites in a state or region, or a random selection from all sites in the state or region) through the RBCA process. Results from any demonstration projects may also be integrated into planning level studies. This study can often give a clear picture of the potential resource savings made possible by adopting a RBCA program, as well as the potential impact of a given policy decision on the rate of site closures under Tiers 1 and 2.

X1.11 *Available Resources*—Development and implementation of a RBCA program will require a significant commitment on the part of the development team. However, those RBCA programs presently in place in various states have demonstrated that this effort can yield significant benefits in terms of expediting the site remediation process and ensuring efficient allocation of limited resources to high priority sites. Parties interested in developing a RBCA program are encouraged to contact those state agencies with programs currently underway for examples of written guidelines and direct experience with procedural challenges and successes. The EPA Office of Underground Storage Tanks (OUST) and Office of Solid Waste and Emergency Response (OSWER) are presently maintaining an information clearinghouse for RBCA programs and can provide data regarding document resources and contact names. Table X1.2 shows some program attributes of the various state programs.

TABLE X1.2 Suggested Action Item Checklist for RBCA Program Implementation

Program Design Tasks
- Response Action Evaluation System
- Chemicals of Concern List
- Target Risk Limits
- Applicable Exposure Factors
- Tier 1 RBCA Equations
- Tier 2 RBCA Modeling Requirements
- Point of Compliance Definitions
- Compliance Monitoring Specifications
- Risk Management Options (Institutional controls, long-term engineering controls, other activity and use limitations)
- Minimum Site Characterization Requirements
- Data Sources and Uncertainty Guidelines

Agency Guidance Documents
- RBCA Guidance Manual (includes all of the following)
- Tier 1 RBSL
- Tier 2 Modeling Guidance (default parameters, approved analytical models, etc.)
- Tier 3 Modeling Guidance
- Standardized Report Formats
- Customized Tier 1/Tier 2
- RBCA Application Review Checklist

Administrative/Institutional Tasks
- Legislative Action
- Regulatory Action
- Coordination/Review with Stakeholders
- Agency Staff Training
- Education/Outreach to Regulated Community and Contractors
- RBCA Demonstration Studies

X2. CHEMICALS: THE ROLE THAT PROPERTIES AND EFFECTS PLAY IN THE RBCA PROCESS

X2.1 Introduction:

X2.1.1 The purpose of this appendix is to:

X2.1.1.1 Highlight issues that a user should consider when looking at/for site-related chemicals,

X2.1.1.2 Identify common chemical groups that may be encountered at sites,

X2.1.1.3 Define chemical properties that are environmentally relevant for examining the fate and behavior of chemicals at a site, and

X2.1.1.4 Discuss the potential human health and ecological effects of chemicals at a site.

X2.1.2 Users for whom this appendix is intended include an individual or group involved in the RBCA process including owners, operators, regulators, UST Fund managers, attorneys, consultants, legislators, and others.

X2.2 Issues for the User:

X2.2.1 Chemical data may be gathered for a variety of purposes such as supporting site assessment, response actions, comparison to RBSL, and determining SSTL. Consistent with the tiered approach employed within RBCA, additional site-specific chemical data and information may need to be collected at successive tiers to appropriately incorporate the concepts presented in this appendix into the evaluation. Examples of the types of data used during Tier 2 and 3 evaluations are presented in this appendix. Such information should be summarized in a clear and concise format in RBCA reports.

X2.2.2 The user should consider obtaining information on chemical properties and effects commensurate with the qualitative/quantitative level of the Tier (1,2, or 3) Evaluation. This appendix highlights properties and effects of chemicals as they pertain to:

X2.2.2.1 Identifying pathways of exposure,

X2.2.2.2 Providing values that are used in fate and transport estimates or models,

X2.2.2.3 Identifying the kinds of toxic effects that a chemical may pose,

X2.2.2.4 Identifying the degree of toxicity that a chemical may pose,

X2.2.2.5 Developing RBSL and SSTL values, and

X2.2.2.6 Identifying sampling and analytical needs.

X2.3 *Chemicals - Groupings, Properties, and Chemical Behavior:*

X2.3.1 *Chemical Groupings:*

X2.3.1.1 This RBCA standard has been developed for use at sites that could contain any number of chemicals, and hence crosses over many types of manufacturing, production, and disposal processes. When the user plans how to approach the collection of data to support the tiered evaluation at any given level, consideration must be given to determining chemical concentrations for groupings of chemicals appropriate to the site such that fate, transport, behavior, and exposure are addressed. The chemical groupings selected as examples for this appendix are based on the frequency they are encountered

at sites, and environmentally relevant physicochemical properties that determine their fate and behavior at the site. These groupings correlate with many of the analyses developed in the Ref **(3)** that were designed to capture broad classes of chemicals in a variety of sample matrices (see Table X2.1). The table provides the user with insight into commonly defined broad classes of chemicals as well as the predominant methods used for their analysis. While it is not all encompassing, it provides the user with guidance as a possible approach for categorizing chemicals and for requesting appropriate analytical methods for measuring those chemicals in different environmental media. The analytical methods in Table X2.1 are used only to illustrate logical groupings of chemicals. Because methods change with time, the user needs to identify the analytical methods that are acceptable and appropriate for the specific application.

X2.3.2 *Chemical Properties*:

X2.3.2.1 The fate and transport of chemicals in the environment is largely a function of their physicochemical properties under differing ambient environmental conditions. The physicochemical properties of a chemical can be used to infer its equilibrium distribution between the various environmental compartments and to study its behavior within a single environmental medium. Exposures may also occur under non-equilibrium conditions. In such cases, the rate of release of a chemical may influence exposure. The relationships between chemical properties and environmental media govern these processes. Rates of chemical release can affect a chemical's bioavailability. Environmental conditions and route of exposure to human or ecological receptors also influence rates of release and bioavailability. Information on soil properties can be helpful for evaluating and modeling the bioavailability of inorganic and organic chemicals.

X2.3.2.2 For organic compounds, investigators often consider the following physicochemical properties when studying environmental behavior, transport, and accumulation: aqueous solubility (S or C_w), vapor pressure (V_p or P^o), Henry's Law constant (H or K_H), octanol-water partition coefficient (K_{ow}), and organic carbon partition coefficient (K_{oc}). The fate and transport of inorganic compounds, such as metals, can be influenced by their chemical speciation and properties such as complexation reactivity, surface reactivity, and aqueous solubility. Although these physicochemical properties govern the transfer of chemicals between the various environmental media and do not reflect the rates of the various exchange processes (that is, no consideration of kinetics), knowledge of such physicochemical properties is useful when assessing chemical movement between media and the relative importance of various source and sink terms within media. Other important processes that affect the transport and fate for organic and inorganic compounds can include biodegradation, chemical release from soil and sediment solids, sequestration, chemical transformations such as acid-base reactions, redox reactions, hydrolysis reactions, and direct and indirect photochemical transformations. The kinetics of chemical release is a key aspect of exposure for chemicals that are adsorbed or sequestered. In cases where equilibrium relationships overestimate exposures, information on the kinetics of release can be especially valuable. These may be important for ground water, exposure to humans, and exposure to ecological receptors.

X2.3.3 *Defining Physicochemical Properties:*

X2.3.3.1 Aqueous solubility (S or C_w) refers to the maximum concentration that a pure compound can achieve in water at equilibrium. This property is measured in the laboratory and provided in various texts on environmental chemistry.

X2.3.3.2 Vapor pressure (V_p or P^o) is a measure of the partial pressure of the vapor phase of a compound at equilibrium with its pure condensed phase (either liquid or solid). Vapor pressure reflects the tendency of a compound to flee the condensed phase and enter the gaseous phase and is highly dependent upon temperature. This property is measured in the laboratory and provided in various texts on environmental chemistry.

X2.3.3.3 The Henry's Law constant (H or K_H) is the ratio of the partial pressure of a compound in air to its concentration in water at equilibrium. The Henry's Law constant is an air-water partitioning coefficient and, for a particular compound, it can be simply estimated by knowing the compound's aqueous

TABLE X2.1 Chemical Grouping Summary Derived from EPA SW-846 Methods (3)

Chemical Grouping	Chemical Analytical Method Number	Analytical Method	Description of Chemicals in Grouping
Halogenated VOCs	8010 B II (see also 8240/8260)	GC	Mixed aromatics and aliphatics, single and multiple halogens
Aromatic VOCs	8021 A II (see also 8240/8260)	Capillary GC/PID & ECD in series	BTEXs, mixed aromatic and aliphatics, without halogens, and with single/multiple halogens
Phenols	8040	GC	Basic phenol, plus chloro, methyl and nitro substituted phenols
Phthalate Esters	8061 II	Capillary GC/ECD	Various phthalate esters, substituted and non-substituted
Organochlorine Pesticides + PCBs as Arochlors	8080 A II/8081 II	8080 A II: GC 8081 II: Capillary GC	Organochlorine Pesticides, PCBs as Arochlors
PAHs	8100, 8310	8100: GC, 8310: LC	PAHs
Chlorinated Hydrocarbons	8120 A II, 8121 II	8120 A II: GC II: Capillary GC	8121 8120 A II: Aromatics, saturated/unsaturated aliphatics (subset of 8121 II), 8121 II: more compounds than 8120 A II
Non-Halogenated VOCs	8240 B II, 8260 A II	8240 B II: GC/MS A II: Capillary GC/MS	8260 8240 B II: Broad list of compounds, 8260 A II: more compounds than 8240 B II, isomeric resolution
Non-Halogenated SVOCs	8250 A II, 8270 B II	8250 A II: GC/MS 8270 B II: Capillary GC/MS	8250 A II: Broad list of compounds, 8270 B II: more compounds than 8250 A II, isomeric resolution
Metals	7000 Series	AA/direct aspiration, furnace technique, gaseous hydride, borohydride reduction	All metals except mercury
Mercury	7470 A II, 7471 A II	Manual cold vapor technique	Mercury

solubility and vapor pressure at a given temperature. This property is measured in the laboratory and provided in various texts on environmental chemistry.

X2.3.3.4 The octanol-water partition coefficient (K_{ow}) is a dimensionless constant which reflects the tendency of a chemical to partition between an organic phase (octanol) and water. The octanol-water partition coefficient is essentially a measure of a compound's hydrophobicity, and more hydrophobic compounds will preferentially partition into the more nonpolar octanol phase as well as into other nonpolar phases such as natural organic matter. This property is measured in the laboratory and provided in various texts on environmental chemistry.

X2.3.3.5 The organic carbon partition coefficient (K_{oc}) is a measure of the tendency of a chemical to partition between organic carbon in soil or sediment and water. This property is either measured in the laboratory or estimated from Kow.

X2.3.3.6 Chemical speciation refers to the oxidation state of a metal. It can be measured in the laboratory or estimated from environmental conditions.

X2.3.3.7 Complexation reactivity refers to the tendency of two dissolved species to react to form a third species. Complexation reactions are reversible processes, and the product species can be either soluble or insoluble as a precipitate. This property can be measured in the laboratory or estimated from environmental conditions.

X2.3.3.8 Surface reactivity refers to the tendency of solutes (for example, charged metals) to react with solid surfaces. Surface reactions can involve the formation of chemical bonds between solutes and surface moieties (for example, carboxyl, phenolic, or sulfhydryl groups) or electrostatic interaction between ions and charged surfaces (for example, ion exchange).

X2.3.3.9 Density refers to the mass of a substance per unit volume (g/cc). This parameter is measured in the laboratory under specific conditions, and estimated or modeled under field conditions.

X2.3.3.10 Availability referes to the ability of a chemical to be released from a soil particle and thus be available for degradation, volatilization, or other mechanisms that have an effect on the transport, exposure and toxicity of the chemical. Laboratory protocols can be used to estimate values for rapid and slow, long-term release of this process in soils.

X2.3.4 *Environmental Behavior and Exposure Pathways:*

X2.3.4.1 The chemical groupings presented in this section are based upon the SW-846 groups given in Table X2.1. These groups are further organized by physicochemical properties (see Table X2.2) and environmental behavior (see Table X2.3). Toxicological criteria and effects information is presented in X2.4 to X2.6.

X2.3.4.2 The table on physicochemical properties (see Table X2.2) gives the user examples of chemicals within each of the chemical groupings presented in Table X2.1. The example chemicals were chosen to illustrate the range of physicochemical properties that exists within each grouping. It is critical that the user understand that reported values for these physicochemical properties can vary widely among reference sources and that the values reported in Table X2.2 reflect only the references cited.

X2.3.4.3 The table on environmental behavior (See Table X2.3) provides the user with a semi-quantitative indication of how chemicals might move between different environmental media. It is intended to be used at an early stage of investigation to guide sampling activities and to aid in the development of an exposure analysis. It is not intended to provide an indication of the level of risk associated with exposure because it does not incorporate toxicity information. The table employs qualitative designations of low, medium, and high (L, M, and H) to rank potential exposure pathways. The semi-quantitative designations in the table usually span a range (for example, L-M, M-H) which reflects both variations in physicochemical properties within the chemical groupings and possible site-specific variations. In some cases potential for exposure will depend on specific activities (for example, excavation of soil) or on other site-specific conditions. The user is advised to review the footnotes for additional guidance on these modifying factors.

X2.3.4.4 The effects that these properties have on environmental behavior and exposure pathways are discussed below with an example compound(s) provided for each chemical grouping. Again, these descriptions are general, as site-specific factors can influence the behavior of compounds.

X2.3.5 *Halogenated Volatile Organic Compounds:*

X2.3.5.1 These compounds are volatile and soluble in water as indicated by their Henry's Law constants and solubility values, respectively. They tend to have a low residence time in surface soil and surface water environments. However, they can leach to and migrate in ground water where they are typically more persistent than non-halogenated compounds.

X2.3.5.2 Major exposure routes include the ingestion of impacted ground water and the inhalation of vapors. These compounds usually do not accumulate in the food chain.

X2.3.6 *Non-Halogenated Volatile Organic Compounds:*

X2.3.6.1 These chemicals tend to be relatively soluble in water, and therefore can be transported to ground water systems, and be distributed between the various environmental media in a similar fashion to the halogenated VOCs. While their environmental fates are similar to the halogenated VOCs, abiotic transformations and biodegradation can be more important processes for non-halogenated VOCs, reducing their residence times in the subsurface environment.

X2.3.6.2 The potentially important exposure pathways again include the ingestion of impacted ground water and the inhalation of vapors from soil and ground water.

X2.3.7 *Alkylated Benzenes:*

X2.3.7.1 Alkylated benzenes such as the BTEX compounds (benzene, toluene, ethylbenzene, and xylenes) have high vapor pressures and are relatively soluble in water. Due to their high vapor pressures, volatilization is often an important removal process for these compounds. These compounds also have a tendency to leach from impacted soils to the water table, with subsequent transport in ground water. They are mobile in the subsurface due to their relatively high aqueous solubilities and low octanol-water partition coefficients. Biodegradation can be

TABLE X2.2 Physicochemical Properties of Sample Compounds Selected to Represent the Magnitude and Range of Properties within Environmentally Significant Compound Classes[A]

Compound Class	Sample Compounds	C_w Aqueous Solubility (mg/L)	P° Vapor Pressure (torr)	K_H Henry's Law Constant (L atm mol^{-1})	log K_{ow} Octanol-Water Partition Coefficient	K_{oc} Organic Carbon Partition Coefficient (mL/g)[B]
Organics						
Halogenated Volatile Organic Compounds	Dichloromethane	1.9E+04	4.5E+02	2.60E+00	1.15	1.1E+01
	Tetrachloroethene	1.50E+02	1.91E+01	2.75E+01	2.88	3.7E+02
Non-halogenated Volatile Organic Compounds	Carbon Disulfide[C]	2.10E+03 (20°C)	2.97E+02 (20°C)	1.4E+00 (20°C)	1.70-4.16	6.5E+01
	Methyl Ethyl Ketone[C]	2.39E+05	9.06E+01	1.05E-02	0.29	4.8E+00
Alkylated Benzenes (subset of Aromatic VOCs)	Benzene	1.79E+03	9.6E+01	5.5E+00	2.13	5.4E+01
	Ethylbenzene	1.68E+02	9.57E+00	7.9E+00	3.15	5.8E+02
Chlorinated Benzenes (subset of Chlorinated Hydrocarbons)	1,2-Dichlorobenzene	1.18E+02	1.48E+00	2.5E+00	3.38	1.0E+03
	Hexachlorobenzene	5.81E-03	2.35E-05	1.50E+00	5.5	7.4E+04
Phenols	Phenol	9.0E+05	1.95E-01	4.1E-04	1.45	2.3E+00
	2-Chlorophenol[C]	2.80E+04	1.42E+00	5.6E-04	2.15	6.2E+01
Phthalate Esters	Dimethyl Phthalate	4.25E+03	1.82E-02	1.10E-03	1.53	4.4E+01
	Di-n-butyl Pththalate	9.43E+00	7.26E-05	1.29E-03	4.57	1.3E+03
Polychlorinated Biphenyls (PCBs)	Aldrin[C]	0.02(20°C)	0.0000375 (20°C)	5.0E-01	6.5	3.8E+04
and Organochlorine Pesticides	Dieldrin	2.20E-01	5.02E-06	1.12E-02	5.48	9.9E+03
Organic Acids and Bases	Benzoic Acid[C,D]	2700 (18°C)	4.5e-3 (20°C)	7.00E-05	1.87	5.7E+01
	Aniline[C,E]	3.61E+04	4.89E-01	1.20E-01	0.9	1.4E+01
Polycyclic Aromatic Hydrocarbons (PAHs)	Naphthalene	3.15E+02	7.96E-02	4.3E-01	3.36	1.4E+03
	Benzo(a)pyrene	1.52E-03	5.51E-09	1.20E-03	6.50	1.9E+06
Inorganics						
Metals[C]	Lead	NA	1.00E+01 (1160°C)	NA	NA	NA
	Mercury	NA	2.00E-03	NA	NA	NA

[A] All data is for 25°C and was taken from Schwarzenbach et al. **(4)**unless otherwise noted.
[B] All K_{oc} values estimated using linear free energy relationships.
[C] Data from Howard **(5)**.
[D] Benzoic Acid is an organic acid and has an acid dissociation (pKa) of 4.1 **(5)**.
[E] Aniline is an organic base and has a base dissociation constant (pKb) of 9.4 **(5)**.

an important removal process for alkylated benzenes in soil and aquifer systems, thus reducing their residence times in these media.

X2.3.7.2 Ingestion of, or dermal contact with, impacted ground water, and inhalation of vapors from soil and water can be important exposure pathways for alkylated benzenes.

X2.3.8 *Polycyclic Aromatic Hydrocarbons (PAHs):*

X2.3.8.1 These compounds have a high affinity for organic matter and are relatively insoluble in water, as reflected in high Koc and Kow values, and low aqueous solubilities. PAHs tend to remain bound to particulates and dissolve slowly in water. As such, the physical fate of these chemicals is usually controlled by the transport of particulates and the release of the chemicals from soil and sediment solids. Consequently, soil, sediment, and suspended particulate matter are the more common media for transport. Biodegradation by microorganisms is an important removal process for PAHs. Volatilization can also be an important removal process for the lighter molecular weight PAHs.

X2.3.8.2 Direct contact with impacted media, as well as inhalation of fugitive dust can be important exposure pathways for PAHs. PAHs may occur in select food stuffs, including the leaves of plants after atmospheric deposition and in shellfish through bioaccumulation. These chemicals do not typically bioaccumulate in vertebrates such as fish.

X2.3.9 Phenols:

X2.3.9.1 These compounds are highly water soluble and can leach from soil into underlying ground water systems. They are not persistent in surface waters due to rapid microbial and indirect photolytic degradation. Phenols are not highly volatile compounds, nor are they readily bioaccumulated by terrestrial or aquatic biota.

X2.3.9.2 Important exposure pathways for phenols could include ingestion of ground and surface waters, as well as dermal contact with such waters. Exposure to phenols would have to occur soon after their release due to their rapid disappearance from natural waters.

X2.3.10 *Phthalate Esters:*

X2.3.10.1 Phthalate esters vary greatly in their water solubility and sorptive characteristics. Some can be very water-soluble and can thus migrate horizontally in surface runoff to surface water bodies, or can vertically migrate in soil solutions to the underlying water table. Others tend to sorb strongly to organic matter. Direct photolysis can also act to remove phthalate esters in surface waters. Volatilization is not an

TABLE X2.3 Qualitative Ranking of Important Potential Exposure Pathways Based on Chemical Behavior for Common Site Contaminants Grouped by Compound Class[A,B,C,D]

Compound Class	Contaminated Media				
	Surface Soils	Sub-surface Soils[E]	Ground Water[F]	Sediment[G]	Surface Water[G]
Organics					
Halogenated Volatile Organic Compounds (e.g., dichloromethane, tetrachloroethene)	direct contact: L→M leaching to gw: M→H vapor formation: H fugitive dusts: L→M surface runoff: M→H	direct contact: L→M vapor formation: H leaching to gw: M→H fugitive dust: L	vapor formation: H ingestion: M→H transport to surface water: M→H	direct contact: M→H ingestion of biota: L vapor formation: H transfer to overlying waters: H	direct contact: M→H vapor formation: H ingestion of water: M→H ingestion of biota: L
Non-halogenated Volatile Organic Compounds (e.g., carbon disulfide, methyl ethyl ketone)	direct contact: L→M leaching to gw: M→H vapor formation: H fugitive dusts: L→M surface runoff: M→H	direct contact: L→M vapor formation: H leaching to gw: M→H fugitive dust: L	vapor formation: H ingestion: L→M transport to surface water: L→M	direct contact: M→H ingestion of biota: L vapor formation: H transfer to overlying waters: H	direct contact: M→H vapor formation: H ingestion of water: M→H ingestion of biota: L
Alkylated Benzenes (subset of Aromatic VOCs) (e.g., benzene, ethylbenzene)	direct contact: L→M leaching to gw: M→H vapor formation: H fugitive dusts: L→M surface runoff: M→H	direct contact: L→M vapor formation: H leaching to gw: M→H fugitive dust: L→M	vapor formation: H ingestion: M→H transport to surface water: M→H	direct contact: L→M ingestion of biota: L vapor formation: H transfer to overlying waters: H	direct contact: M→H vapor formation: H ingestion of water: M→H ingestion of biota: L
Chlorinated Benzenes (subset of Chlorinated Hydrocarbons) e.g., 1,2-dichlorobenzene, hexachlorobenzene)	direct contact: M→H leaching to gw: L→M vapor formation: L→M fugitive dusts: M→H surface runoff: L→M	direct contact: M→H vapor formation: L→M leaching to gw: L→M fugitive dust: M→H	vapor formation: L→M ingestion: M→H transport to surface water: M→H	direct contact: M→H ingestion of biota: L→N vapor formation: L→M transfer to overlying waters: L→M	direct contact: M→H vapor formation: L→M ingestion of water: M→H ingestion of biota: L→M
Phenols (e.g., phenol, 2-chlorophenol)	direct contact: M leaching to gw: H vapor formation: L→M fugitive dusts: M surface runoff: H	direct contact: L→M vapor formation: L→M leaching to gw: H fugitive dust: L→M	vapor formation: L→M ingestion: M→H transport to surface water: M→H	direct contact: L→M ingestion of biota: L vapor formation: L→M transfer to overlying waters: H	direct contact: M→H vapor formation: L ingestion of water: M→H ingestion of biota: L
Phthalate Esters (e.g., dimethyl phthalate, di-n-butyl-phthalate)	direct contact: M→H leaching to gw: L→M vapor formation: L fugitive dusts: M→H surface runoff: L→M	direct contact: M→H vapor formation: L leaching to gw: L→M fugitive dust: M→H	vapor formation: L ingestion: M→H transport to surface water: L→M	direct contact: M→H ingestion of biota: L vapor formation: L transfer to overlying waters: L→M	direct contact: M→H vapor formation: L ingestion of water: M→H ingestion of biota: L
Polychlorinated Biphenyls (PCBs) and Organochlorine Pesticides (e.g., aldrin, dieldrin)	direct contact: M→H leaching to gw: L→M vapor formation: L→M fugitive dusts: M→H surface runoff: L→M	direct contact: M→H vapor formation: L→M leaching to gw: L→M fugitive dust: M→H	vapor formation: L→M ingestion: M→H transport to surface water: M→H	direct contact: M→H ingestion of biota: M→H vapor formation: L→M transfer to overlying waters: L→M	direct contact: M→H vapor formation: L→M ingestion of water: M→H ingestion of biota: M→H
Polycyclic Aromatic Hydrocarbons (PAHs) (e.g., naphthalene, benzo(a)pyrene)	direct contact: M→H leaching to gw: L vapor formation: L fugitive dusts: M→H surface runoff: L→M	direct contact: M→H vapor formation: L leaching to gw: L→M fugitive dust: M→H	vapor formation: L ingestion: M→H transport to surface water: L→M	direct contact: M→H ingestion of biota: L→M vapor formation: L transfer to overlying waters: L→M	direct contact: M→H vapor formation: L ingestion of water: M→H ingestion of biota: L→M
Inorganics					
Metals (e.g., lead, mercury)	direct contact: M→H leaching to gw: L→M vapor formation: L[H] fugitive dusts: M→H surface runoff: L→M	direct contact: M→H vapor formation: L[H] leaching to gw: L→M fugitive dust: M→H	vapor formation: L[H] ingestion: L→M transport to surface water: L→M	direct contact: M→H ingestion of biota: L→M vapor formation: L[H] transfer to overlying waters: L→M	direct contact: M→H vapor formation: L[H] ingestion of water: M→H ingestion of biota: L→M

[A] Assumes chemical release directly into media of interest with subsequent fate and transport processes acting to influence contaminant concentration in media of interest (that is, through transformations and distribution among other media).
[B] L = low, M = moderate, and H = high
[C] Direct contact refers to both incidental ingestion and dermal contact.
[D] gw = ground water
[E] For direct contact and fugitive dust, potential exposure is via excavation.
[F] For ingestion, potential exposure is via transport to a water supply.
[G] For ingestion, potential exposure is via bioaccumulation in edible aquatic organisms.
[H] Mercury is a extremely volatile metal when present in its elemental form [Hg(O)], and vapors are thus often an important exposure pathway for this metal.

important fate processes for phthalate esters due to low vapor pressures and Henry's Law constants.

X2.3.10.2 Potential exposure to phthalate esters can occur via direct contact with impacted media and through ingestion of ground and surface waters.

X2.3.11 *Polychlorinated Biphenyls (PCBs) and Organochlorine Pesticides:*

X2.3.11.1 Polychlorinated biphenyls and organochlorine pesticides are generally very hydrophobic and persistent in environmental media due to low aqueous solubilities, high

octanol-water partition coefficients, and high organic carbon partition coefficients. Therefore, these compounds tend to sorb to soil matrices where they are effectively sequestered and are not easily released for subsequent transport by water or air. However, due to high Henry's Law constants, if solubilized these compounds can be transferred from water surfaces to the overlying air.

X2.3.11.2 Important exposure pathways for PCBs include direct contact with impacted media and ingestion of PCB-containing foodstuffs. Exposure to PCBs, in particular the less highly chlorinated species, can also occur via inhalation of vapors. PCBs and organochlorine pesticides can bioaccumulate and biomagnify.

X2.3.12 *Chlorinated Benzenes:*

X2.3.12.1 Physicochemical properties of the chlorinated benzenes span a wide range and consequently the various chlorinated benzenes have contrasting environmental fates. Volatilization from ground and water surfaces are important processes for the mono- and di-chlorinated compounds as these compounds have high vapor pressures, and high Henry's Law constants. The less chlorinated compounds are also more soluble in water, potentially resulting in leaching through the vadose zone to the underlying water table. The more chlorinated benzenes, such as pentachlorobenzene and hexachlorobenzene, are more hydrophobic and tend to sorb to soil and sediment organic carbon. As a result, these more hydrophobic compounds can be persistent in soils and sediments.

X2.3.12.2 Exposure pathways for chlorinated benzenes vary depending on the degree of chlorination. Inhalation of vapors and ingestion of, or dermal contact with contaminated waters can be relevant exposure pathways for the lesser chlorinated compounds. Ingestion of soil and sediments, either directly or indirectly via inhalation of fugitive dust, are the more important exposure pathways for the more chlorinated compounds.

X2.3.13 *Organic Acids and Bases:*

X2.3.13.1 Organic acids and bases include a variety of compounds that either have proton donor or proton acceptor properties. Organic acids and bases can have a number of different functional groups, such as aromatic rings with hydroxyl groups (for example, phenolic compounds), aliphatic and aromatic carboxyl groups, aliphatic and aromatic amino groups, and aromatic rings containing nitrogen atoms (for example, pyridines). Although encompassing numerous compounds with greatly differing chemical structures, organic acids and bases are generally extremely water-soluble and are hence very mobile in surface runoff and soil pore waters. Leaching to ground water and subsequent transport in ground water systems are common fate processes for organic acids and bases. Organic acids and bases are generally not volatile compounds. Sorption of organic acids and bases can occur for both their ionized and neutral forms, although partitioning into organic phases is often decreased for ionized forms relative to neutral forms. The persistence of organic acids and bases in environmental media depends upon their chemical structure and, as a result, generalizations can not be made for the compound class as a whole. The fate of organic acids and bases is largely dependent upon ambient pH in aquatic and soil environments because pH affects the magnitude of dissociation of organic acids and bases (that is, the relative concentrations of ionized and neutral forms). Benzoic acid is an example of an organic acid that is not extremely persistent in aquatic and soil environments due to high rates of biodegradation and a limited sorption capability. Aniline is an example of an organic base that is rapidly removed from surface waters and soils through photodegradation and biodegradation. However, aniline can be relatively persistent in soil environments due to its ability to sorb to soils. Thus, sorption is stronger at lower pH due to a greater fraction of the neutral form.

X2.3.13.2 Exposure to organic acids and bases can occur via dermal contact with contaminated waters and through ingestion of ground and surface waters. Depending upon the physicochemical properties of organic acids and bases and such site-specific conditions as pH, sorption to soils can occur in some circumstances. As a result, potential exposure to organic acids and bases could also occur through incidental ingestion of soil or via inhalation of fugitive dust.

X2.3.14 *Metals:*

X2.3.14.1 The environmental behavior of metals is highly dependent on their chemical speciation. The aqueous solubility of metals is moderated by their ability to react with other dissolved species to form insoluble precipitates (complexation) and to adsorb to charged surfaces (surface reactivity). Reactive ligands for metals in natural waters include sulfates, carbonates, sulfides, and hydroxides. As a rule-of-thumb, the transition metals have been demonstrated to have the complex stability sequence: $Mn2+ < Fe2+ < Co2+ < Ni2+ < Cu2+ < Zn2+$. Divalent metal species are generally more strongly adsorbed onto charged surfaces than monovalent metals, and smaller cations are more preferentially retained by charged surfaces in competitions for exchange sites with larger cations. Complexed and adsorbed metals can be retained in soils and sediments.

X2.3.14.2 The potentially important exposure pathways for metals can include ingestion of contaminated ground and surface waters, as well as dermal contact with these waters. Ingestion of soils and sediments, either directly or via fugitive dust, can also be important. Mercury is a unique metal because it is volatile (see Table X2.2). As a result, inhalation of vapors should be considered a possible exposure pathway for this metal in its non-complexed form.

X2.3.15 *Mixtures:*

X2.3.15.1 The fate and transport of individual chemicals within mixtures can greatly differ from the behavior observed for those compounds in their pure forms. Co-factors, such as the presence of solvents or cosolvents, can potentiate the mobilization of compounds that individually might be expected to sorb onto organic matter and be retained (for example, PAHs). Similarly, vapor pressures and aqueous solubilities can vary between individual components and mixtures. For example, the presence of inorganic salts can decrease the solubility of neutral nonpolar compounds in an aqueous environment.

X2.3.15.2 Potentially important exposure pathways for mixtures need to be assessed on a case-by-case basis, as they are dependent upon the nature of the mixture and site-specific conditions.

X2.3.16 *Media of Exposure:*

X2.3.16.1 Site-specific conditions are important in influencing the environmental behavior of chemicals. Which site-specific conditions are most important depends upon the compound's physicochemical properties and the media of interest. For example, the composition, pH or organic carbon content of the contaminated soils are very important to some chemical groupings, while wind or elevated ground surface temperatures can be very important for others. Bioavailability, may also be influenced by site-specific conditions.

X2.3.16.2 The following descriptions indicate a number of environmental parameters which can influence the behavior of and exposure to common chemicals in the environment. These descriptions are followed by short discussions of media-specific conditions which can be important modifiers of the behavior of, and exposure to, environmentally released chemicals.

X2.3.17 *Defining Environmental Parameters:*

X2.3.17.1 Acid-volatile sulfides (AVS) are reactive solid-phase sulfides which can bind certain metals such as cadmium and lead in aquatic environments, thus removing them from interstitial waters and reducing their bioavailability to sediment-dwelling organisms. The ratio of AVS to SEM (simultaneously extracted metals) on a molar basis is commonly used to predict the bioavailability and toxicity of metals in sediments.

X2.3.17.2 Total organic carbon (TOC) refers to solid phase organic carbon in natural organic matter which can bind chemicals in soil and sedimentary environments. Natural organic matter typically consists of 50 % organic carbon. TOC is a commonly measured analytical parameter for soil and sediment samples because sorption to organic carbon can be an important fate process for chemical species.

X2.3.17.3 The pH of a solution is a measure of the concentration of hydrogen or hydroxide ions present in a solution. The pH of surface waters, ground waters, and soil solutions is an important parameter with respect to the speciation and mobilization of chemicals. The pH of natural waters normally lies between 4 and 9.

X2.3.17.4 Conductivity refers to the current carrying capacity of dissolved ions (for example, Ca2+, Na+, Mg2+, Al3+, etc.). Conductivity is a commonly measured environmental parameter because it is a reflection of the concentration of ions available for reaction with dissolved chemical species such as metals.

X2.3.17.5 Redox potential (EH) is an analytical measure of the oxidative/reductive conditions present in an aquatic environment. Positive redox potentials are reflective of highly oxidizing conditions, while negative redox potentials are common of reducing environments. Redox potential influences the speciation and hence the mobilization and toxicity of chemical species such as metals.

X2.3.17.6 Cation exchange capacity (CEC) is a measure of the ion exchange properties of a soil environment. Clay minerals typically have high CECs and can efficiently retain and exchange cations. The CEC of soils is dependent upon soil mineralogy and pH.

X2.3.18 *Soil:*

X2.3.18.1 Both soil characteristics and physical properties can be important when considering the fate and transport of chemicals. Soil characteristics such as organic carbon content, soil composition (percent sand, silt and clay, iron oxide content, etc.), and cation exchange capacity (CEC) can influence the environmental behavior of chemicals. Adsorption of chemicals to soil surfaces can be important processes that serve to bind and retain chemicals. For some metals, soil constituents such as iron oxides can induce chemical reactions that result in the formation of immobile and insoluble precipitates. The cation exchange capacity (CEC) of soils is dependent upon soil mineralogy and pH, and can indicate whether the retention of charged species through ion exchange will be an important process. Soil pH and redox conditions can also affect the form and speciation of chemicals, and in turn influence their fate and transport. Physical properties such as soil strength, soil moisture, and soil particle size are important with respect to the erosion of soil and the formation of fugitive dust. Hydraulic conductivity affects the rate of vertical and horizontal transport in soil systems and is thus of importance with respect to the transport of chemicals in soils to the underlying water table and to nearby surface water bodies.

X2.3.18.2 The bioavailability of chemicals in soil varies with soil type, and the residence time of the chemical(s). Due to interactions between chemicals and soil matrices, the fraction of a chemical which is bioavailable to organisms generally is less than the bulk concentration, even for newly introduced chemicals. Chemicals may also weather in soil systems, may become sequestered within soil matrices, and hence may show diminished availability to organisms as shown in Ref **(6)**. Consequently, the residence time of chemicals in a soil along with the soil characteristics can influence the bioavailability of chemicals in soils via oral or dermal exposure.

X2.3.19 *Sediment:*

X2.3.19.1 Sediment properties such as total organic carbon content (TOC), particle size distribution, clay type and content, CEC, and pH affect the sorption of organic and inorganic compounds to sediment. Sorbed compounds tend to be less bioavailable to organisms and, as a result, direct exposure through ingestion of sediments and exposure through the food chain are often reduced.

X2.3.19.2 The bioavailability of some metals in sediments is related to the presence of Acid Volatile Sulfides (AVS) Ref **(7)**. It has been shown that insoluble metal sulfides, typically iron and manganese sulfides, control metal availability in anoxic sediments by reacting with available divalent metals. A comparison of the level of AVS to the amount of available divalent metal (Simultaneously Extracted Metal or SEM) on a molar basis indicates whether there is sufficient AVS to effectively sequester the available metal species, and reduce availability to receptors.

X2.3.20 *Surface and Ground Water*—Chemicals in water may be affected by water characteristics such as suspended solids, transparency, dissolved organic carbon, temperature, pH, redox potential, and advective/dispersive processes. These characteristics interact with the physicochemical properties of the chemicals to influence their fate and transport. For example, suspended solids affect the distribution of hydrophobic

organic compounds which preferentially sorb to particles, and transparency affects the rate of photodegradation. Furthermore, dissolved organic carbon, nutrient concentrations and the prevalence of oxic or anoxic conditions can affect microbial degradation.

X2.3.21 *Non-Aqueous Phase Liquids (NAPL)*— At some sites, organic chemicals may be present in the form of non-aqueous phase liquids (NAPLs) and, as such, represent a noteworthy site-specific condition. NAPLs can be thought of both as a chemical mixture and as a medium that is important to behavior and exposure. NAPLs may either float on the ground water surface (light or L-NAPL) or sink through water (dense or D-NAPL). An example of a potential L-NAPL mixture is gasoline. An example of a chemical that can occur as a D-NAPL is trichloroethylene. The chemicals within the NAPL behave differently than they do when dissolved in water or adsorbed onto soils and sediments. NAPLs may move along density gradients in response to gravity. L-NAPLs may flow along the ground water surface while D-NAPLs may move along interfaces in subsurface geologic formations. Further, the fate of chemicals within the NAPL are affected by the NAPL medium. For example, the hydrophobic nature of the NAPL medium and the surface tension of the NAPL may limit diffusion of chemicals within the NAPL into surrounding ground water.

X2.3.22 *Air*— Volatilization can be affected by air temperature and wind velocity. Wind velocity can also affect the transport of airborne pollutants from their sources. Precipitation events and gravitational settling can result in the redeposition of airborne pollutant onto ground and water surfaces.

X2.4 *Toxicity Values and Effects Considerations:*

X2.4.1 In the previous sections of this appendix, the physical and chemical properties of chemicals and how these properties determine the environmental distribution of chemicals was discussed. Knowing the approximate long-term concentrations of chemicals in different environmental media is necessary for determining long-term exposures. In addition to needing some estimate of the affect of time on the concentration of chemicals in different environmental media, knowledge of the potential toxicity of chemicals is necessary to provide an estimation of risk from exposure to released chemicals. In order to estimate an acceptable level of exposure to a chemical(s), for either human or ecological receptors, an understanding of the basis for, and the derivation of toxicity values (for example, reference doses, reference concentrations, slope factors, sediment quality criteria) and how these values should be applied to different exposure scenarios is necessary. This section describes how toxicity is assessed using laboratory animal experiments and epidemiologic data, how those data are used to derive toxicity values used for risk assessment, and how simultaneous exposures to multiple chemicals (that is, mixtures) are assessed.

X2.4.1.1 *Toxicity Assessment Process*—Dose-response data (either from animal or epidemiological studies) are typically used to identify levels above and below which adverse effects are observed as well as the magnitude of these effects. Observed adverse effects may include whole body effects (for example, weight loss), effects on specific body organs (for example, central nervous system), teratogenic effects (that is, birth defects), mutagenic effects (that is, alters genetic material) and carcinogenic effects (that is, produces malignant tumors). The assessment process involves either defining a toxicity value that represents an exposure level below which effects are not expected (as is done for most non-cancer effects) or a value that represents the relationship between dose and response for environmental exposure levels (as is done for most carcinogens.)

X2.4.2 *Non-Cancer Effects:*

X2.4.2.1 Chemicals are generally believed to elicit non-cancer effects via threshold mechanisms. Therefore, for most chemicals, toxicologists have defined levels of exposure that will not result in any adverse effects in exposed individuals or ecological receptors. Scientific methods for determining the level of exposure that will not result in adverse non-cancer effects in exposed populations are briefly outlined below.

X2.4.2.2 Most estimates of an acceptable dose for humans are based on animal studies. In rare instances, well defined human epidemiological information is available on a chemical. Animal or human data are used in establishing a Reference Dose (RfD) or Reference Concentration (RfC) - (see Table X2.4). The extrapolation of animal bioassay results when predicting human risk involves a number of assumptions regarding effects thresholds, dosing/exposure duration differences, interspecies and intraspecies extrapolation, high- to low-dose extrapolation, and route-to-route extrapolation. When calculating toxicological criteria for non-cancer effects, generally uncertainty factors (see Table X2.4) of ten, are applied to either the No-Observed-Adverse-Effect-Level (NOAEL) or Lowest-Observed-Adverse-Effect-Level (LOAEL) in animal or epidemiologic studies to account for uncertainties in predicting a NOAEL for humans. The toxicity values derived by applying uncertainty and modifying factors to NOAELs and LOAELs are termed RfDs and RfCs, for oral and inhalation exposures, respectively. The application of uncertainty factors (for example, 10 for interspecies, 10 for intraspecies, 5-10 for subchronic to lifetime, etc.) results in estimates that are more likely to overestimate than underestimate risks. The uncertainties in estimating acceptable levels of exposure at any site, based on RfDs/RfCs should be clearly communicated in each assessment

X2.4.2.3 Toxicity studies used for deriving toxicological criteria can generally be broken into five categories based on the frequency and duration of exposure to the risk agent. These studies can be described as follows:

X2.4.2.4 Acute studies typically use one exposure or multiple exposures over a short duration (24 h). Symptoms are usually observed within a short time after dosing. Acute studies are generally designed to measure frank effects such as neurological damage or death, and are often used to define dose ranges for use in studies of longer duration. The level of exposure necessary to elicit acute effects is generally much larger than that required to elicit effects after repeated exposures. Acute studies are not generally used for estimating acceptable levels of longer-term exposure.

TABLE X2.4 Definitions of Important Toxicological Characteristics

NOAEL (No-observed-adverse-effect level): An exposure level at which there are no statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control; some effects may be produced at this level, but they are not considered as adverse, not precursors to adverse effects. In an experiment with several NOAELs, the regulatory focus is primarily on the highest one, leading to the common usage of the term NOAEL as the highest exposure without adverse effects.
LOAEL (Lowest-observed-adverse-effect level): The lowest exposure level at which there are statistically or biologically significant increases in the frequency or severity of adverse effects between the exposed population and its appropriate control group.
Uncertainty factor: One of several, generally 10–fold factors, used in operationally deriving the Reference Dose (RfD) or Reference Concentration (RfC) from experimental data. Ufs are intended to account for *(1)* the variation in sensitivity among the members of the human population; *(2)* the uncertainty in extrapolating animal data to the case of humans; *(3)* the uncertainty in extrapolating from data obtained in a study that is of less-than-lifetime exposure; and, *(4)* the uncertainty in using LOAEL data rather than NOAEL data.
Modifying Factor: An additional uncertainty factor that is greater than zero and less than or equal to 10. The magnitude of the MF depends on the professional assessment of scientific uncertainties of the study not treated by uncertainty factors; such as, the completeness of the overall data base and the number of species tested. The default value of the MF is one.
Reference Dose: A reference dose is an estimate (with an uncertainty typically spanning perhaps an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure.
Reference Concentration: A reference concentration is an estimate (with an uncertainty spanning perhaps an order of magnitude) of a continuous exposure to the human population (including sensitive subgroups) that is likely to be without appreciable deleterious effects during a lifetime.
Slope Factor: The slope of the dose-response curve in the low-dose region. When low-dose linearity cannot be assumed, the slope factor is the slope of the straight line from zero dose to the dose at 1% excess risk. An upper bound on this slope is usually used instead of the slope itself. The units of the slope factor are usually expressed as $(mg/kg/day)^{-1}$.
Drinking Water MCLs & MCLGs: Maximum Contaminant Levels (MCLs) are drinking water standards established by the EPA that are protective of human health. However, these standards take into account the technological capability of attaining these standards. The EPA has, therefore, also established MCL goals (MCLGs) which are based only on the protection of human health. The MCL standards are often used as clean-up criteria.
Drinking Water Health Advisories: The Office of Drinking Water provides health advisories (HAs) as technical guidance for the protection of human health. They are not enforceable federal standards. HAs are the concentration of a substance in drinking water estimated to have negligible deleterious effects in humans, when ingested for specific time periods.
Water Quality Criteria: These criteria are not rules and they do not have regulatory impact. Rather, these criteria present scientific data and guidance of the environmental effects of pollutants which can be useful to derive regulatory requirements based on considerations of water quality impacts.

X2.4.2.5 Subchronic studies use multiple or continuous exposures over an extended period (three months is the usual time frame in rodent studies) generally defined as 10 % or less of an animals lifetime. Subchronic exposures in humans are generally viewed as encompassing seven years or less. Subchronic studies may be designed to assess a particular toxicological endpoint (for example, neurologic effects), but are most often comprehensive in their design. Subchronic studies are suitable for use in determining acceptable levels of subchronic and/or chronic exposure for non-cancer effects.

X2.4.2.6 Chronic studies use multiple exposures over an extended period of time, usually a significant fraction of the animal's lifetime (typically two years for rodents). Chronic studies generally involve numerous physical observations during the dosing period and a complete toxicological/pathological evaluation after dosing has been concluded. Chronic studies in rodents often evaluate both cancer and non-cancer endpoints, and are preferred for use in establishing chronic RfDs/RfCs.

X2.4.2.7 Reproductive and developmental studies examine adverse effects on fertility and fetal development. Exposures in developmental toxicity studies are generally limited to a specific timeframe such as the period of fetal organ development. Observed effects are often limited by study design and include observations such as sperm motility.

X2.4.2.8 Multi-generation studies use multiple or continuous exposures over two or more generations. Observed effects are usually limited to reproductive and/or teratogenic effects in the offspring and gross and pathological changes in the adults.

X2.4.2.9 *Derivation of Toxicity Values and Criteria*—Data from the above studies are used to generate Reference Doses (RfDs), Reference Concentrations (RfCs), slope factors (SFs),

and are also used in generating Drinking Water Maximum Contaminant Levels (MCLs) and Goals (MCLGs), Health Advisories (HAs) and Water Quality Criteria. See Table X2.4 for definitions of these important criteria.

X2.4.3 *Cancer Effects*— Agents may elicit carcinogenic effects through either threshold or non-threshold mechanisms. However, defining the carcinogenic threshold for agents that exert their carcinogenic effects via non-genotoxic/threshold mechanisms has proven much more difficult than defining the threshold for non-carcinogenic effects. Due to that difficulty, U.S. regulatory agencies generally assume that carcinogens act via non-threshold mechanisms and that any level of exposure to a carcinogen, no matter how small, presents some risk of developing cancer. International regulatory agencies (for example, WHO), however, apply safety factors similar to those used in the U.S. for non-cancer effects when establishing acceptable levels of exposure to carcinogenic agents. The U.S. Environmental Protection Agency calculates Slope factors that are used to calculate upper-bound numerical estimates of carcinogenic risk. Because of the uncertainty regarding the ability of risk agents to produce incremental carcinogenic effects in humans, USEPA has also developed weight-of-evidence criteria for carcinogenicity (see Table X2.5). The weight-of-evidence criteria are used to aid in risk management decisions, by defining the confidence scientists have in the ability of the slope factor to predict human risk or the confidence scientist have that the agent is not carcinogenic under a defined set of circumstances. *USEPA is revising their scheme for categorizing carcinogens and estimating their carcinogenic risk to better reflect chemical-specific differences in scientific knowledge.*

X2.4.4 Integrated Risk Information System (IRIS) is generally considered the primary source for RfD, RfC, and SF values, see Ref **(8)**.

X2.4.5 Health Effects Assessment Summary Tables (HEAST) reference a larger database than IRIS. HEAST is often used as a secondary source of health effects information when toxicity criteria are not available in IRIS. Whereas the information in IRIS has been subject to at least Agency-wide verification, the information in the HEAST tables has not. Thus, extra care should be exercised in using the values in HEAST as they are solely reflective of the opinions of a limited number of EPA scientists. Furthermore, the toxicity criteria listed in HEAST are not updated on any regular basis. The user is expected to consult the original U.S. EPA assessment documents and recent scientific studies to determine the strengths and limitations of the data in HEAST, see Ref **(9)**.

TABLE X2.5 Weight of Evidence Criteria for Carcinogens

Category	Criterion
A	Human carcinogen, with sufficient evidence from epidemiological studies.
B1	Probable human carcinogen, with limited evidence from epidemiological studies.
B2	Probable human carcinogen, with sufficient evidence from animal studies and inadequate evidence or no data from epidemiological studies.
C	Possible human carcinogen, with limited evidence from animal studies in the absence of human data.
D	Not classifiable as to human carcinogenicity, owing to inadequate human and animal evidence.
E	Evidence of noncarcinogenicity for humans, with no evidence of carcinogenicity in at least two adequate animal tests in different species, or in both adequate animal and epidemiological studies.

X2.4.6 If toxicity criteria (that is, RfDs, RfCs, and SFs) are not available, or are inappropriately listed in IRIS, HEAST, or State approved databases, a toxicologist should be consulted for appropriate values for use in the assessment. If project toxicologists with experience in the derivation of toxicity criteria are not available, toxicologists at the EPA's National Center for Exposure Assessment (NCEA) in Cincinnati are often able to supply appropriate criteria for site-specific use. The derivation basis for toxicity criteria obtained from sources other than IRIS or HEAST should be documented in greater detail.

X2.5 *Chemicals of Concern (COCs) for Risk Assessments:*

X2.5.1 *Selection and Evaluation of COCs*—It is often not necessary to assess in detail the potential human health or environmental risk associated with every site-related compound present in an environmental release. For this reason, risk management decisions are generally based on the assessment of the potential impacts from a selected group of indicator compounds or chemicals of concern (COC). It is inherently assumed in this approach that the chemicals of interest contribute the vast majority of the total potential impact from all chemicals present in the affected media. The chemicals of interest are selected based primarily on consideration of potential exposure routes, concentrations, toxicological properties and mobility in the affected media. In the Tier 1 evaluation, toxicological information, such as presented above, is used to develop Risk-Based Screening Levels (RBSL). If further Tiers of evaluation are necessary based on the results of the Tier 1 analysis, only those chemicals that were detected at concentrations above the Tier 1 values are evaluated further. Those chemicals that are evaluated in the RBCA process are termed chemicals of concern (COCs). In Tiers 2 and 3 more detailed evaluation of the toxicological criteria and physicochemical data is performed. In Tiers 2 and 3 of any site evaluation, potential additive and synergistic effects of COCs may be evaluated.

X2.5.2 *How Toxicity Is Assessed: Individual Chemicals Versus Mixtures*— The toxicity of an individual chemical is typically established based on dose-response studies which estimate the relationship between different dose levels and the magnitude of their adverse effects (that is, toxicity). When evaluating exposures to multiple chemicals, preference is given to data on actual mixtures. For example, often a single toxicity factor is used when evaluating exposures to PCBs. However, when data on mixtures is not available, a relative toxicity approach is sometimes used within chemical classes. The relative toxicity approach is most applicable when the toxicity of individual congeners is structure-dependent. For example, as discussed above, the cancer potencies of certain PAHs relative to the most studied compound of this class, benzo[a]pyrene, are presently approximated using an "estimated order of potential

potency" approach. Interim relative potencies that are suggested for use by U.S. EPA Ref **(10)** for seven carcinogenic PAHs are shown in Table X2.6. Also, when calculating a Hazard Index to evaluate the potential for additive noncarcinogenic effects, only hazard quotients for chemicals effecting the same target organ and mechanism of action should be summed.

X2.5.2.1 Generally, the risks associated with individual constituents of a complex mixture are assumed to be additive, and carcinogenic and noncarcinogenic risks are determined separately (for noncarcinogenic endpoints it is only appropriate to sum hazard quotients of compounds with similar toxicological endpoints and mechanisms of action). Lack of sufficient toxicological information is often an impediment to this procedure. When toxicological information is unavailable from a published database, health scientists may be utilized to derive values appropriate for use in the risk assessment.

TABLE X2.6 Cancer Potencies of Seven PAHs Relative to Benzo[a]pyrene[A]

Compound	Relative Cancer Potency
Benzo[a]pyrene	1.0
Benzo[a]anthracene	0.1
Benzo[b]fluoranthene	0.1
Benzo[k]fluoranthene	0.01
Chrysene	0.001
Dibenzo[a,h]anthracene	1.0
Indeno[1,2,3-cd]pyrene	0.1

[A] Interim values provided as temporary guidance for risk evaluation of PAHs in *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons* **(10)**.

X2.5.3 *Use of TPH or TOC Measurements in Risk Assessments*— Various chemical analysis methods commonly referred to as "Total Petroleum Hydrocarbons" (TPH) or "Total Organic Content" (TOC) are often used during an initial site assessments to focus future investigations toward particular compounds and/or media. These methods usually determine the total amount of hydrocarbons present as a single number, and give no information on the types of hydrocarbons present. Such TPH or TOC methods may be useful in screening assessments where the whole product toxicity approach is appropriate to determine the need for further sampling. In general, these measurements should not be used for risk assessments, because the general measure of TPH or TOC provides insufficient information about the amounts of individual compounds present to accurately characterize potential risk. More information on petroleum hydrocarbons is available from the Total Petroleum Hydrocarbon Working Group (TPHWG) effort. Refs **(11-14)**.

X3. DEVELOPMENT OF EXAMPLE RISK-BASED SCREENING LEVELS (RBSLs)

X3.1 *Introduction*:

X3.1.1 This appendix contains the equations and parameters used to develop example RBSLs (Table X3.1). This appendix was prepared solely for the purpose of presenting example calculations for RBSLs. These values should not be viewed, or misused, as proposed remediation "standards". The reader should note that the example is for an adult male, not all possible pathways have been considered, and a number of assumptions concerning exposure scenarios and parameter values have been made. In developing RBSLs, evaluate all assumptions for appropriateness. The selected chemicals in this appendix should not be viewed as an inclusive or exclusive list for purpose of site investigation.

X3.1.2 The approaches used to calculate example RBSLs appearing in this appendix are briefly discussed as follows for exposure to vapors, ground water, surficial soils, and subsurface soils by means of the following representative pathways:

X3.1.2.1 Direct inhalation of vapors,

X3.1.2.2 Ingestion of ground water,

X3.1.2.3 Inhalation of outdoor vapors originating from dissolved chemicals in ground water,

X3.1.2.4 Inhalation of indoor vapors originating from dissolved chemicals in ground water,

X3.1.2.5 Ingestion of surficial soil, inhalation of outdoor vapors and particulates emanating from surficial soils, and dermal absorption resulting from surficial soil contact with skin,

X3.1.2.6 Inhalation of outdoor vapors originating from chemicals in subsurface soils,

X3.1.2.7 Inhalation of indoor vapors originating from chemicals in subsurface soils,

X3.1.2.8 Ingestion of ground water impacted by aqueous leaching of dissolved chemicals from unsaturated soils,

X3.1.2.9 Migration of a free-phase liquid in unsaturated soil, and

X3.1.2.10 Migration of a free-phase liquid plume in saturated soil.

X3.1.3 For the pathways considered, approaches used in this appendix are consistent with guidelines contained in Ref. **(15)**.

X3.1.4 The development presented as follows focuses only on human-health RBSLs for chronic (long-term) exposures.

X3.1.4.1 In the case of compounds that have been classified as carcinogens, the example RBSLs are based on the general equation:

$$\textit{risk} = \textit{average lifetime compound intake}\ [\text{mg/kg}-\text{day}] \quad \text{(X3.1)}$$
$$\text{x}\ \textit{slope factor}\ [\text{mg/kg}-\text{day}]^{-1}$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The slope factor is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) **(8)** database, USEPA Health Effects Assessment Summary Tables (HEAST) **(9)**, and peer-reviewed sources. Note that this risk value does not reflect the actual probability for the specified exposure scenario to occur.

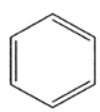
X3.1.4.2 The slope factor may be equivalently defined in terms of a unit risk factor,

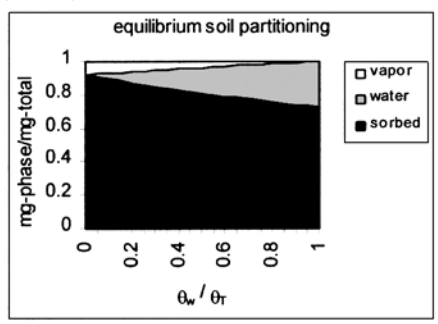
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21)

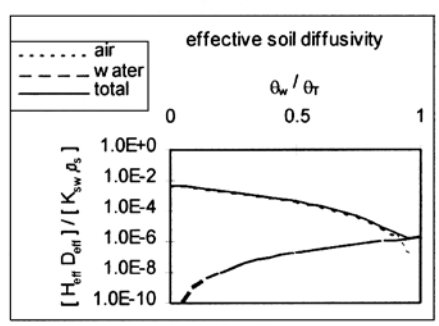
NOTE 1—Reference Note A: Estimated from Kow given in USEPA (1994) (**16**) and a Kow to Koc regression equation from USEPA (1996) (**17**).
NOTE 2—Reference Note B: Vapor pressure estimated from aqueous solubility limit and Henry's law coefficient.
NOTE 3—Reference R-to-R: An exposure route to exposure route extrapolation of available IRIS or HEAST data, consistent with USEPA (1996) (**17**).
NOTE 4—Reference FR: United States Federal Register.

CASRN	71-43-2		
name	benzene		
	C_6H_6		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
($\mu g/m^3$)	TR_U	2.94E+01	4.93E+01
	TR_L	2.94E-01	4.93E-01
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
($\mu g/m^3$)	TR_U	3.92E+01	4.93E+01
	TR_L	3.92E-01	4.93E-01
groundwater ingestion			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	2.94E-01	9.87E-01
	TR_L	2.94E-03	9.87E-03
	MCL	5.00E-03	5.00E-03
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	9.60E-01	3.22E+00
	TR_L	9.60E-03	3.22E-02
	MCL	1.63E-02	1.63E-02
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	3.79E+02	6.37E+02
	TR_L	3.79E+00	6.37E+00
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	2.43E+00	7.66E+00
	TR_L	2.43E-02	7.66E-02
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	1.29E+01	2.16E+01
	TR_L	1.29E-01	2.16E-01
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	7.63E-01	2.40E+00
	TR_L	7.63E-03	2.40E-02
residual phase mobility limit			
$RBSL_s$	unsat.	9.05E+03	9.05E+03
(mg/kg)	sat.	9.24E+03	9.24E+03
surficial soil exposure			
$RBSL_{ss}$	THQ	NA	NA
(mg/kg)	TR_U	4.70E+02	7.76E+02
	TR_L	4.70E+00	7.76E+00
surficial soil exposure apportionment [2]			
(%)	THQ		
(i-d-v-p)	TR_U	08-63-28-00	03-62-33-00
	TR_L	08-63-28-00	03-62-33-00
derived parameters:			
$VF_{s,esp}$		5.13E-05	2.05E-05
$VF_{gw,esp}$		1.61E-05	6.44E-06
$VF_{ss,amb,1}$		2.28E-07	2.50E-07
$VF_{ss,amb,2}$		1.80E-08	2.16E-08
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08
LF_{sw}		3.06E-01	3.06E-01
$VF_{s,amb}$		2.28E-06	2.28E-06
$VF_{gw,amb}$		7.75E-08	7.75E-08

transport and thermodynamic parameters			[references]
MW	7.81E+01	(g/mole)	USEPA(1996)
D_{air}	8.80E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	9.80E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	1.77E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.13E+00	log10(L-wat/kg)	USEPA(1996)
H	5.55E-03	(atm-m^3/mol)	USEPA(1996)
H	2.31E-01	(L-wat/L-air)	(calculated)
P_v	9.52E+01	(mm Hg)	USEPA(1994)
S	1.75E+03	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	8.77E-01	(g/mL)	USEPA(1996)
T_{nbp}	8.01E+01	(°C)	USEPA(1994)
T_{mp}	5.50E+00	(°C)	CRC(1996)
toxicity parameters			
RfD_o		(mg/kg-day)	
RfC_i		(mg/m^3)	
SF_o	2.90E-02	1/(mg/kg-day)	IRIS (1994)
SF_i	2.90E-02	1/(mg/kg-day)	HEAST (07/93)
W of E	A		IRIS (1994)
MCL	5.00E-03	(mg/L-wat)	52 FR 25690
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	2.31E-01	(L-wat/L-air)	
$C_{sat,vap}$	4.07E+08	($\mu g/m^3$-air)	
K_{sw}	6.95E-01	(L-wat/kg-soil)	
$C_{sat,soil}$	1.22E+03	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	1.22E+03	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	6.87E-03	(cm^2/sec)	
$D_{eff,cap}$	1.96E-05	(cm^2/sec)	
$D_{eff,ws}$	1.01E-03	(cm^2/sec)	
$D_{eff,crk}$	6.87E-03	(cm^2/sec)	





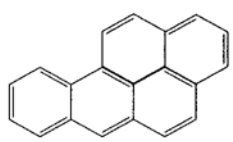


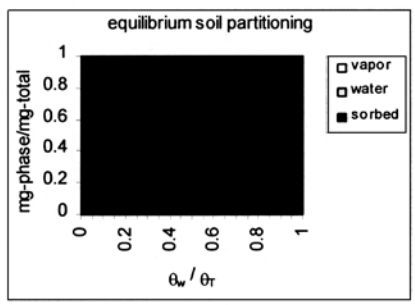
Notes:
(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).
(3) NA - not applicable.

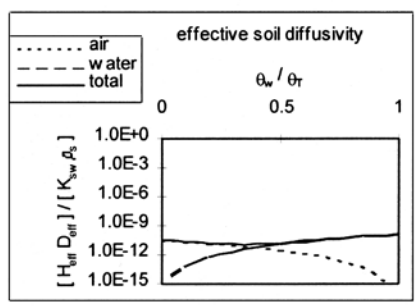
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	50-32-8		
name	benzo(a)pyrene		
	$C_{20}H_{12}$		
Risk-Based Screening-Level Concentrations [1]			
risk or			
hazard	scenario:		
criteria:	residential	industrial	
ambient vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
(µg/m^3)	TR_U	P< (1.17E-01)	P< (1.96E-01)
	TR_L	1.17E-03	1.96E-03
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
(µg/m^3)	TR_U	P< (1.56E-01)	P< (1.96E-01)
	TR_L	1.56E-03	1.96E-03
groundwater ingestion			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	1.17E-03	S< (3.92E-03)
	TR_L	1.17E-05	3.92E-05
	MCL	2.00E-04	2.00E-04
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	Rs (5.62E+01)	S< (1.89E+02)
	TR_L	5.62E-01	1.89E+00
	MCL	9.63E+00	9.63E+00
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	P< (1.63E+03)	P< (2.74E+03)
	TR_L	S< (1.63E+01)	S< (2.74E+01)
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	P< (3.67E+01)	P< (1.16E+02)
	TR_L	S< (3.67E-01)	S< (1.16E+00)
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	P< (5.65E+06)	P< (9.50E+06)
	TR_L	Rs (5.65E+04)	Rs (9.50E+04)
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	P< (3.35E+05)	P< (1.06E+06)
	TR_L	Rs (3.35E+03)	Rs (1.06E+04)
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	NA	NA
(mg/kg)	TR_U	1.30E+01	3.03E+01
	TR_L	1.30E-01	3.03E-01
surficial soil exposure apportionment [2]			
(%)	THQ		
(i-d-v-p)	TR_U	55-44-00-00	38-61-00-00
	TR_L	55-44-00-00	38-61-00-00
derived parameters:			
$VF_{s,esp}$		4.64E-13	1.86E-13 (g-soil/cm^3-air)
$VF_{gw,esp}$		4.23E-09	1.69E-09 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		2.17E-11	2.38E-11 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		2.17E-11	2.38E-11 (g-soil/cm^3-air)
LF_{sw}		2.08E-05	2.08E-05 (g-soil/cm^3-wat)
$VF_{s,amb}$		2.06E-14	2.06E-14 (g-soil/cm^3-air)
$VF_{gw,amb}$		7.14E-11	7.14E-11 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	2.52E+02	(g/mole)	USEPA(1996)
D_{air}	4.30E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	9.00E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	6.01E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	6.11E+00	log10(L-wat/kg)	USEPA(1996)
H	1.13E-06	(atm-m^3/mol)	USEPA(1996)
H	4.70E-05	(L-wat/L-air)	(calculated)
P_v	1.77E-10	(mm Hg)	Mott(1995)
S	1.62E-03	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.11E+00	(g/mL)	USEPA(1994)
T_{nbp}	5.27E+02	(°C)	Mott(1995)
T_{mp}	2.52E+02	(°C)	CRC(1996)
toxicity parameters			
RfD_o		(mg/kg-day)	
RfC_i		(mg/m^3)	
SF_o	7.30E+00	1/(mg/kg-day)	IRIS (1994)
SF_i	7.30E+00	1/(mg/kg-day)	Route-to-Route
W of E	B2		IRIS (1994)
MCL	2.00E-04	(mg/L-wat)	57 31776 (17 Jul 92) Effective 01/17/94
RAF_o	1.00E+00		
RAF_d	5.00E-02		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	4.70E-05	(L-wat/L-air)	
$C_{sat,vap}$	2.44E-03	(µg/m^3-air)	
K_{sw}	1.02E+04	(L-wat/kg-soil)	
$C_{sat,soil}$	1.66E+01	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	5.32E-01	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	4.49E-03	(cm^2/sec)	
$D_{eff,cap}$	3.72E-02	(cm^2/sec)	
$D_{eff,ws}$	4.56E-03	(cm^2/sec)	
$D_{eff,crk}$	4.49E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

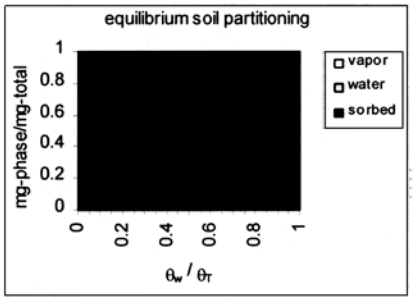
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

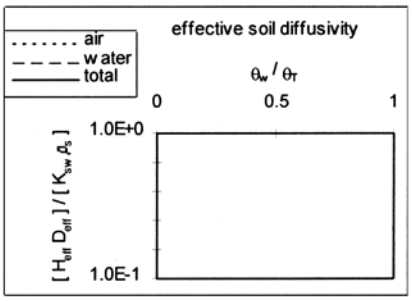
(3) NA - not applicable.

TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	7440-43-9		
name	cadmium		
	Cd		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
($\mu g/m^3$)	TR_U	P< (1.35E-01)	P< (2.27E-01)
	TR_L	P< (1.35E-03)	P< (2.27E-03)
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	NA	NA
($\mu g/m^3$)	TR_U	P< (1.80E-01)	P< (2.27E-01)
	TR_L	P< (1.80E-03)	P< (2.27E-03)
groundwater ingestion			
$RBSL_{gw}$	THQ	1.82E-02	5.11E-02
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	5.00E-03	5.00E-03
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	3.69E+02	1.03E+03
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	1.01E+02	1.01E+02
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	NA	NA
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	NA	NA
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	3.65E+02	1.02E+03
(mg/kg)	TR_U	1.96E+07	3.29E+07
	TR_L	1.96E+05	3.29E+05
surficial soil exposure apportionment [2]			
(%)	THQ	99-00-00-00	99-00-00-00
(i-d-v-p)	TR_U	00-00-00-99	00-00-00-99
	TR_L	00-00-00-99	00-00-00-99
derived parameters:			
$VF_{s,esp}$	NA	NA	(g-soil/cm^3-air)
$VF_{gw,esp}$	NA	NA	(cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$	0.00E+00	0.00E+00	(g-soil/cm^3-air)
$VF_{ss,amb,2}$	1.80E-08	2.16E-08	(g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$	0.00E+00	0.00E+00	(g-soil/cm^3-air)
LF_{sw}	4.94E-05	4.94E-05	(g-soil/cm^3-wat)
$VF_{s,amb}$	NA	NA	(g-soil/cm^3-air)
$VF_{gw,amb}$	NA	NA	(cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	1.12E+02	(g/mole)	USEPA(1996)
D_{air}	NA	(cm^2/sec)	
D_{wat}	NA	(cm^2/sec)	
K_d	3.63E+00	log10(L-wat/kg-soil)	USEPA(1996); pH=8.0
K_{ow}		log10(L-wat/kg)	
H	0.00E+00	(atm-m^3/mol)	(nonvolatile)
H	0.00E+00	(L-wat/L-air)	(calculated)
P_v	0.00E+00	(mm Hg)	(nonvolatile)
S	NA	(mg/L)	(no limit imposed)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ		(g/mL)	
T_{nbp}		(°C)	
T_{mp}		(°C)	
toxicity parameters			
RfD_o	5.00E-04	(mg/kg-day)	IRIS (1994)
RfC_i	NA	(mg/m^3)	Route-to-Route inappropriate
SF_o		1/(mg/kg-day)	
SF_i	6.30E+00	1/(mg/kg-day)	IRIS (1994)
W of E	B1		IRIS (1994)
MCL	5.00E-03	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	0.00E+00		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	0.00E+00	(L-wat/L-air)	
$C_{sat,vap}$	0.00E+00	($\mu g/m^3$-air)	
K_{sw}	4.30E+03	(L-wat/kg-soil)	
$C_{sat,soil}$	NA	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	NA	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	NA	(cm^2/sec)	
$D_{eff,cap}$	NA	(cm^2/sec)	
$D_{eff,ws}$	NA	(cm^2/sec)	
$D_{eff,crk}$	NA	(cm^2/sec)	





Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

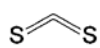
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

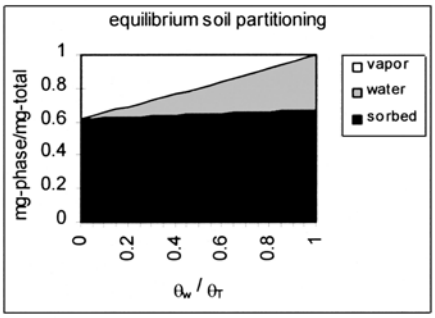
(3) NA - not applicable.

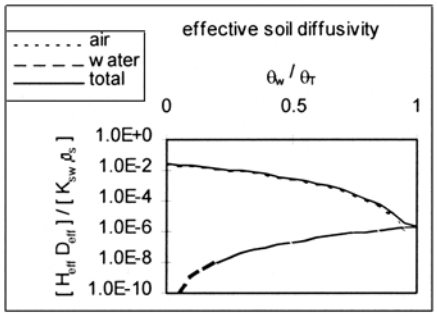
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	75-15-0		
name	carbon disulfide		
	CS_2		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	7.30E+02	1.02E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	9.73E+02	1.02E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	3.65E+00	1.02E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	1.24E+01	3.46E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (2.14E+03)	S< (3.00E+03)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	1.19E+01	3.13E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	5.14E+01	7.20E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	3.05E+00	8.00E+00
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	1.21E+04	1.21E+04
(mg/kg)	sat.	1.21E+04	1.21E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	6.82E+03	9.68E+03
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	09-73-16-00	04-74-20-00
(i-d-v-p)	TR_U		
	TR_L		

transport and thermodynamic parameters			[references]
MW	7.61E+01	(g/mole)	USEPA(1996)
D_{air}	1.04E-01	(cm^2/sec)	USEPA(1996)
D_{wat}	1.00E-05	(cm^2/sec)	USEPA(1996)
K_{oc}	1.66E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.00E+00	log10(L-wat/kg)	USEPA(1996)
H	3.03E-02	(atm-m^3/mol)	USEPA(1996)
H	1.26E+00	(L-wat/L-air)	(calculated)
P_v	3.66E+02	(mm Hg)	USEPA(1994)
S	1.19E+03	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.26E+00	(g/mL)	USEPA(1996)
T_{nbp}	4.63E+01	(°C)	USEPA(1994)
T_{mp}	-1.12E+02	(°C)	CRC(1996)
toxicity parameters			
RfD_o	1.00E-01	(mg/kg-day)	IRIS (1994)
RfC_i	7.00E-01	(mg/m^3)	IRIS (08/01/95)
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E			
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	1.26E+00	(L-wat/L-air)	
$C_{sat,vap}$	1.53E+09	($\mu g/m^3$-air)	
K_{sw}	7.20E-01	(L-wat/kg-soil)	
$C_{sat,soil}$	8.57E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	8.72E+02	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	8.12E-03	(cm^2/sec)	
$D_{eff,cap}$	1.50E-05	(cm^2/sec)	
$D_{eff,ws}$	8.10E-04	(cm^2/sec)	
$D_{eff,crk}$	8.12E-03	(cm^2/sec)	







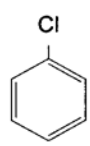
derived parameters:			
$VF_{s,esp}$	3.19E-04	1.28E-04	(g-soil/cm^3-air)
$VF_{gw,esp}$	8.17E-05	3.27E-05	(cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$	5.70E-07	6.24E-07	(g-soil/cm^3-air)
$VF_{ss,amb,2}$	1.80E-08	2.16E-08	(g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$	1.80E-08	2.16E-08	(g-soil/cm^3-air)
LF_{sw}	2.95E-01	2.95E-01	(g-soil/cm^3-wat)
$VF_{s,amb}$	1.42E-05	1.42E-05	(g-soil/cm^3-air)
$VF_{gw,amb}$	3.40E-07	3.40E-07	(cm^3-wat/cm^3-air)

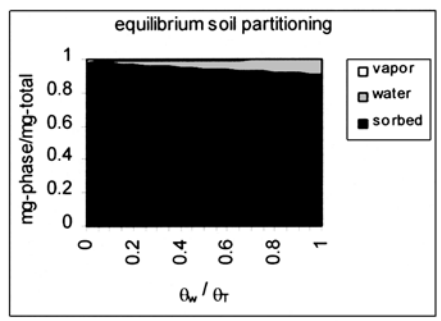
Notes:
(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).
(3) NA - not applicable.

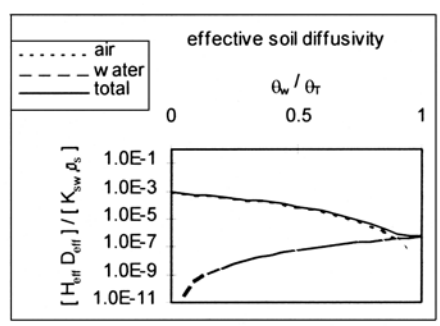
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	108-90-7		
name	chlorobenzene		
	C_6H_5Cl		
Risk-Based Screening-Level Concentrations [1]			
risk or			
hazard	scenario:		
criteria:	residential	industrial	
ambient vapor inhalation			
$RBSL_{air}$	THQ	2.09E+01	2.92E+01
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	2.78E+01	2.92E+01
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	7.30E-01	2.04E+00
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	1.00E-01	1.00E-01
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	7.84E+00	2.19E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	1.07E+00	1.07E+00
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	4.02E+02	S< (5.63E+02)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	2.81E+00	7.38E+00
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	5.43E+01	7.60E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	3.22E+00	8.45E+00
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	1.10E+04	1.10E+04
(mg/kg)	sat.	1.10E+04	1.10E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	6.80E+02	8.70E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	04-36-58-00	02-33-64-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		8.64E-06	3.46E-06 (g-soil/cm^3-air)
$VF_{gw,esp}$		9.89E-06	3.96E-06 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		9.38E-08	1.03E-07 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
LF_{sw}		9.32E-02	9.32E-02 (g-soil/cm^3-wat)
$VF_{s,amb}$		3.84E-07	3.84E-07 (g-soil/cm^3-air)
$VF_{gw,amb}$		5.19E-08	5.19E-08 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	1.13E+02	(g/mole)	USEPA(1996)
D_{air}	7.30E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	8.70E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	2.34E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.86E+00	log10(L-wat/kg)	USEPA(1996)
H	3.70E-03	(atm-m^3/mol)	USEPA(1996)
H	1.54E-01	(L-wat/L-air)	(calculated)
P_v	1.18E+01	(mm Hg)	USEPA(1994)
S	4.72E+02	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.11E+00	(g/mL)	USEPA(1996)
T_{nbp}	1.32E+02	(°C)	USEPA(1994)
T_{mp}	-4.52E+01	(°C)	CRC(1996)
toxicity parameters			
RfD_o	2.00E-02	(mg/kg-day)	IRIS (1994)
RfC_i	2.00E-02	(mg/m^3)	HEAST (07/93)
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL	1.00E-01	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	1.54E-01	(L-wat/L-air)	
$C_{sat,vap}$	7.27E+07	(μg/m^3-air)	
K_{sw}	2.28E+00	(L-wat/kg-soil)	
$C_{sat,soil}$	1.08E+03	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	1.08E+03	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	5.70E-03	(cm^2/sec)	
$D_{eff,cap}$	2.04E-05	(cm^2/sec)	
$D_{eff,ws}$	1.01E-03	(cm^2/sec)	
$D_{eff,crk}$	5.70E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

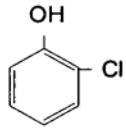
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

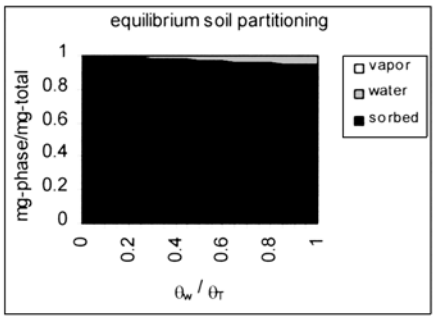
(3) NA - not applicable.

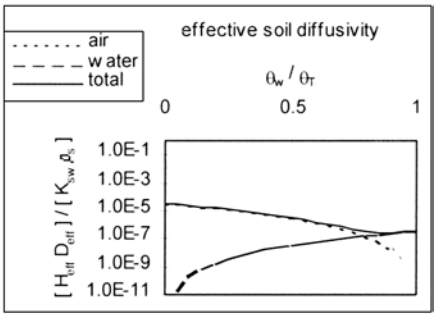
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	95-57-8		
name	chlorophenol, 2-		
	C_6H_5CLO		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	1.83E+01	2.56E+01
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	2.43E+01	2.56E+01
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	1.83E-01	5.11E-01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	3.48E+00	9.74E+00
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	1.34E+03	1.87E+03
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	2.13E+01	5.59E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	1.19E+03	1.67E+03
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	7.06E+01	1.85E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	1.00E+05	1.00E+05
(mg/kg)	sat.	1.04E+05	1.04E+05
surficial soil exposure			
$RBSL_{ss}$	THQ	2.92E+02	4.09E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	08-63-28-00	03-63-32-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		3.45E-07	1.38E-07 (g-soil/cm^3-air)
$VF_{gw,esp}$		1.14E-06	4.57E-07 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		1.87E-08	2.05E-08 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.05E-08 (g-soil/cm^3-air)
LF_{sw}		5.25E-02	5.25E-02 (g-soil/cm^3-wat)
$VF_{s,amb}$		1.53E-08	1.53E-08 (g-soil/cm^3-air)
$VF_{gw,amb}$		1.36E-08	1.36E-08 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	1.29E+02	(g/mole)	USEPA(1996)
D_{air}	5.01E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	9.46E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	2.60E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.15E+00	log10(L-wat/kg)	USEPA(1996)
H	3.91E-04	(atm-m^3/mol)	USEPA(1996)
H	1.63E-02	(L-wat/L-air)	(calculated)
P_v	1.40E+00	(mm Hg)	USEPA(1994)
S	2.20E+04	(mg/L)	USEPA(1996)
pK_a	8.40E+00	log10(mole/mole)	USEPA(1996)
pK_b		log10(mole/mole)	
ρ	1.26E+00	(g/mL)	USEPA(1996)
T_{nbp}	1.76E+02	(°C)	USEPA(1994)
T_{mp}	9.80E+00	(°C)	CRC(1996)
toxicity parameters			
RfD_o	5.00E-03	(mg/kg-day)	IRIS (1994)
RfC_i	1.75E-02	(mg/m^3)	Route-to-Route
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E			
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on			
chemical properties and soil parameters			
UF	9.75E-01	(unitless)	
H_{eff}	1.59E-02	(L-wat/L-air)	
$C_{sat,vap}$	9.85E+06	($\mu g/m^3$-air)	
K_{sw}	4.05E+00	(L-wat/kg-soil)	
$C_{sat,soil}$	8.92E+04	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	2.52E+03	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	3.91E-03	(cm^2/sec)	
$D_{eff,cap}$	1.22E-04	(cm^2/sec)	
$D_{eff,ws}$	2.58E-03	(cm^2/sec)	
$D_{eff,crk}$	3.91E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

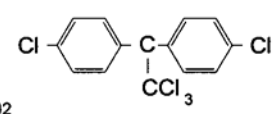
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

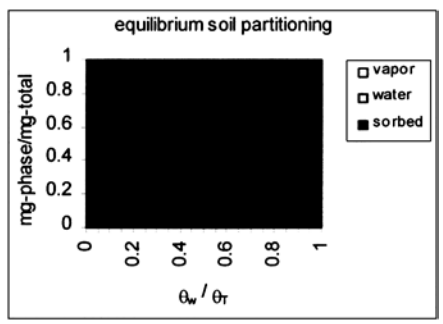
(3) NA - not applicable.

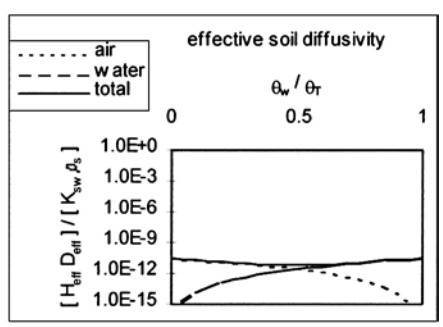
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	50-29-3		
name	DDT (4,4'-ddt)		
	$C_{14}H_9Cl_5$		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	1.83E+00	2.56E+00
($\mu g/m^3$)	TR_U	2.50E+00	P< (4.21E+00)
	TR_L	2.50E-02	4.21E-02
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	2.43E+00	2.56E+00
($\mu g/m^3$)	TR_U	P< (3.34E+00)	P< (4.21E+00)
	TR_L	3.34E-02	4.21E-02
groundwater ingestion			
$RBSL_{gw}$	THQ	1.82E-02	S< (5.11E-02)
(mg/L)	TR_U	S< (2.50E-02)	S< (8.42E-02)
	TR_L	2.50E-04	8.42E-04
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	Rs (2.26E+03)	S< (6.32E+03)
(mg/kg)	TR_U	S< (3.10E+03)	S< (1.04E+04)
	TR_L	3.10E+01	1.04E+02
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (1.39E+04)	S< (1.95E+04)
(mg/L)	TR_U	S< (1.91E+04)	P< (3.21E+04)
	TR_L	S< (1.91E+02)	S< (3.21E+02)
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	S< (3.12E+02)	S< (8.18E+02)
(mg/L)	TR_U	P< (4.28E+02)	P< (1.35E+03)
	TR_L	S< (4.28E+00)	S< (1.35E+01)
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (1.23E+08)	Rs (1.72E+08)
(mg/kg)	TR_U	Rs (1.69E+08)	P< (2.84E+08)
	TR_L	Rs (1.69E+06)	Rs (2.84E+06)
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	Rs (7.30E+06)	Rs (1.92E+07)
(mg/kg)	TR_U	P< (1.00E+07)	P< (3.16E+07)
	TR_L	Rs (1.00E+05)	Rs (3.16E+05)
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	2.03E+02	3.95E+02
(mg/kg)	TR_U	2.79E+02	6.50E+02
	TR_L	2.79E+00	6.50E+00
surficial soil exposure apportionment [2]			
(%)	THQ	55-44-00-00	38-61-00-00
(i-d-v-p)	TR_U	55-44-00-00	38-61-00-00
	TR_L	55-44-00-00	38-61-00-00
derived parameters:			
$VF_{s,esp}$		3.33E-13	1.33E-13
$VF_{gw,esp}$		7.80E-09	3.12E-09
$VF_{ss,amb,1}$		1.84E-11	2.02E-11
$VF_{ss,amb,2}$		1.80E-08	2.16E-08
$VF_{ss,amb,min(1,2)}$		1.84E-11	2.02E-11
LF_{sw}		8.08E-06	8.08E-06
$VF_{s,amb}$		1.48E-14	1.48E-14
$VF_{gw,amb}$		1.31E-10	1.31E-10

transport and thermodynamic parameters			[references]
MW	3.54E+02	(g/mole)	USEPA(1996)
D_{air}	1.37E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	4.95E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	6.42E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	6.53E+00	log10(L-wat/kg)	USEPA(1996)
H	8.10E-06	(atm-m^3/mol)	USEPA(1996)
H	3.37E-04	(L-wat/L-air)	(calculated)
P_v	1.50E-07	(mm Hg)	USEPA(1994)
S	2.50E-02	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.18E+00	(g/mL)	USEPA(1994)
T_{nbp}	2.60E+02	(°C)	USEPA(1994)
T_{mp}	1.09E+02	(°C)	CRC(1996)
toxicity parameters			
RfD_o	5.00E-04	(mg/kg-day)	IRIS (1994)
RfC_i	1.75E-03	(mg/m^3)	Route-to-Route
SF_o	3.40E-01	1/(mg/kg-day)	IRIS (1994)
SF_i	3.40E-01	1/(mg/kg-day)	HEAST (07/93)
W of E	B2		IRIS (1994)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-02		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	3.37E-04	(L-wat/L-air)	
$C_{sat,vap}$	2.91E+00	($\mu g/m^3$-air)	
K_{sw}	2.63E+04	(L-wat/kg-soil)	
$C_{sat,soil}$	6.58E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	2.27E+02	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	1.16E-03	(cm^2/sec)	
$D_{eff,cap}$	2.86E-03	(cm^2/sec)	
$D_{eff,ws}$	1.17E-03	(cm^2/sec)	
$D_{eff,crk}$	1.16E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

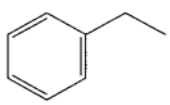
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

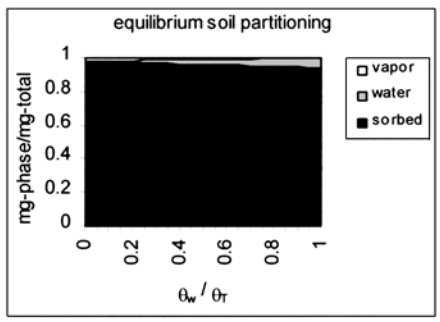
(3) NA - not applicable.

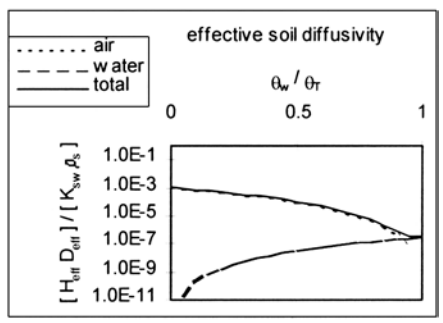
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	100-41-4		
name	ethylbenzene		
	C_8H_{10}		
Risk-Based Screening-Level Concentrations [1]			
risk or			
hazard	scenario:		
criteria:	residential	industrial	
ambient vapor inhalation			
$RBSL_{air}$	THQ	1.04E+03	1.46E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	1.39E+03	1.46E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	3.65E+00	1.02E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	7.00E-01	7.00E-01
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	6.44E+01	1.80E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	1.24E+01	1.24E+01
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (1.27E+04)	S< (1.78E+04)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	7.73E+01	S< (2.03E+02)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (2.04E+03)	Rs (2.86E+03)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	1.21E+02	3.17E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	8.39E+03	8.39E+03
(mg/kg)	sat.	8.40E+03	8.40E+03
surficial soil exposure			
$RBSL_{ss}$	THQ	7.19E+03	1.03E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	09-77-12-00	05-79-15-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		1.15E-05	4.60E-06
$VF_{gw,esp}$		1.80E-05	7.19E-06
$VF_{ss,amb,1}$		1.08E-07	1.18E-07
$VF_{ss,amb,2}$		1.80E-08	2.16E-08
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08
LF_{sw}		5.67E-02	5.67E-02
$VF_{s,amb}$		5.11E-07	5.11E-07
$VF_{gw,amb}$		8.20E-08	8.20E-08

transport and thermodynamic parameters			[references]
MW	1.06E+02	(g/mole)	USEPA(1996)
D_{air}	7.50E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	7.80E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	2.56E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	3.14E+00	log10(L-wat/kg)	USEPA(1996)
H	7.88E-03	(atm-m^3/mol)	USEPA(1996)
H	3.28E-01	(L-wat/L-air)	(calculated)
P_v	9.51E+00	(mm Hg)	Mott(1995)
S	1.69E+02	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	8.67E-01	(g/mL)	USEPA(1996)
T_{nbp}	1.36E+02	(°C)	Mackay(1992a)
T_{mp}	-9.50E+01	(°C)	Mackay(1992a)
toxicity parameters			
RfD_o	1.00E-01	(mg/kg-day)	IRIS (1994)
RfC_i	1.00E+00	(mg/m^3)	IRIS (1994)
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL	7.00E-01	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	3.28E-01	(L-wat/L-air)	
$C_{sat,vap}$	5.53E+07	($\mu g/m^3$-air)	
K_{sw}	3.75E+00	(L-wat/kg-soil)	
$C_{sat,soil}$	6.34E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	6.32E+02	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	5.85E-03	(cm^2/sec)	
$D_{eff,cap}$	1.43E-05	(cm^2/sec)	
$D_{eff,ws}$	7.51E-04	(cm^2/sec)	
$D_{eff,crk}$	5.85E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

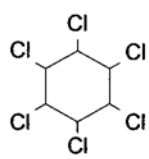
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

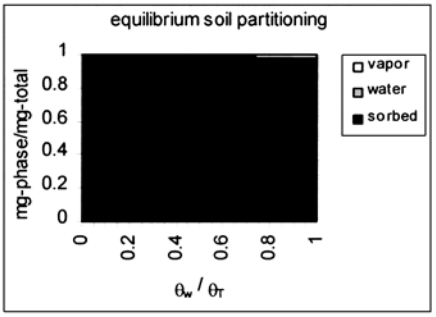
(3) NA - not applicable.

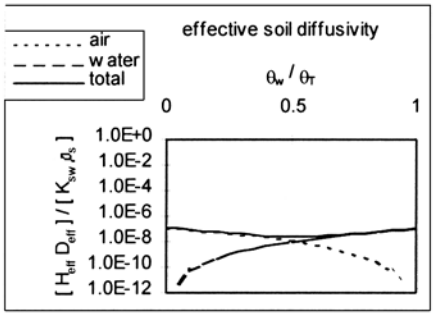
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	58-89-9		
name	lindane, (gamma-BHC)		
	$C_6 H_6 CL_6$		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	1.09E+00	1.53E+00
($\mu g/m^3$)	TR_U	6.55E-01	1.10E+00
	TR_L	6.55E-03	1.10E-02
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	1.46E+00	1.53E+00
($\mu g/m^3$)	TR_U	8.74E-01	1.10E+00
	TR_L	8.74E-03	1.10E-02
groundwater ingestion			
$RBSL_{gw}$	THQ	1.09E-02	3.07E-02
(mg/L)	TR_U	6.55E-03	2.20E-02
	TR_L	6.55E-05	2.20E-04
	MCL	2.00E-04	2.00E-04
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	5.56E-01	1.56E+00
(mg/kg)	TR_U	3.32E-01	1.12E+00
	TR_L	3.32E-03	1.12E-02
	MCL	1.01E-02	1.01E-02
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (4.73E+03)	S< (6.62E+03)
(mg/L)	TR_U	S< (2.83E+03)	S< (4.75E+03)
	TR_L	S< (2.83E+01)	S< (4.75E+01)
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	S< (1.06E+02)	S< (2.78E+02)
(mg/L)	TR_U	S< (6.33E+01)	S< (1.99E+02)
	TR_L	6.33E-01	1.99E+00
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (1.71E+04)	Rs (2.40E+04)
(mg/kg)	TR_U	Rs (1.03E+04)	Rs (1.72E+04)
	TR_L	Rs (1.03E+02)	Rs (1.72E+02)
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	Rs (1.02E+03)	Rs (2.67E+03)
(mg/kg)	TR_U	Rs (6.08E+02)	Rs (1.91E+03)
	TR_L	6.08E+00	1.91E+01
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	1.08E+02	1.97E+02
(mg/kg)	TR_U	6.45E+01	1.42E+02
	TR_L	6.45E-01	1.42E+00
surficial soil exposure apportionment [2]			
(%)	THQ	49-38-11-00	32-50-17-00
(i-d-v-p)	TR_U	49-38-11-00	32-50-17-00
	TR_L	49-38-11-00	32-50-17-00
derived parameters:			
$VF_{s,esp}$		1.44E-09	5.75E-10 (g-soil/cm^3-air)
$VF_{gw,esp}$		1.38E-08	5.52E-09 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		1.21E-09	1.32E-09 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.21E-09	1.32E-09 (g-soil/cm^3-air)
LF_{sw}		1.97E-02	1.97E-02 (g-soil/cm^3-wat)
$VF_{s,amb}$		6.39E-11	6.39E-11 (g-soil/cm^3-air)
$VF_{gw,amb}$		2.32E-10	2.32E-10 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	2.91E+02	(g/mole)	USEPA(1996)
D_{air}	1.42E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	7.34E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	3.03E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	3.73E+00	log10(L-wat/kg)	USEPA(1996)
H	1.40E-05	(atm-m^3/mol)	USEPA(1996)
H	5.82E-04	(L-wat/L-air)	(calculated)
P_v	1.09E-05	(mm Hg)	USEPA(1994)
S	6.80E+00	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.87E+00	(g/mL)	USEPA(1994)
T_{nbp}	3.90E+02	(°C)	USEPA(1994)
T_{mp}	1.13E+02	(°C)	CRC(1996)
toxicity parameters			
RfD_o	3.00E-04	(mg/kg-day)	IRIS (1994)
RfC_i	1.05E-03	(mg/m^3)	Route-to-Route
SF_o	1.30E+00	1/(mg/kg-day)	HEAST (07/93)
SF_i	1.30E+00	1/(mg/kg-day)	Route-to-Route
W of E	B2 - C		HEAST (07/93)
MCL	2.00E-04	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	5.00E-02		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	5.82E-04	(L-wat/L-air)	
$C_{sat,vap}$	1.74E+02	($\mu g/m^3$-air)	
K_{sw}	1.08E+01	(L-wat/kg-soil)	
$C_{sat,soil}$	7.33E+01	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	3.22E+00	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	1.18E-03	(cm^2/sec)	
$D_{eff,cap}$	2.45E-03	(cm^2/sec)	
$D_{eff,ws}$	1.19E-03	(cm^2/sec)	
$D_{eff,crk}$	1.18E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

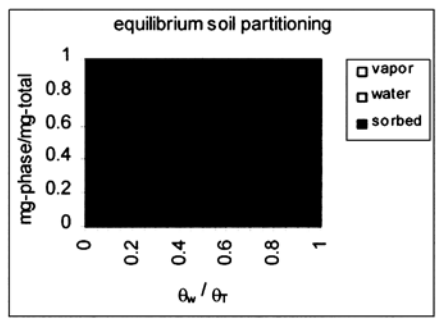
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

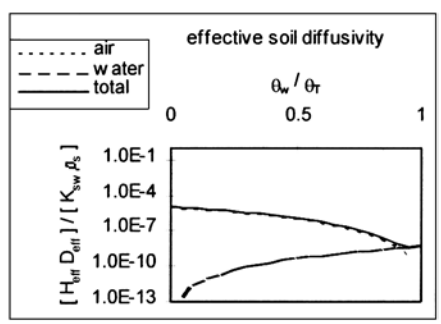
(3) NA - not applicable.

TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	7439-97-6		
name	mercury (inorganic)		
	Hg		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	3.13E-01	4.38E-01
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	4.17E-01	4.38E-01
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	1.09E-02	3.07E-02
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	2.00E-03	2.00E-03
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	1.03E+01	2.89E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	1.88E+00	1.88E+00
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	5.85E+00	8.19E+00
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	3.70E-02	9.70E-02
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	5.51E+01	7.72E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	3.27E+00	8.57E+00
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	2.44E+01	3.32E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	11-00-88-00	05-00-94-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		1.28E-07	5.11E-08 (g-soil/cm^3-air)
$VF_{gw,esp}$		1.13E-05	4.51E-06 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		1.14E-08	1.25E-08 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.14E-08	1.25E-08 (g-soil/cm^3-air)
LF_{sw}		1.06E-03	1.06E-03 (g-soil/cm^3-wat)
$VF_{s,amb}$		5.68E-09	5.68E-09 (g-soil/cm^3-air)
$VF_{gw,amb}$		5.35E-08	5.35E-08 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	2.01E+02	(g/mole)	USEPA(1996)
D_{air}	3.07E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	6.30E-06	(cm^2/sec)	USEPA(1996)
K_d	2.30E+00	log10(L-wat/kg-soil)	USEPA(1996); pH=8.0, Hg+2
K_{ow}		log10(L-wat/kg)	
H	1.14E-02	(atm-m^3/mol)	USEPA(1996)
H	4.74E-01	(L-wat/L-air)	(calculated)
P_v	1.20E-03	(mm Hg)	USEPA(1979)
S	NA	(mg/L)	(no limit imposed)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ		(g/mL)	
T_{nbp}		(°C)	
T_{mp}		(°C)	
toxicity parameters			
RfD_o	3.00E-04	(mg/kg-day)	HEAST (07/93)
RfC_i	3.00E-04	(mg/m^3)	HEAST (05/95) Under Review
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (05/01/95)
MCL	2.00E-03	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	0.00E+00		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	4.74E-01	(L-wat/L-air)	
$C_{sat,vap}$	1.32E+04	($\mu g/m^3$-air)	
K_{sw}	2.00E+02	(L-wat/kg-soil)	
$C_{sat,soil}$	NA	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	5.56E+00	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	2.40E-03	(cm^2/sec)	
$D_{eff,cap}$	6.55E-06	(cm^2/sec)	
$D_{eff,ws}$	3.38E-04	(cm^2/sec)	
$D_{eff,crk}$	2.40E-03	(cm^2/sec)	





Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

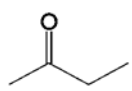
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

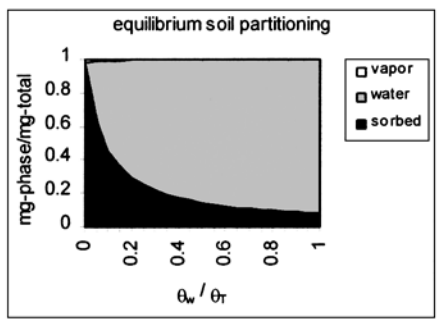
(3) NA - not applicable.

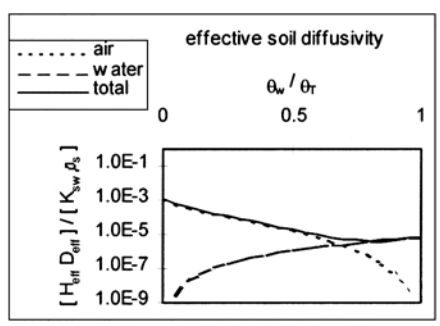
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	78-93-3		
name	methyl ethyl ketone		
	$C_4 H_8 O$		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	1.04E+03	1.46E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	1.39E+03	1.46E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	2.19E+01	6.13E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	9.26E+00	2.59E+01
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	2.95E+05	S< (4.14E+05)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	6.15E+03	1.61E+04
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	8.18E+03	1.14E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	4.85E+02	1.27E+03
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	3.89E+04	3.89E+04
(mg/kg)	sat.	8.96E+04	8.96E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	2.66E+04	3.51E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	06-48-45-00	02-45-51-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		2.87E-06	1.15E-06 (g-soil/cm^3-air)
$VF_{gw,esp}$		2.26E-07	9.05E-08 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		5.40E-08	5.92E-08 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
LF_{sw}		2.36E+00	2.36E+00 (g-soil/cm^3-wat)
$VF_{s,amb}$		1.28E-07	1.28E-07 (g-soil/cm^3-air)
$VF_{gw,amb}$		3.53E-09	3.53E-09 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	7.21E+01	(g/mole)	Versch.(1996)
D_{air}	8.08E-02	(cm^2/sec)	TPHCWG (1997)
D_{wat}	9.80E-06	(cm^2/sec)	TPHCWG (1997)
K_{oc}	2.80E-01	log10(L-wat/kg-oc)	TPHCWG (1997)
K_{ow}	2.60E-01	log10(L-wat/kg)	Versch.(1996)
H	4.35E-05	(atm-m^3/mol)	TPHCWG (1997)
H	1.81E-03	(L-wat/L-air)	(calculated)
P_v	7.75E+01	(mm Hg)	Versch.(1996)
S	3.53E+05	(mg/L)	Versch.(1996)
pK_a	1.47E+01	log10(mole/mole)	GRI(1993)
pK_b		log10(mole/mole)	
ρ	8.00E-01	(g/mL)	Versch.(1996)
T_{nbp}	7.96E+01	(°C)	Versch.(1996)
T_{mp}	-8.64E+01	(°C)	Versch.(1996)
toxicity parameters			
RfD_o	6.00E-01	(mg/kg-day)	IRIS (05/01/93)
RfC_i	1.00E+00	(mg/m^3)	HEAST (07/93)
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	1.81E-03	(L-wat/L-air)	
$C_{sat,vap}$	3.06E+08	($\mu g/m^3$-air)	
K_{sw}	8.99E-02	(L-wat/kg-soil)	
$C_{sat,soil}$	3.17E+04	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	1.52E+04	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	6.34E-03	(cm^2/sec)	
$D_{eff,cap}$	1.06E-03	(cm^2/sec)	
$D_{eff,ws}$	5.85E-03	(cm^2/sec)	
$D_{eff,crk}$	6.34E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

(3) NA - not applicable.

TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	75-09-2		
name	methylene chloride		
	CH_2CL_2		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	3.13E+03	4.38E+03
($\mu g/m^3$)	TR_U	5.32E+02	8.94E+02
	TR_L	5.32E+00	8.94E+00
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	4.17E+03	4.38E+03
($\mu g/m^3$)	TR_U	7.10E+02	8.94E+02
	TR_L	7.10E+00	8.94E+00
groundwater ingestion			
$RBSL_{gw}$	THQ	2.19E+00	6.13E+00
(mg/L)	TR_U	1.14E+00	3.82E+00
	TR_L	1.14E-02	3.82E-02
	MCL	5.00E-03	5.00E-03
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	2.08E+00	5.83E+00
(mg/kg)	TR_U	1.08E+00	3.63E+00
	TR_L	1.08E-02	3.63E-02
	MCL	4.75E-03	4.75E-03
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (5.80E+04)	S< (8.12E+04)
(mg/L)	TR_U	9.87E+03	S< (1.66E+04)
	TR_L	9.87E+01	1.66E+02
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	4.57E+02	1.20E+03
(mg/L)	TR_U	7.78E+01	2.45E+02
	TR_L	7.78E-01	2.45E+00
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	8.80E+02	1.23E+03
(mg/kg)	TR_U	1.50E+02	2.52E+02
	TR_L	1.50E+00	2.52E+00
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	5.22E+01	1.37E+02
(mg/kg)	TR_U	8.88E+00	2.80E+01
	TR_L	8.88E-02	2.80E-01
residual phase mobility limit			
$RBSL_s$	unsat.	1.45E+04	1.45E+04
(mg/kg)	sat.	1.62E+04	1.62E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	4.79E+03	7.05E+03
(mg/kg)	TR_U	2.35E+03	4.09E+03
	TR_L	2.35E+01	4.09E+01
surficial soil exposure apportionment [2]			
(%)	THQ	10-86-02-00	05-90-03-00
(i-d-v-p)	TR_U	10-81-07-00	05-84-09-00
	TR_L	10-81-07-00	05-84-09-00
derived parameters:			
$VF_{s,esp}$		8.00E-05	3.20E-05 (g-soil/cm^3-air)
$VF_{gw,esp}$		9.13E-06	3.65E-06 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		2.85E-07	3.12E-07 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
LF_{sw}		1.05E+00	1.05E+00 (g-soil/cm^3-wat)
$VF_{s,amb}$		3.55E-06	3.55E-06 (g-soil/cm^3-air)
$VF_{gw,amb}$		5.39E-08	5.39E-08 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	8.49E+01	(g/mole)	USEPA(1996)
D_{air}	1.01E-01	(cm^2/sec)	USEPA(1996)
D_{wat}	1.17E-05	(cm^2/sec)	USEPA(1996)
K_{oc}	1.07E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	1.25E+00	log10(L-wat/kg)	USEPA(1996)
H	2.19E-03	(atm-m^3/mol)	USEPA(1996)
H	9.11E-02	(L-wat/L-air)	(calculated)
P_v	4.38E+02	(mm Hg)	USEPA(1994)
S	1.30E+04	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.33E+00	(g/mL)	USEPA(1996)
T_{nbp}	3.98E+01	(°C)	USEPA(1994)
T_{mp}	-9.51E+01	(°C)	CRC(1996)
toxicity parameters			
RfD_o	6.00E-02	(mg/kg-day)	IRIS (1994)
RfC_i	3.00E+00	(mg/m^3)	HEAST (07/93)
SF_o	7.50E-03	1/(mg/kg-day)	IRIS (1994)
SF_i	1.60E-03	1/(mg/kg-day)	IRIS (1994) SF/URF
W of E	B2		IRIS (1994)
MCL	5.00E-03	(mg/L-wat)	57 FR 31776 (17 Jul 92) Effecti
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	9.11E-02	(L-wat/L-air)	
$C_{sat,vap}$	2.04E+09	($\mu g/m^3$-air)	
K_{sw}	2.02E-01	(L-wat/kg-soil)	
$C_{sat,soil}$	2.63E+03	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	4.51E+03	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	7.88E-03	(cm^2/sec)	
$D_{eff,cap}$	3.80E-05	(cm^2/sec)	
$D_{eff,ws}$	1.78E-03	(cm^2/sec)	
$D_{eff,crk}$	7.88E-03	(cm^2/sec)	

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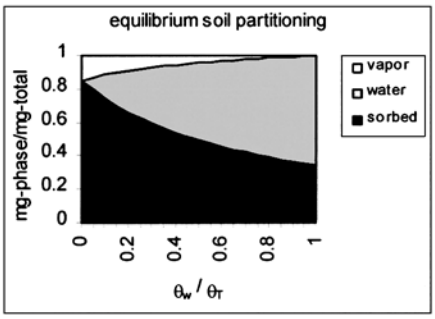
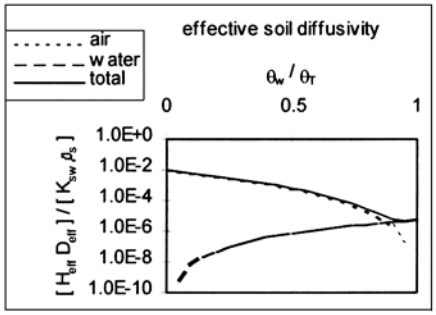




Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

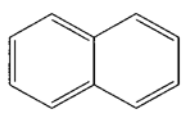
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

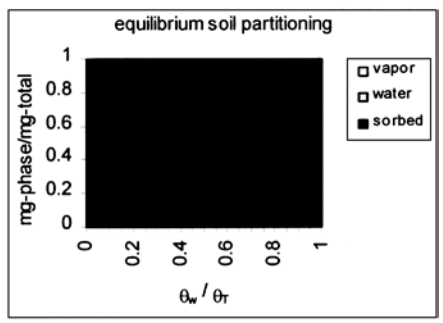
(3) NA - not applicable.

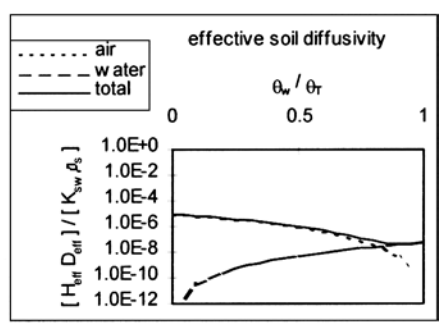
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	91-20-3		
name	naphthalene		
	$C_{10}H_8$		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	3.13E+00	4.38E+00
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	4.17E+00	4.38E+00
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	7.30E-01	2.04E+00
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	6.88E+01	1.93E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (1.97E+02)	S< (2.76E+02)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	2.61E+00	6.84E+00
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (6.77E+02)	Rs (9.48E+02)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	4.01E+01	1.05E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	2.93E+02	3.80E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	02-01-96-00	00-01-97-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		1.04E-07	4.16E-08
$VF_{gw,esp}$		1.60E-06	6.40E-07
$VF_{ss,amb,1}$		1.03E-08	1.13E-08
$VF_{ss,amb,2}$		1.80E-08	2.16E-08
$VF_{ss,amb,min(1,2)}$		1.03E-08	1.13E-08
LF_{sw}		1.06E-02	1.06E-02
$VF_{s,amb}$		4.62E-09	4.62E-09
$VF_{gw,amb}$		1.59E-08	1.59E-08

transport and thermodynamic parameters			[references]
MW	1.28E+02	(g/mole)	USEPA(1996)
D_{air}	5.90E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	7.50E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	3.30E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	3.36E+00	log10(L-wat/kg)	USEPA(1996)
H	4.83E-04	(atm-m^3/mol)	USEPA(1996)
H	2.01E-02	(L-wat/L-air)	(calculated)
P_v	1.82E-01	(mm Hg)	Mott(1995)
S	3.10E+01	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.03E+00	(g/mL)	USEPA(1996)
T_{nbp}	2.18E+02	(°C)	CRC(1996)
T_{mp}	8.02E+01	(°C)	CRC(1996)
toxicity parameters			
RfD_o	2.00E-02	(mg/kg-day)	IRIS (09/17/98)
RfC_i	3.00E-03	(mg/m^3)	IRIS (09/17/98)
SF_o		1/(mg/kg-day)	IRIS (09/17/98)
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (09/17/98)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-02		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	2.01E-02	(L-wat/L-air)	
$C_{sat,vap}$	1.28E+06	(μg/m^3-air)	
K_{sw}	2.00E+01	(L-wat/kg-soil)	
$C_{sat,soil}$	6.21E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	1.27E+03	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	4.61E-03	(cm^2/sec)	
$D_{eff,cap}$	8.02E-05	(cm^2/sec)	
$D_{eff,ws}$	2.37E-03	(cm^2/sec)	
$D_{eff,crk}$	4.61E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

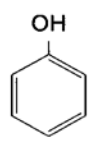
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

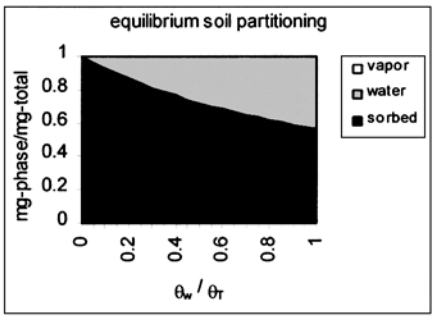
(3) NA - not applicable.

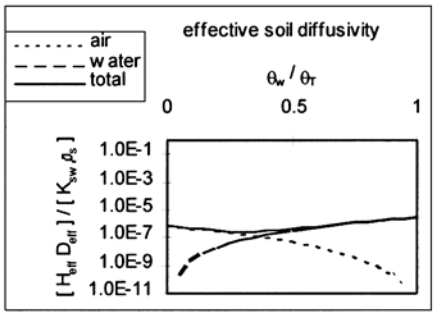
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	108-95-2		
name	phenol		
	C_6H_6O		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	2.19E+03	3.07E+03
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	2.92E+03	3.07E+03
(μg/m^3)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	2.19E+01	6.13E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	3.70E+01	1.04E+02
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (4.05E+07)	S< (5.67E+07)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	S< (9.12E+05)	S< (2.39E+06)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (4.92E+06)	Rs (6.89E+06)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	Rs (2.92E+05)	Rs (7.66E+05)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	NA	NA
(mg/kg)	sat.	NA	NA
surficial soil exposure			
$RBSL_{ss}$	THQ	4.59E+04	6.74E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	10-82-06-00	05-86-07-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		1.00E-08	4.00E-09 (g-soil/cm^3-air)
$VF_{gw,esp}$		3.20E-09	1.28E-09 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		3.19E-09	3.49E-09 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		3.19E-09	3.49E-09 (g-soil/cm^3-air)
LF_{sw}		5.92E-01	5.92E-01 (g-soil/cm^3-wat)
$VF_{s,amb}$		4.45E-10	4.45E-10 (g-soil/cm^3-air)
$VF_{gw,amb}$		5.40E-11	5.40E-11 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	9.41E+01	(g/mole)	USEPA(1996)
D_{air}	8.20E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	9.10E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	1.46E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	1.48E+00	log10(L-wat/kg)	USEPA(1996)
H	3.97E-07	(atm-m^3/mol)	USEPA(1996)
H	1.65E-05	(L-wat/L-air)	(calculated)
P_v	3.41E-01	(mm Hg)	USEPA(1994)
S	8.28E+04	(mg/L)	USEPA(1996)
pK_a	1.00E+01	log10(mole/mole)	USEPA(1996)
pK_b		log10(mole/mole)	
ρ	1.05E+00	(g/mL)	USEPA(1996)
T_{nbp}	1.82E+02	(°C)	USEPA(1994)
T_{mp}	4.09E+01	(°C)	CRC(1996)
toxicity parameters			
RfD_o	6.00E-01	(mg/kg-day)	IRIS (1994)
RfC_i	2.10E+00	(mg/m^3)	Route-to-Route
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on chemical properties and soil parameters			
UF	9.99E-01	(unitless)	
H_{eff}	1.65E-05	(L-wat/L-air)	
$C_{sat,vap}$	1.76E+06	(μg/m^3-air)	
K_{sw}	3.59E-01	(L-wat/kg-soil)	
$C_{sat,soil}$	2.97E+04	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	3.82E+04	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	9.68E-03	(cm^2/sec)	
$D_{eff,cap}$	1.07E-01	(cm^2/sec)	
$D_{eff,ws}$	9.83E-03	(cm^2/sec)	
$D_{eff,crk}$	9.68E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

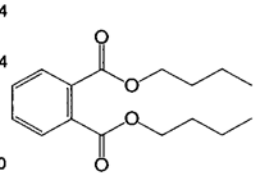
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

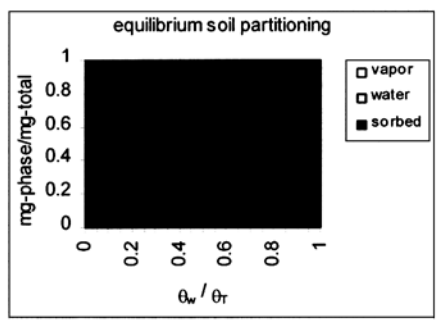
(3) NA - not applicable.

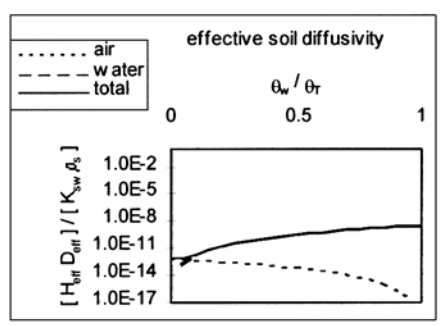
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	84-74-2		
name	phthalate, di-n-butyl		
	$C_{16}H_{22}O_4$		
Risk-Based Screening-Level Concentrations [1]			
risk or			
hazard	scenario:		
criteria:	residential	industrial	
ambient vapor inhalation			
$RBSL_{air}$	THQ	3.65E+02	5.11E+02
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	4.87E+02	5.11E+02
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	3.65E+00	1.02E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	Rs (5.82E+03)	Rs (1.63E+04)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (2.30E+07)	S< (3.22E+07)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	S< (5.30E+05)	S< (1.37E+06)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (2.64E+09)	Rs (3.70E+09)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	Rs (1.61E+08)	Rs (4.15E+08)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	1.32E+04	1.32E+04
(mg/kg)	sat.	1.32E+04	1.32E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	4.05E+04	7.85E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	55-43-00-00	38-60-00-00
(i-d-v-p)	TR_U		
	TR_L		
derived parameters:			
$VF_{s,esp}$		3.03E-12	1.23E-12
$VF_{gw,esp}$		9.18E-10	3.72E-10
$VF_{ss,amb,1}$		5.62E-11	6.16E-11
$VF_{ss,amb,2}$		1.80E-08	2.16E-08
$VF_{ss,amb,min(1,2)}$		5.62E-11	6.16E-11
LF_{sw}		6.27E-04	6.27E-04
$VF_{s,amb}$		1.38E-13	1.38E-13
$VF_{gw,amb}$		1.59E-11	1.59E-11

transport and thermodynamic parameters			[references]
MW	2.78E+02	(g/mole)	Versch.(1996)
D_{air}	4.38E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	7.86E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	4.53E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	4.57E+00	log10(L-wat/kg)	Versch.(1996)
H	9.38E-10	(atm-m^3/mol)	USEPA(1996)
H	3.90E-08	(L-wat/L-air)	(calculated)
P_v	1.00E+00	(mm Hg)	Versch.(1996)
S	1.12E+01	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.05E+00	(g/mL)	Versch.(1996)
T_{nbp}	3.40E+02	(°C)	Versch.(1996)
T_{mp}	-3.50E+01	(°C)	Versch.(1996)
toxicity parameters			
RfD_o	1.00E-01	(mg/kg-day)	IRIS (1994)
RfC_i	3.50E-01	(mg/m^3)	Route-to-Route
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-02		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	3.90E-08	(L-wat/L-air)	
$C_{sat,vap}$	1.52E+07	($\mu g/m^3$-air)	
K_{sw}	3.39E+02	(L-wat/kg-soil)	
$C_{sat,soil}$	3.80E+03	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	1.32E+11	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	1.20E+00	(cm^2/sec)	
$D_{eff,cap}$	3.92E+01	(cm^2/sec)	
$D_{eff,ws}$	1.22E+00	(cm^2/sec)	
$D_{eff,crk}$	1.20E+00	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

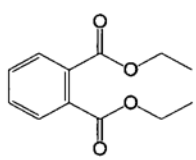
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

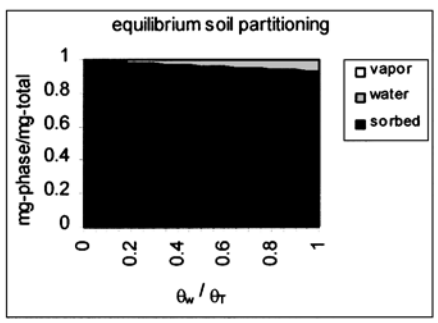
(3) NA - not applicable.

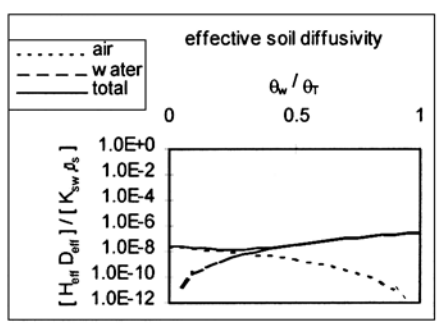
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	84-66-2		
name	phthalate, diethyl		
	$C_{12}H_{14}O_4$		
Risk-Based Screening-Level Concentrations [1]			
risk or			
hazard	scenario:		
criteria:	residential	industrial	
ambient vapor inhalation			
$RBSL_{air}$	THQ	2.92E+03	4.09E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	3.89E+03	4.09E+03
($\mu g/m^3$)	TR_U	NA	NA
	TR_L	NA	NA
groundwater ingestion			
$RBSL_{gw}$	THQ	2.92E+01	8.18E+01
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	4.06E+02	Rs (1.14E+03)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
	MCL	NA	NA
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (1.15E+08)	S< (1.61E+08)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	S< (2.58E+06)	S< (6.78E+06)
(mg/L)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	Rs (1.15E+08)	Rs (1.61E+08)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	Rs (6.81E+06)	Rs (1.79E+07)
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
residual phase mobility limit			
$RBSL_s$	unsat.	1.06E+04	1.06E+04
(mg/kg)	sat.	1.07E+04	1.07E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	6.45E+04	9.54E+04
(mg/kg)	TR_U	NA	NA
	TR_L	NA	NA
surficial soil exposure apportionment [2]			
(%)	THQ	11-87-01-00	05-92-01-00
(i-d-v-p)	TR_U		
	TR_L		

transport and thermodynamic parameters			[references]
MW	2.22E+02	(g/mole)	Versch.(1996)
D_{air}	2.56E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	6.35E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	2.46E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.42E+00	log10(L-wat/kg)	Versch.(1996)
H	4.50E-07	(atm-m^3/mol)	USEPA(1996)
H	1.87E-05	(L-wat/L-air)	(calculated)
P_v	1.40E+01	(mm Hg)	Versch.(1996)
S	2.10E+02	(mg/L)	Versch.(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.12E+00	(g/mL)	Versch.(1996)
T_{nbp}	2.98E+02	(°C)	Versch.(1996)
T_{mp}	-4.05E+01	(°C)	Versch.(1996)
toxicity parameters			
RfD_o	8.00E-01	(mg/kg-day)	IRIS (1994)
RfC_i	2.80E+00	(mg/m^3)	Route-to-Route
SF_o		1/(mg/kg-day)	
SF_i		1/(mg/kg-day)	
W of E	D		IRIS (1994)
MCL		(mg/L-wat)	
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	1.87E-05	(L-wat/L-air)	
$C_{sat,vap}$	1.70E+08	($\mu g/m^3$-air)	
K_{sw}	2.95E+00	(L-wat/kg-soil)	
$C_{sat,soil}$	6.20E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	2.69E+07	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	4.01E-03	(cm^2/sec)	
$D_{eff,cap}$	6.60E-02	(cm^2/sec)	
$D_{eff,ws}$	4.08E-03	(cm^2/sec)	
$D_{eff,crk}$	4.01E-03	(cm^2/sec)	







derived parameters:

$VF_{s,esp}$	5.72E-10	2.29E-10	(g-soil/cm^3-air)
$VF_{gw,esp}$	1.51E-09	6.03E-10	(cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$	7.63E-10	8.36E-10	(g-soil/cm^3-air)
$VF_{ss,amb,2}$	1.80E-08	2.16E-08	(g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$	7.63E-10	8.36E-10	(g-soil/cm^3-air)
LF_{sw}	7.19E-02	7.19E-02	(g-soil/cm^3-wat)
$VF_{s,amb}$	2.54E-11	2.54E-11	(g-soil/cm^3-air)
$VF_{gw,amb}$	2.54E-11	2.54E-11	(cm^3-wat/cm^3-air)

Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

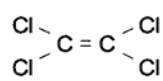
(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

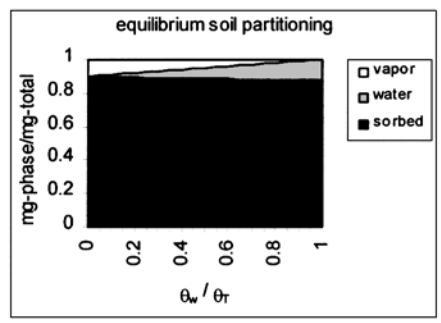
(3) NA - not applicable.

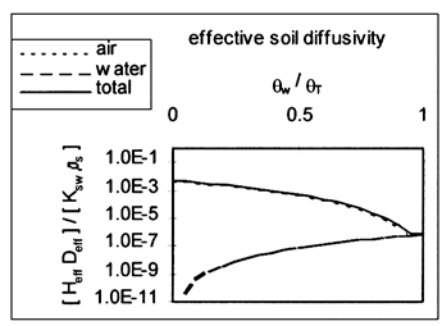
TABLE X3.1 Chemical-Specific Parameters and Risk-Based Screening Level Concentrations (See Refs. 2, 16-21) *(continued)*

CASRN	127-18-4		
name	tetrachloroethene		
	C_2CL_4		
Risk-Based Screening-Level Concentrations [1]			
	risk or		
	hazard	scenario:	
	criteria:	residential	industrial
ambient vapor inhalation			
$RBSL_{air}$	THQ	3.65E+01	5.11E+01
(μg/m^3)	TR_U	4.26E+02	7.15E+02
	TR_L	4.26E+00	7.15E+00
enclosed space vapor inhalation			
$RBSL_{air}$	THQ	4.87E+01	5.11E+01
(μg/m^3)	TR_U	5.68E+02	7.15E+02
	TR_L	5.68E+00	7.15E+00
groundwater ingestion			
$RBSL_{gw}$	THQ	3.65E-01	1.02E+00
(mg/L)	TR_U	1.64E-01	5.50E-01
	TR_L	1.64E-03	5.50E-03
	MCL	5.00E-03	5.00E-03
soil leaching to groundwater ingestion			
$RBSL_s$	THQ	2.98E+00	8.35E+00
(mg/kg)	TR_U	1.34E+00	4.50E+00
	TR_L	1.34E-02	4.50E-02
	MCL	4.08E-02	4.08E-02
groundwater to ambient vapor inhalation			
$RBSL_{gw}$	THQ	S< (2.35E+02)	S< (3.28E+02)
(mg/L)	TR_U	S< (2.74E+03)	S< (4.60E+03)
	TR_L	2.74E+01	4.60E+01
groundwater to enclosed space vapor inhalation			
$RBSL_{gw}$	THQ	1.34E+00	3.52E+00
(mg/L)	TR_U	1.56E+01	4.93E+01
	TR_L	1.56E-01	4.93E-01
subsurface soil volatilization to ambient air			
$RBSL_s$	THQ	1.47E+01	2.06E+01
(mg/kg)	TR_U	1.72E+02	2.89E+02
	TR_L	1.72E+00	2.89E+00
subsurface soil volatilization to enclosed space			
$RBSL_s$	THQ	8.74E-01	2.29E+00
(mg/kg)	TR_U	1.02E+01	3.21E+01
	TR_L	1.02E-01	3.21E-01
residual phase mobility limit			
$RBSL_s$	unsat.	1.49E+04	1.49E+04
(mg/kg)	sat.	1.49E+04	1.49E+04
surficial soil exposure			
$RBSL_{ss}$	THQ	5.84E+02	8.04E+02
(mg/kg)	TR_U	3.62E+02	6.42E+02
	TR_L	3.62E+00	6.42E+00
surficial soil exposure apportionment [2]			
(%)	THQ	08-63-28-00	03-62-33-00
(i-d-v-p)	TR_U	11-87-01-00	05-92-01-00
	TR_L	11-87-01-00	05-92-01-00
derived parameters:			
$VF_{s,esp}$		5.57E-05	2.23E-05 (g-soil/cm^3-air)
$VF_{gw,esp}$		3.63E-05	1.45E-05 (cm^3-wat/cm^3-air)
$VF_{ss,amb,1}$		2.38E-07	2.61E-07 (g-soil/cm^3-air)
$VF_{ss,amb,2}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$		1.80E-08	2.16E-08 (g-soil/cm^3-air)
LF_{sw}		1.22E-01	1.22E-01 (g-soil/cm^3-wat)
$VF_{s,amb}$		2.48E-06	2.48E-06 (g-soil/cm^3-air)
$VF_{gw,amb}$		1.56E-07	1.56E-07 (cm^3-wat/cm^3-air)

transport and thermodynamic parameters			[references]
MW	1.66E+02	(g/mole)	USEPA(1996)
D_{air}	7.20E-02	(cm^2/sec)	USEPA(1996)
D_{wat}	8.20E-06	(cm^2/sec)	USEPA(1996)
K_{oc}	2.19E+00	log10(L-wat/kg-oc)	USEPA(1996)
K_{ow}	2.67E+00	log10(L-wat/kg)	USEPA(1996)
H	1.84E-02	(atm-m^3/mol)	USEPA(1996)
H	7.65E-01	(L-wat/L-air)	(calculated)
P_v	1.90E+01	(mm Hg)	USEPA(1994)
S	2.00E+02	(mg/L)	USEPA(1996)
pK_a		log10(mole/mole)	
pK_b		log10(mole/mole)	
ρ	1.62E+00	(g/mL)	USEPA(1996)
T_{nbp}	1.21E+02	(°C)	USEPA(1994)
T_{mp}	-2.23E+01	(°C)	CRC(1996)
toxicity parameters			
RfD_o	1.00E-02	(mg/kg-day)	IRIS (1994)
RfC_i	3.50E-02	(mg/m^3)	Route-to-Route
SF_o	5.20E-02	1/(mg/kg-day)	ECAO (1992)
SF_i	2.00E-03	1/(mg/kg-day)	ECAO (1992)
W of E	C-B2		ECAO (1992)
MCL	5.00E-03	(mg/L-wat)	56 FR 3526 (30 Jan 91)
RAF_o	1.00E+00		
RAF_d	5.00E-01		
derived parameters dependent on			
chemical properties and soil parameters			
UF	1.00E+00	(unitless)	
H_{eff}	7.65E-01	(L-wat/L-air)	
$C_{sat,vap}$	1.72E+08	(μg/m^3-air)	
K_{sw}	1.74E+00	(L-wat/kg-soil)	
$C_{sat,soil}$	3.47E+02	(mg/kg-soil)	[based on S]
$C_{sat,soil}$	3.91E+02	(mg/kg-soil)	[based on P_v]
$D_{eff,vad}$	5.62E-03	(cm^2/sec)	
$D_{eff,cap}$	1.14E-05	(cm^2/sec)	
$D_{eff,ws}$	6.10E-04	(cm^2/sec)	
$D_{eff,crk}$	5.62E-03	(cm^2/sec)	







Notes:

(1) RBSL values are compared to physical limits of aqueous solubility (S<), saturated vapor pressure (<P), or either (Rs), and flagged if the calculated value is physically unrealistic. For cases where this occurs, the calculated values are given in parentheses.

(2) Percent of surficial soil exposure due to contributions of ingestion, dermal contact, vapor inhalation, and particulate inhalation (i-d-v-p).

(3) NA - not applicable.

$$\textit{slope factor}\ [\text{mg/kg}-\text{day}]^{-1} = \textit{unit risk factor}\ [\text{mg/m}^3]^{-1} \tag{X3.2}$$

$$/\textit{defined average lifetime media intake}\ [\text{m}^3/\text{kg}-\text{day}]^{-1}$$

where the defined average lifetime media intake (of water or air) is based on defined exposure parameters (media ingestion rate, exposure duration, and so forth) for direct ingestion or inhalation of the chemical.

X3.1.4.3 The example RBSL values appearing in this appendix correspond to upper bound conservative probabilities of adverse health effects ("risks") in the range from 10^{-6} to 10^{-4} resulting from the specified exposure.

X3.1.4.4 In the case of compounds that have not been classified as carcinogens, the example RBSLs are based on the general equation:

$$\textit{hazard quotient} = \textit{average intake}\ [\text{mg/kg}-\text{day}] \tag{X3.3}$$

$$/\textit{reference dose}\ [\text{mg/kg}-\text{day}]$$

where the intake depends on exposure parameters (ingestion rate, exposure duration, and so forth), the source concentration, and transport rates between the source and receptor. The reference dose is selected after reviewing a number of sources, including the USEPA Integrated Risk Information System (IRIS) **(8)** database, USEPA Health Effects Assessment Summary Tables (HEAST) **(9)**, and peer-reviewed sources. Note that this hazard quotient value does not reflect the actual probability for the specified exposure scenario to occur.

X3.1.4.5 The reference dose may be equivalently defined in terms of a reference concentration,

$$\textit{reference dose}\ [\text{mg/kg}-\text{day}] = \textit{reference concentration}\ [\text{mg/m}^3] \tag{X3.4}$$

$$\text{x}\ \textit{defined average daily media intake}\ [\text{m}^3/\text{kg}-\text{day}]$$

where the defined average daily media intake (of water or air) is based on defined exposure parameters (media ingestion rate, exposure duration, and so forth) for direct ingestion or inhalation of the chemical.

X3.1.4.6 The example RBSL values appearing in this appendix correspond to upper bound conservative estimates for hazard quotients of unity resulting from the specified exposure. Note that this hazard quotient value does not reflect the actual probability for the specified exposure scenario to occur.

X3.1.5 Tables X3.2-X3.4 summarize the equations and parameters used to prepare the example RBSLs (Table X3.1). The basis for each of these equations is discussed in X3.2-X3.12.

TABLE X3.2 Site and Scenario-Specific Parameters *(continued)*

parameter	residential	industrial	definition, units
specified risk or hazard criteria			
THQ	1	1	target hazard quotient for individual chemicals (unitless)
TR_U	1.00E-04	1.00E-04	target excess individual lifetime cancer risk - upper range value (unitless)
TR_L	1.00E-06	1.00E-06	target excess individual lifetime cancer risk - lower range value (unitless)
exposure parameters (adult male)			
AT_c	70	70	defined carcinogen averaging time (years)
AT_n	30	25	defined averaging time for non-carcinogen (years), = ED
BW	70	70	body weight (kg)
ED	30	25	exposure duration (years)
EF	350	250	exposure frequency (days/year)
IR_{soil}	100	50	soil ingestion rate (mg/day)
IR_{air}-indoor	15	20	daily inhalation rate (m^3/day) - indoor
IR_{air}-outdoor	20	20	daily inhalation rate (m^3/day) - outdoor
IR_w	2	1	daily water ingestion rate (L/day)
SA	3160	3160	seasonally-averaged skin surface area (cm^2/day)
M	0.5	0.5	soil to skin adherence factor (mg/cm^2)
building parameters			
L_b	200	300	enclosed space volume/infiltration area ratio (cm)
ER	12	20	enclosed space air exchange rate (1/day)
L_{crack}	15	15	enclosed-space foundation or wall thickness (cm)
η	0.01	0.01	foundation crack fraction (cm^2-cracks/cm^2-total area)
dP	0	0	indoor/outdoor differential pressure (g/cm-s^2)
k_v	1.00E-08	1.00E-08	soil permeability (cm^2)
Z_{crack}	15	15	depth to bottom of slab (cm)
X_{crack}	3400	3400	slab perimeter (cm)
A_b	700000	700000	slab area (cm^2)
surface parameters			
τ	30	25	averaging time for surface emission vapor flux (years)
U_{air}	225	225	ambient air velocity in mixing zone (cm/s)
δ_{air}	200	200	mixing zone height (cm)
A	20250000	20250000	source-zone area (cm^2)
W	4500	4500	width of source-zone area (cm)
L_{ss}	100	100	thickness of surficial soils (cm)
P_e	6.90E-14	6.90E-14	Areal total respirable particulate emission flux from source (g/cm^2-s)
derived parameters			
$LF_{pw,gw}$	4.70E+00	4.70E+00	leaching factor, ground water/soil pore water ratio (cm^3-wat/cm^3-wat)
Q_s	0	0	convective flow through basement slab (cm^3-air/sec)

TABLE X3.2 *Continued*

parameter	residential	industrial	definition, units
DF_{esp}	2.78E-02	6.94E-02	dispersion factor for enclosed-space air (g-cm^2/s)/(g/cm^3)
DF_{amb}	10	10	dispersion factor for ambient air (g-cm^2/s)/(g/cm^3)
VF_p	6.9E-15	6.9E-15	total respirable particulate concentration from soil source (g-soil/cm^3-air)
mobility limit parameters			
S_r	0.04	0.04	specified residual void fraction in vadose zone soil (cm^3-oil/cm^3-void)
S_r	0.04	0.04	specified residual void fraction in saturated zone soil (cm^3-oil/cm^3-void)
soil parameters			
h_{cap}	5		capillary zone thickness (cm)
h_v	295		vadose zone thickness (cm)
θ_{wcap}	0.342		soil water content - capillary fringe region (cm^3-water/cm^3-soil)
θ_{wvad}	0.12		soil water content - vadose zone (cm^3-water/cm^3-soil)
θ_{wcrk}	0.12		soil water content - soil filled foundation cracks (cm^3-water/cm^3-soil)
θ_{acap}	0.038		soil air content - capillary fringe region (cm^3-air/cm^3-soil)
θ_{avad}	0.26		soil air content - vadose zone (cm^3-air/cm^3-soil)
θ_{acrk}	0.26		soil air content - soil filled foundation cracks (cm^3-air/cm^3-soil)
ρ_s	1.7		soil bulk density - dry soil (g/cm^3)
f_{oc}	0.01		mass fraction of organic carbon in soil (g-oc/g-soil)
θ_T	0.38		soil porosity (cm^3-void/cm^3-soil)
L_{gw}	300		depth to ground water (cm)
L_s	100		thickness of surficial soils (cm)
pH	6.8		soil/water pH (unitless)
ground water parameters			
δ_{gw}	200		ground water mixing zone height (cm)
I	30		water infiltration rate (cm/year)
U_{gw}	6.85		ground water Darcy velocity (cm/day)
chemical-specific identifying parameters			
CASRN			Chemical Abstract Service Registration Number
name			common chemical name
chemical-specific transport and thermodynamic parameters			
MW			molecular weight (g/mole)
D_{air}			molecular diffusion coefficient in air (cm^2/sec)
D_{wat}			molecular diffusion coefficient in water (cm^2/sec)
K_{oc}			organic carbon/water partition coefficient log10(L-wat/kg-oc)
K_d			water / soil partition coefficient log10(L-wat/kg-soil) (K_d= K_{oc} f_{oc}*for organic chemicals*)
H			Henry's law constant (atm-m^3/mol) or (L-water/L-air)
P_v			Vapor pressure (mm Hg)
S			Aqueous solubility limit (mg/L-wat)
pK_a			acid ionization equilibrium constant (log10(mole/mole))
pK_b			base ionization equilibrium constant (log10(mole/mole))
chemical-specific toxicity parameters and exposure criteria			
RfD_o			chronic oral reference dose (mg/kg-day)
RfC_i			chronic inhalation reference concentration (mg/m^3)
SF_o			slope factor - oral (1/(mg/kg-day))
SF_i			slope factor - inhalation (1/(mg/kg-day))
W of E			weight of evidence
MCL			Federal maximum contaminant level for public drinking water supply (mg/L-wat)
RAF_o			relative absorption factor - oral (mg-adsorbed/mg-applied)
RAF_d			relative absorption factor - dermal (mg-adsorbed/mg-applied)
PEL-TWA			OSHA Permissable Exposure Level Time-Weighted Average workplace criteria (mg/m^3-air)
TLV-TWA			ACGIH Threshold Limit Value - Time Weighted Average workplace criteria (mg/m^3-air)
derived parameters - dependent on chemical and soil properties			
UF			fraction of unionized chemical in water (unitless)
H_{eff}			effective Henry's law coefficient (L-water/L-air)
$C_{sat,vap}$			saturated vapor concentration (mg/m^3-air)
K_{sw}			soil to water partition coefficient - vadose zone (L-water/kg-soil)
$C_{sat,soil}$			residual soil concentration - vadose zone (mg/kg-soil)
$D_{eff,vad}$			effective diffusivity - vadose zone (cm^2/sec)
$D_{eff,cap}$			effective diffusivity - capillary fringe zone (cm^2/sec)
$D_{eff,ws}$			effective diffusivity - averaged water table to surface (cm^2/sec)
$D_{eff,crk}$			effective diffusivity - enclosed space foundation cracks (cm^2/sec)
R_c			dissolved phase retardation factor for saturated ground water flow ((cm/s)-wat/(cm/s)-phase)
R_i			dissolved phase retardation factor for vadose zone infiltration flow ((cm/s)-wat/(cm/s)-phase)
derived parameters— dependent on scenario parameters, and chemical and soil properties			
$VF_{s,esp}$			volatilization factor, subsurface soil to enclosed space (g-soil/cm^3-air)
$VF_{gw,esp}$			volatilization factor, ground water to enclosed space (cm^3-wat/cm^3-air)

TABLE X3.2 *Continued*

parameter	residential	industrial	definition, units
$VF_{ss,amb,1}$			volatilization factor, surficial soil to ambient air (g-soil/cm^3-air)
$VF_{ss,amb,2}$			volatilization factor, surficial soil to ambient air, mass-limited (g-soil/cm^3-air)
$VF_{ss,amb,min(1,2)}$			applicable volatilization factor, surficial soil to ambient air (g-soil/cm^3-air)
LF_{sw}			leaching factor, soil to ground water (g-soil/cm^3-wat)
$VF_{s,amb}$			volatilization factor, subsurface soil to ambient air (g-soil/cm^3-air)
$VF_{gw,amb}$			volatilization factor, ground water to ambient air (cm^3-wat/cm^3-air)
Risk-Based Screening Level Concentrations			
$RBSL_{air}$			Risk-Based Screening Level for Air (mg/m^3)
			- ambient (outdoor) vapor
			- enclosed space (indoor) vapor
$RBSL_{gw}$			Risk-Based Screening Level for Ground Water (mg/L)
			- ingestion
			- inhalation of evolved vapors to outdoor air
			- inhalation of evolved vapors to indoor air
$RBSL_s$			Risk-Based Screening Level for soils (mg/kg)
			- leaching to ground water ingestion
			- inhalation of evolved vapors from subsurface soil to outdoor air
			- inhalation of evolved vapors from subsurface soil to indoor air
$RBSL_{ss}$			Risk-Based Screening Level for surficial soil (mg/kg)
			- combined exposure to direct ingestion, dermal contact, vapor inhalation, and particulate inhalation
(i-d-v-p)			Apportionment of $RBSL_{ss}$ as a fraction of exposure by direct ingestion, dermal contact, vapor inhalation, and particulate inhalation (% each)

TABLE X3.3 Equations Used to Develop Example Tier 1 Risk-Based Screening Levels (RBSLs) Appearing in Table X3.1 *(continued)*

Risk-Based Screening Level Concentration for Air: Inhalation - indoor and outdoor vapors

for non-carcinogens:

$$RBSL_{air} = \frac{THQ \cdot RfC_i \cdot AT_n \cdot 365\ \text{days/year}}{ED \cdot EF}$$

for carcinogens:

$$RBSL_{air} = \frac{Risk \cdot BW \cdot AT_c \cdot 365\ \text{days/year}}{SF_i \cdot IR_{air} \cdot ED \cdot EF}$$

For $RBSL_{air} > C_{sat,vap}$, the calculated concentration is greater than the pure chemical component saturated vapor concentration limit, and the specified risk or hazard level cannot be achieved in the defined scenario (unless an aerosol of the chemical is inhaled).

$RBSL_{air}$	Risk-Based Screening Level for air inhalation (mg/m^3)
AT_c	defined carcinogen averaging time (years)
AT_n	defined averaging time for non-carcinogen (years), = ED
BW	body weight (kg)
$C_{sat,vap}$	pure chemical saturated vapor concentration (mg/m^3)
ED	exposure duration (years)
EF	exposure frequency (days/year)
IR_{air}	daily inhalation rate (m^3/day) - indoor r outdoor
RfC_i	chronic inhalation reference concentration (mg/m^3)
Risk	target excess individual lifetime cancer risk (TR_U to TR_L range)
SF_i	carcinogenic slope factor - inhalation (mg/kg-day)$^{-1}$
THQ	target hazard quotient for individual chemicals (unitless)

Risk-Based Screening Level Concentration for Ground Water: Ingestion (potable water supply only)

for non-carcinogens:

$$RBSL_{gw} = \frac{THQ \cdot RfD_o \cdot BW \cdot AT_n \cdot 365\ \text{days/year}}{IR_w \cdot ED \cdot EF}$$

for carcinogens:

$$RBSL_{gw} = \frac{Risk \cdot BW \cdot AT_c \cdot 365\ \text{days/year}}{SF_o \cdot IR_w \cdot ED \cdot EF}$$

For $RBSL_{gw} > S$, the calculated concentration is greater than the pure chemical component aqueous solubility limit and the specified risk or hazard level cannot be achieved in the defined scenario (unless free-phase chemical is mixed with the ingested water).

$RBSL_{gw}$	Risk-Based Screening Level for ground water ingestion (mg/L)
AT_c	defined carcinogen averaging time (years)
AT_n	defined averaging time for non-carcinogen (years), = ED
BW	body weight (kg)
ED	exposure duration (years)
EF	exposure frequency (days/year)
IR_w	daily water ingestion rate (L/day)
RfD_o	chronic oral reference dose (mg/kg-day)
Risk	target excess individual lifetime cancer risk (TR_U to TR_L)
S	pure chemical aqueous solubility limit (mg/L)
SF_o	carcinogenic slope factor - oral (mg/kg-day)$^{-1}$
THQ	target hazard quotient for individual chemicals (unitless)

Risk-Based Screening Level Concentration for Ground Water: enclosed-space (indoor) vapor inhalation

$$RBSL_{gw} = \frac{RBSL_{air}}{VF_{gw,esp}} \cdot 10^{-3}\ \frac{m^3}{L}$$

For $RBSL_{gw} > S$, the calculated concentration is greater than the pure chemical component aqueous solubility limit and the specified risk or hazard level cannot be achieved in the defined scenario.

$RBSL_{gw}$	Risk-Based Screening Level for ground water ingestion (mg/L)
$RBSL_{air}$	Risk-Based Screening Level for air inhalation (mg/m^3)
$VF_{gw,esp}$	volatilization factor, ground water to enclosed space air (cm^3-water/cm^3-air)

Risk-Based Screening Level for Surficial Soil: ingestion of soil, inhalation of vapors and particulates, and dermal contact

for non-carcinogens:

$$RBSL_{ss} = \frac{THQ \cdot BW \cdot AT_n \cdot (365\ \text{days/year})}{EF \cdot ED} \Big/ \left[10^{-6}\frac{kg}{mg} \cdot \left(\frac{IR_s \cdot RAF_o}{RfD_o} + \frac{SA \cdot M \cdot RAF_d}{RfD_o}\right) + \frac{BW \cdot (VF_{ss} + VF_p)}{RfC_i} \cdot 10^3\ \frac{cm^3}{m^3}\frac{kg}{g}\right]$$

for carcinogens:

$$RBSL_{ss} = \frac{Risk \cdot BW \cdot AT_c \cdot (365\ \text{days/year})}{EF \cdot ED} \Big/ \left[10^{-6}\frac{kg}{mg} \cdot \left(SF_o \cdot IR_s \cdot RAF_o + SF_o \cdot SA \cdot M \cdot RAF_d\right) + SF_i \cdot IR_{air}\,(VF_{ss} + VF_p) \cdot 10^3\ \frac{cm^3}{m^3}\frac{kg}{g}\right]$$

$RBSL_{ss}$	Risk-Based Screening Level for Surficial Soil (mg/kg)
AT_c	defined carcinogen averaging time (years)
AT_n	defined averaging time for non-carcinogen (years, = ED)
BW	body weight (kg)
ED	exposure duration (years)
EF	exposure frequency (days/year)
IR_{air}	daily inhalation rate (m^3/day) - outdoor
IR_s	soil ingestion rate (mg/day)
M	soil to skin adherence factor (mg/cm^2)
RAF_d	dermal relative absorption factor
RAF_o	oral relative absorption factor
RfC_i	chronic inhalation reference concentration (mg/m^3)
RfD_o	chronic oral reference dose (mg/kg-day)
Risk	target excess individual lifetime cancer risk (TR_U to TR_L)
SA	seasonally-averaged skin surface area (cm^2/day)
SF_i	slope factor - inhalation (mg/kg-day)$^{-1}$
SF_o	slope factor - oral (mg/kg-day)$^{-1}$
THQ	target hazard quotient for individual chemicals (unitless)
VF_{ss}	volatilization factor, surficial soil to ambient air (g-soil/cm^3-air)
VF_p	total respirable particulate concentration from soil source (g-soil/cm^3-air)

TABLE X3.3 *Continued*

Volatilization Factor: subsurface soil to enclosed-space (indoor) vapor inhalation

For $Q_s = 0$,

$$VF_{s,esp} = \frac{1}{\frac{K_{sw}}{H_{eff}}\left(1 + \frac{D_{eff,vad}}{DF_{esp} L_s} + \frac{D_{eff,vad} \cdot L_{crk}}{D_{eff,crk} \cdot L_s \cdot \eta}\right) \cdot \frac{DF_{esp}}{D_{eff,vad}} \cdot L_s} \quad (1a)$$

for $Q_s > 0$,

$$VF_{s,esp} = \frac{1}{\frac{K_{sw}}{H_{eff}}\left(e^{\xi} + \frac{D_{eff,vad}}{DF_{esp} L_s} + \frac{D_{eff,vad} \cdot A_b}{Q_s \cdot L_s} \cdot (e^{\xi} - 1)\right) \cdot \frac{DF_{esp} \cdot L_s}{D_{eff,vad} \cdot e^{\xi}}} \quad (1b)$$

with

$$\xi = \frac{Q_s \cdot L_{crk}}{A_b \cdot D_{eff,crk} \cdot \eta}$$

If a finite depth of subsurface soil is specified, in addition

$$VF_{s,esp} = \frac{d_s \cdot \rho_s}{DF_{esp} \cdot \tau \cdot 31536000 \text{ sec/year}} \quad (2)$$

Of equations (1) and (2), choose whichever is less.

$VF_{s,esp}$	volatilization factor, subsurface soil to enclosed-space air (g-soil/cm^3-air)
A_b	slab area (cm^2)
$D_{eff,crk}$	effective diffusivity in soil-filled foundation cracks (cm^2/sec)
$D_{eff,vad}$	effective diffusion coefficient - vadose zone soils (cm^2/sec)
DF_{esp}	dispersion factor for enclosed-space air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
L_s	depth to subsurface soils (cm)
L_{crk}	enclosed-space foundation or wall thickness (cm)
Q_s	convective flow through basement slab (cm^3/sec)
η	foundation crack fraction (cm^2/cm^2)
d_s	depth of affected subsurface soil layer (cm)
τ	averaging time for surface emission vapor flux (years).

Leaching Factor: soil to groundwater

$$LF_{sw,1} = \frac{LF_{pw,gw}}{K_{sw}} \quad (1)$$

with

$$LF_{pw,gw} = \frac{1}{\left[1 + \frac{U_{gw} \cdot \delta_{gw}}{I \cdot W}\right]}$$

If a finite depth of subsurface soil is specified, in addition

$$LF_{sw,2} = \frac{d_s \cdot \rho_s}{I \cdot \tau} \quad (2)$$

Of equations (1) and (2), choose whichever is less.

LF_{sw}	leaching factor, soil to groundwater (g-soil/cm^3-wat)
I	water infiltration rate (cm/year)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
$LF_{pw,gw}$	leaching factor, ground water / soil pore water concentration ratio (cm^3-water/cm^3-water)
U_{gw}	groundwater Darcy velocity (cm/year)
W	width of source-zone area (cm)
δ_{gw}	groundwater mixing zone height (cm)
τ	averaging time for leaching duration (years)
d_s	depth of affected subsurface soil layer (cm)

Effective Diffusion Coefficient in homogeneous soil layers

$$D_{eff} = D_{air} \cdot \left(\frac{\theta_{air}^{3.33}}{\theta_T^2}\right) + D_{water} \cdot \left(\frac{\theta_{water}^{3.33}}{H_{eff} \cdot \theta_T^2}\right)$$

This semi-empirical equation is applicable for estimating the effective diffusion coefficient for porous media in homogeneous soil. It is used here in calculating a value for the vadose zone ($D_{eff,vad}$), the water table capillary fringe region ($D_{eff,cap}$), and in soil-filled enclosed space basement foundation cracks ($D_{eff,crk}$).

D_{eff}	effective diffusion coefficient (cm^2/sec)
D_{air}	molecular diffusion coefficient in air (cm^2/sec)
D_{water}	molecular diffusion coefficient in water (cm^2/sec)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
θ_{air}	soil air content (cm^3-air/cm^3-soil)
θ_{water}	soil water content (cm^3-water/cm^3-soil)
θ_T	soil porosity (cm^3-air/cm^3-soil), $= \theta_{air} + \theta_{water}$

Refs:

Millington and Quirk (1961): Transactions of the Faraday Society, 57, 1200-1207; Jury, W. A., W. F. Spencer, and W. J. Farmer, 1983: Behavior Assessment Model for Trace Organics in Soil: I. Model Description, Journal of Environmental Quality, 12, 558-564; Bruell, C. J., and G. E. Hoag, 1986: The Diffusion of Gasoline-Range Hydrocarbon Vapors in Porous Media, Experimental Methodologies, in Proceedings of the NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration, November 12-14, Houston.

Effective Diffusion Coefficient: averaged value - water table to soil surface

$$D_{eff,ws} = \frac{L_{gw}}{(h_v / D_{eff,vad}) + (h_{cap} / D_{eff,cap})}$$

$D_{eff,ws}$	effective diffusivity - averaged water table to surface (cm^2/sec)
$D_{eff,vad}$	effective diffusivity - vadose zone soils (cm^2/sec)
$D_{eff,cap}$	effective diffusivity - capillary fringe zone (cm^2/sec)
h_v	vadose zone thickness (cm)
h_{cap}	capillary zone thickness (cm)
L_{gw}	depth to groundwater (cm), $L_{gw} = h_v + h_{cap}$

Equation for Calculating Total Soil Concentration to Pore Water Concentration Ratio

$$K_{sw} = \frac{\theta_w + (K_d \cdot \rho_s) + (H_{eff} \cdot \theta_a)}{\rho_s}$$

This equation is used in calculating the ratio between total soil concentration and pore-water concentration for vadose zone soils. Equilibrium partitioning of the chemical between soil (sorbed), pore water, and pore vapors, at concentrations below the pure component pore water (S) or pore vapor saturation limit ($C_{sat,vap}$) is assumed.

K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
$C_{sat,vap}$	saturated vapor concentration (mg/m^3-air)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_d	soil (sorbed) / water partition coefficient (cm^3-wat/g-soil)
S	pure chemical aqueous solubility limit (mg/L)
ρ_s	dry soil bulk density (g/cm^3)
θ_a	soil air content (cm^3-air/cm^3-soil)
θ_w	soil water content (cm^3-water/cm^3-soil)

TABLE X3.3 *Continued*

Risk-Based Screening Level for Free-Phase Migration: unsaturated soil

$$RBSL_s = S \cdot \frac{\theta_w + (K_d \cdot \rho_s) + H_{eff} \cdot (\theta_a - \theta_o)}{\rho_s} + \frac{\theta_o \cdot \rho_o}{\rho_s} \cdot 10^6 \text{ mg/kg}$$

with

$$\theta_o = S_r \cdot \theta_T$$

This equation is applicable for pure chemicals with finite solubility, S, and which are liquids at ambient temperature and pressure

$RBSL_s$	Risk-Based Screening Level for soil (mg/kg)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_d	soil (sorbed) / water partition coefficient (cm^3-wat/g-soil)
S	pure chemical aqueous solubility limit (mg/L-water)
ρ_s	dry soil bulk density (g-soil/cm^3-soil)
ρ_o	density of chemical residual phase liquid (g-res/cm^3-res)
θ_a	soil air content (cm^3-air/cm^3-soil)
θ_w	soil water content (cm^3-water/cm^3-soil)
θ_o	residual phase volume fraction (cm^3-res/cm^3-soil)
θ_T	soil porosity (cm^3-void/cm^3-soil) = $\theta_a + \theta_w$
S_r	residual phase void fraction (cm^3-res/cm^3-void)

Risk-Based Screening Level for Free-Phase Migration: saturated soil

$$RBSL_s = S \cdot \frac{(\theta_T - \theta_o) + (K_d \cdot \rho_s)}{\rho_s} + \frac{\theta_o \cdot \rho_o}{\rho_s} \cdot 10^6 \text{ mg/kg}$$

with

$$\theta_o = S_r \cdot \theta_T$$

This equation is applicable for pure chemicals with finite solubility, S, and which are liquids at ambient temperature and pressure

$RBSL_s$	Risk-Based Screening Level for soil (mg/kg)
K_d	soil (sorbed) / water partition coefficient (cm^3-wat/g-soil)
S	pure chemical aqueous solubility limit (mg/L-water)
ρ_s	dry soil bulk density (g-soil/cm^3-soil)
ρ_o	density of chemical residual phase liquid (g-res/cm^3-res)
θ_o	residual phase volume fraction (cm^3-res/cm^3-soil)
θ_T	soil porosity (cm^3-void/cm^3-soil)
S_r	residual phase void fraction (cm^3-res/cm^3-void)

TABLE X3.4 Calculated Parameters Used in Example Tier 1 Risk-Based Screening Level Equations of Table X3.3 *(continued)*

Volatilization Factor: ground water to enclosed-space (indoor) vapor inhalation

For $Q_s = 0$,

$$VF_{gw,esp} = \frac{1}{\frac{1}{H_{eff}}\left(1 + \frac{D_{eff,ws}}{DF_{esp}\,L_{gw}} + \frac{D_{eff,ws}\cdot L_{crk}}{D_{eff,crk}\cdot L_{gw}\cdot \eta}\right)\cdot\frac{DF_{esp}}{D_{eff,ws}}\cdot L_{gw}}$$

for $Q_s > 0$,

$$VF_{gw,esp} = \frac{1}{\frac{1}{H_{eff}}\left(e^{\xi} + \frac{D_{eff,ws}}{DF_{esp}\,L_{gw}} + \frac{D_{eff,ws}\cdot A_b}{Q_s\cdot L_{gw}}\cdot(e^{\xi}-1)\right)\cdot\frac{DF_{esp}\cdot L_{gw}}{D_{eff,ws}\cdot e^{\xi}}}$$

with

$$\xi = \frac{Q_s\cdot L_{crk}}{A_b\cdot D_{crk}\cdot \eta}$$

$VF_{gw,esp}$	volatilization factor, ground water to enclosed space air (cm^3-water/cm^3-air)
$D_{eff,crk}$	effective diffusivity in soil-filled foundation cracks (cm^2/sec)
$D_{eff,ws}$	effective diffusivity - averaged water table to surface (cm^2/sec)
DF_{esp}	dispersion factor for indoor air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
L_{gw}	depth to ground water (cm)
L_{crk}	enclosed-space foundation or wall thickness (cm)
Q_s	convective flow through basement slab (cm^3/sec)
η	foundation crack fraction (cm^2/cm^2)

Volatilization Factor: ground water to ambient (outdoor) vapor inhalation

$$VF_{gw,amb} = \frac{1}{\left(1 + \frac{DF_{amb}\cdot L_{gw}}{D_{eff,ws}}\right)\frac{1}{H_{eff}}}$$

$VF_{gw,amb}$	volatilization factor, groundwater to ambient air (cm^3-water/cm^3-air)
$D_{eff,ws}$	effective diffusivity - averaged water table to surface (cm^2/sec)
DF_{amb}	dispersion factor for ambient air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
L_{gw}	depth to ground water (cm)

Particulate Concentration: total respirable particulate concentration originating from surficial soil source

$$VF_p = \frac{P_e}{DF_{amb}}$$

VF_p	total respirable particulate concentration from soil source (g-soil/cm^3-air)
DF_{amb}	dispersion factor for ambient air (cm/sec)
P_e	Areal total respirable particulate emission flux from source (g/cm^2-sec)

Volatilization Factor: surficial soils to ambient air (vapors)

$$VF_{ss} = \frac{\rho_s}{DF_{amb}}\cdot\sqrt{\frac{4\cdot D_{eff,vad}}{\pi\cdot\tau\cdot 31536000\ \text{sec/year}}\cdot\frac{H_{eff}}{K_{sw}\cdot\rho_s}} \quad (1)$$

or

$$VF_{ss} = \frac{L_{ss}\cdot\rho_s}{DF_{amb}\cdot\tau\cdot 31536000\ \text{sec/year}} \quad (2)$$

Of equations (1) or (2), choose whichever is less.

VF_{ss}	volatilization factor, surficial soil to ambient air (g-soil/cm^3-air)
$D_{eff,vad}$	effective diffusion coefficient for vadose-zone soils (cm^2/sec)
DF_{amb}	dispersion factor for ambient air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
L_{ss}	thickness of surficial soils (cm)
ρ_s	dry soil bulk density (g/cm^3)
τ	averaging time for surface emission vapor flux (years)

Volatilization Factor: subsurface soil to ambient (outdoor) vapor inhalation

$$VF_{s,amb} = \frac{1}{\left(1 + \frac{DF_{amb}\cdot L_s}{D_{eff,vad}}\right)\cdot\frac{K_{sw}}{H_{eff}}} \quad (1)$$

If a finite depth of subsurface soil is specified, in addition

$$VF_{s,amb} = \frac{d_s\cdot\rho_s}{DF_{amb}\cdot\tau\cdot 31536000\ \text{sec/year}} \quad (2)$$

Of equations (1) and (2), choose whichever is less.

$VF_{s,amb}$	volatilization factor, subsurface soil to ambient air (g-soil/cm^3-air)
$D_{eff,vad}$	effective diffusion coefficient - vadose zone soils (cm^2/sec)
DF_{amb}	dispersion factor for ambient air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
L_s	depth to subsurface soils (cm)
d_s	depth of affected subsurface soil layer (cm)
τ	averaging time for surface emission vapor flux (years)

TABLE X3.4 *Continued*

Volatilization Factor: subsurface soil to enclosed-space (indoor) vapor inhalation

For $Q_s = 0$,

$$VF_{s,esp} = \frac{1}{\frac{K_{sw}}{H_{eff}}\left(1 + \frac{D_{eff,vad}}{DF_{esp} L_s} + \frac{D_{eff,vad} \cdot L_{crk}}{D_{eff,crk} \cdot L_s \cdot \eta}\right) \cdot \frac{DF_{esp}}{D_{eff,vad}} \cdot L_s} \quad (1a)$$

for $Q_s > 0$,

$$VF_{s,esp} = \frac{1}{\frac{K_{sw}}{H_{eff}}\left(e^{\xi} + \frac{D_{eff,vad}}{DF_{esp} L_s} + \frac{D_{eff,vad} \cdot A_b}{Q_s \cdot L_s} \cdot (e^{\xi} - 1)\right) \cdot \frac{DF_{esp} \cdot L_s}{D_{eff,vad} \cdot e^{\xi}}} \quad (1b)$$

with

$$\xi = \frac{Q_s \cdot L_{crk}}{A_b \cdot D_{crk} \cdot \eta}$$

If a finite depth of subsurface soil is specified, in addition

$$VF_{s,esp} = \frac{d_s \cdot \rho_s}{DF_{esp} \cdot \tau \cdot 31536000 \text{ sec/year}} \quad (2)$$

Of equations (1) and (2), choose whichever is less.

$VF_{s,esp}$	volatilization factor, subsurface soil to enclosed-space air (g-soil/cm^3-air)
A_b	slab area (cm^2)
$D_{eff,crk}$	effective diffusivity in soil-filled foundation cracks (cm^2/sec)
$D_{eff,vad}$	effective diffusion coefficient - vadose zone soils (cm^2/sec)
DF_{esp}	dispersion factor for enclosed-space air (cm/s)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
L_s	depth to subsurface soils (cm)
L_{crk}	enclosed-space foundation or wall thickness (cm)
Q_s	convective flow through basement slab (cm^3/sec)
η	foundation crack fraction (cm^2/cm^2)
d_s	depth of affected subsurface soil layer (cm)
τ	averaging time for surface emission vapor flux (years)

Leaching Factor: soil to groundwater

$$LF_{sw,1} = \frac{LF_{pw,gw}}{K_{sw}} \quad (1)$$

with

$$LF_{pw,gw} = \frac{1}{\left[1 + \frac{U_{gw} \cdot \delta_{gw}}{I \cdot W}\right]}$$

If a finite depth of subsurface soil is specified, in addition

$$VF_{s,amb,2} = \frac{d_s \cdot \rho_s}{I \cdot \tau} \quad (2)$$

Of equations (1) and (2), choose whichever is less.

LF_{sw}	leaching factor, soil to groundwater (g-soil/cm^3-wat)
I	water infiltration rate (cm/year)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
$LF_{pw,gw}$	leaching factor, soil pore water / ground water concentration ratio (cm^3-water/cm^3-water)
U_{gw}	groundwater Darcy velocity (cm/year)
W	width of source-zone area (cm)
δ_{gw}	groundwater mixing zone height (cm)
τ	averaging time for leaching duration (years)
d_s	depth of affected subsurface soil layer (cm)

Effective Diffusion Coefficient in homogeneous soil layers

$$D_{eff} = D_{air} \cdot \left(\frac{\theta_{air}^{3.33}}{\theta_T^2}\right) + D_{water} \cdot \left(\frac{\theta_{water}^{3.33}}{H_{eff} \cdot \theta_T^2}\right)$$

This semi-empirical equation is applicable for estimating the effective diffusion coefficient for porous media in homogeneous soil. It is used here in calculating a value for the vadose zone ($D_{eff,vad}$), the water table capillary fringe region ($D_{eff,cap}$), and in soil-filled enclosed space basement foundation cracks ($D_{eff,crk}$).

D_{eff}	effective diffusion coefficient (cm^2/sec)
D_{air}	molecular diffusion coefficient in air (cm^2/sec)
D_{water}	molecular diffusion coefficient in water (cm^2/sec)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
θ_{air}	soil air content (cm^3-air/cm^3-soil)
θ_{water}	soil water content (cm^3-water/cm^3-soil)
θ_T	soil porosity (cm^3-air/cm^3-soil), $= \theta_{air} + \theta_{water}$

Refs:
Millington and Quirk (1961): Transactions of the Faraday Society, 57, 1200-1207; Jury, W. A., W. F. Spencer, and W. J. Farmer, 1983: Behavior Assessment Model for Trace Organics in Soil: I. Model Description, Journal of Environmental Quality, 12, 558-564; Bruell, C. J., and G. E. Hoag, 1986: The Diffusion of Gasoline-Range Hydrocarbon Vapors in Porous Media, Experimental Methodologies, in Proceedings of the NWWA/API Conference on Petroleum Hydrocarbons and Organic Chemicals in Groundwater: Prevention, Detection, and Restoration, November 12-14, Houston.

Effective Diffusion Coefficient: averaged value - water table to soil surface

$$D_{eff,ws} = \frac{L_{gw}}{(h_v / D_{eff,vad}) + (h_{cap} / D_{eff,cap})}$$

$D_{eff,ws}$	effective diffusivity - averaged water table to surface (cm^2/sec)
$D_{eff,vad}$	effective diffusivity - vadose zone soils (cm^2/sec)
$D_{eff,cap}$	effective diffusivity - capillary fringe zone (cm^2/sec)
h_v	vadose zone thickness (cm)
h_{cap}	capillary zone thickness (cm)
L_{gw}	depth to groundwater (cm), $L_{gw} = h_v + h_{cap}$

Equation for Calculating Total Soil Concentration to Pore Water Concentration Ratio

$$K_{sw} = \frac{\theta_w + (K_d \cdot \rho_s) + (H_{eff} \cdot \theta_a)}{\rho_s}$$

This equation is used in calculating the ratio between total soil concentration and pore-water concentration for vadose zone soils. Equilibrium partitioning of the chemical between soil (sorbed), pore water, and pore vapors, at concentrations below the pure component pore water (S) or pore vapor saturation limit ($C_{sat,vap}$) is assumed.

K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
$C_{sat,vap}$	saturated vapor concentration (mg/m^3-air)
H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
K_d	soil (sorbed) / water partition coefficient (cm^3-wat/g-soil)
S	pure chemical aqueous solubility limit (mg/L)
ρ_s	dry soil bulk density (g/cm^3)
θ_a	soil air content (cm^3-air/cm^3-soil)
θ_w	soil water content (cm^3-water/cm^3-soil)

TABLE X3.4 *Continued*

Equation for calculating dispersion factor for ambient (outdoor) air

$$DF_{amb} = \frac{U_{air} \cdot W \cdot \delta_{air}}{A}$$

DF_{amb}	dispersion factor for ambient air (cm/sec), or source emission flux / vapor concentration (g/cm^2-sec)/(g/cm^3)
A	source-zone area (cm^2)
U_{air}	ambient air velocity in mixing zone (cm/s)
W	width of source-zone area (cm)
δ_{air}	mixing zone height (cm)

Equation for calculating dispersion factor for enclosed-space (indoor) air

$$DF_{esp} = L_b \cdot ER \cdot \frac{1}{86400\ sec/day}$$

DF_{esp}	dispersion factor for enclosed-space air (cm/sec), or source emission flux / vapor concentration (g/cm^2-sec)/(g/cm^3)
ER	enclosed space air exchange rate (1/day)
L_b	enclosed space volume/infiltration area ratio (cm)

Equation for calculating effective Henry's law coefficient

$$H_{eff} = H' \cdot UF$$

with

$$H' = \frac{H}{R \cdot T_{amb}} \cdot 10^3 \frac{L}{m^3}$$

H_{eff}	effective Henry's law coefficient (cm^3-water/cm^3-air)
H'	Henry's law coefficient (cm^3-water/cm^3-air)
H	Henry's law coefficient (atm-m^3/mol)
R	ideal gas constant (atm-L/g-mol-K), = 0.08206
T_{amb}	ambient temperature (K), = 293
UF	fraction of unionized chemical in water (g-mol/g-mol)

Equation for pressure-driven convective flow through basement slab

$$Q_s = \frac{2 \cdot \pi \cdot dP \cdot k_v \cdot X_{crk}}{\mu_a \cdot \ln\left(\frac{2 \cdot Z_{crk}}{R_{crk}}\right)}$$

with

$$R_{crk} = \frac{A_b \cdot \eta}{X_{crk}}$$

This equation describes volumetric flow through a crack of total length X_{crk}, width R_{crk}, and a cylinderical pressure field and orthogonal flow field which extends into the soil.

Q_s	convective flow through basement slab (cm^3/sec)
A_b	slab area (cm^2)
dP	indoor/outdoor differential pressure (g/cm-s^2)
k_v	soil permeability (cm^2)
X_{crk}	slab perimeter - total crack length (cm)
Z_{crk}	depth to bottom of slab (cm)
μ_{air}	viscosity of air (g/cm-s), = $1.81 \cdot 10^{-4}$
η	foundation crack fraction (cm^2-cracks/cm^2-total area)

Ref: Johnson, P. C. and R. A. Ettinger, 1991: "Heuristic Model for Predicting the Intrusion Rate of Contaminant Vapors into Buildings", Environmental Science & Technology, 25, 1445-1452.

Equation for Calculating Saturated Vapor Concentration

$$C_{sat,vap} = \frac{P_v}{760\ mm\ Hg/atm} \cdot \frac{MW}{R\ T_{amb}} \cdot 10^6\ \frac{mg/m^3}{g/L}$$

This equation is used in calculating the saturated vapor concentration for a pure chemical constiuent. Saturated vapor concentration is the highest concentration achievable in air for a pure chemical constituent under thermodynamic equilibrium at a specified temperature. Saturated vapor concentration is a defined thermodynamic property.

$C_{sat,vap}$	saturated vapor concentration (mg/m^3-air)
MW	molecular weight (g/g-mol)
P_v	saturated vapor pressure (mm Hg)
R	ideal gas constant (atm-L/g-mol-K), = 0.08206
T_{amb}	ambient temperature (K), = 293

Equation for soil / water partition coefficient

For organic chemicals,

$$K_d = K_{oc} \cdot f_{oc}$$

K_d	soil (sorbed) / water partition coefficient (cm^3-wat/g-soil)
f_{oc}	mass fraction of organic carbon in soil (g-oc/g-soil)
K_{oc}	organic carbon / water partition coefficient (L-water/kg-oc)

for inorganic chemicals, K_d is specified directly.

Equation for Calculating Unionized Fraction of Ionizing Chemicals

For acids,

$$UF = \frac{1}{1 + 10^{pH - pK_a}}$$

for bases,

$$UF = \frac{1}{1 + 10^{14 - pH - pK_b}}$$

otherwise,

$$UF = 1$$

For chemicals capable of forming ions in the normal soil/water pH range, the unionized fraction of the chemical in water is calculated. Only the unionized chemical is available for volatilization. Some chemicals may form multiple-charged ions (X++ or X--, etc.). Only singly-charged ions are included in the current equations.

UF	fraction of unionized chemical in water (g-mol/g-mol)
pH	Soil/water pH
pK_a	acid ionization equilibrium constant (log10(g-mol/g-mol))
pK_b	base ionization equilibrium constant(log10(g-mol/g-mol))

Ref:
Values of pK_a and pK_b as defined in Waucoupe, 1992: Reviews of Environmental Contamination and Toxicology, 123, 1-155.
Aalund, Leo R., 1986: "One-Step Method Determines Sour Water H_2S Hazard, Oil and Gas Journal, 24 February, 55 - 58.

TABLE X3.4 *Continued*

Equation for Calculating Residual Soil Concentration	
$C_{sat,soil} = S \cdot K_{sw}$	
For a pure chemical constituent, $C_{sat,soil}$ is a value at and above which the chemical is present in soil pore water at its aqueous solubility limit and is present in soil pore air at its saturated vapor concentration. This value may also be calculated as	
$C_{sat,soil} = \frac{C_{sat,vap}}{H' \cdot (10^3\ L/m^3)} \cdot K_{sw}$	
$C_{sat,soil}$	residual soil concentration (mg/kg)
K_{sw}	soil to water partition coefficient (cm^3-water/g-soil)
S	pure chemical aqueous solubility limit (mg/L)
$C_{sat,vap}$	saturated vapor concentration (mg/m^3-air)
H'	Henry's law coefficient (cm^3-water/cm^3-air)

X3.2 *Air-Inhalation of Vapors (Outdoors/Indoors)*:

X3.2.1 In this case chemical intake results from the inhalation of vapors. It is assumed that vapor concentrations remain constant over the duration of exposure, and all inhaled chemicals are absorbed. Equations appearing in Table X3.3 for estimating RBSLs for vapor concentrations in the breathing zone follow guidance given in Ref. **(15)**. Should the example RBSL exceed the saturated vapor concentration for any individual component, "P<" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that chemical and the specified exposure scenario (unless an aerosol of the chemical is inhaled).

X3.2.2 A target vapor concentration other than the RBSL for inhalation may be selected and used as an alternate inhalation criteria (e.g. PEL-TWA or TLV-TWA workplace exposure criteria as listed in Table X3.1, or odor nuisance level). The reader should review the restrictions and assumptions embodied in these alternate criteria for appropriateness before their use as Tier 1 air inhalation screening criteria.

X3.3 *Ground Water-Ingestion of Ground Water*:

X3.3.1 In this case chemical intake results from ingestion of ground water. It is assumed that the dissolved chemical concentrations remain constant over the duration of exposure. Equations appearing in Table X3.3 for estimating RBSLs for drinking water concentrations follow guidance given in Ref. **(15)** for ingestion of chemicals in drinking water. Should the example RBSL exceed the pure component aqueous solubility limit for any component, "S<" is entered in the table to indicate the selected risk level or hazard quotient cannot be reached for that compound and the specified exposure scenario (unless immiscible free-phase chemical is mixed with the ingested water).

X3.3.2 A target concentration other than the RBSL for ground water ingestion may be selected and used as an alternate ground water criteria (e.g., Federal drinking water MCL criteria for a public water supply as listed in Table X3.1, taste or odor threshold, or ecological criteria). Determining and validating the basis of these alternate criteria is necessary before their use as Tier 1 ground water ingestion screening criteria.

X3.4 *Ground Water-Inhalation of Outdoor Vapors*:

X3.4.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from dissolved chemicals in ground water located some distance below ground surface. Here the goal is to determine the RBSL for the chemical dissolved in ground water that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in Table X3.3. A target vapor concentration value other than the RBSL for inhalation (as discussed in X3.2.2) may be selected and substituted for the $RBSL_{air}$ parameter appearing in the equations given in Table X3.3.

X3.4.2 A conceptual model for the transport of chemicals from ground water to ambient air is depicted in Fig. X3.1. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the relationship between outdoor air and dissolved ground water concentrations is represented in Table X3.3 by the "volatilization factor", $VF_{gw,amb}$ [(mg/cm^3-air)/(mg/cm^3-water)], defined in Table X3.4. It is based on the following assumptions:

X3.4.2.1 A constant dissolved chemical concentration in ground water,

X3.4.2.2 Linear equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table,

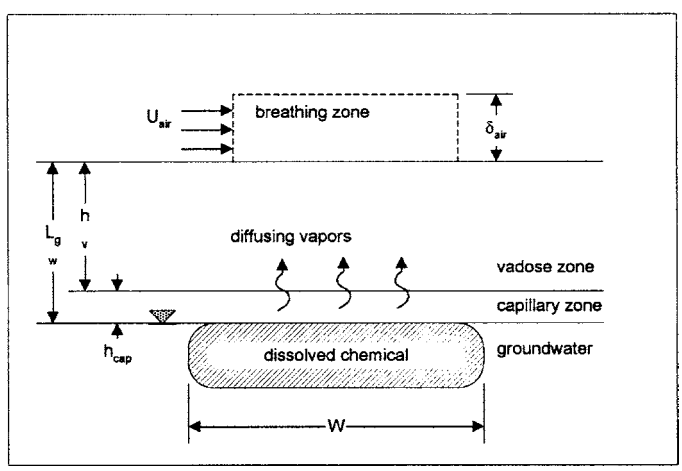


FIG. X3.1 Volatilization from Ground Water to Ambient Air

X3.4.2.3 Steady-state vapor- and liquid-phase diffusion through the capillary fringe and vadose zones to ground surface,

X3.4.2.4 No loss of chemical as it diffuses toward ground surface (that is, no biodegradation), and

X3.4.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X3.4.3 Should the example $RBSL_{gw}$ exceed the pure component solubility for any individual component, "S<" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X3.5 *Ground Water-Inhalation of Enclosed-Space (Indoor) Vapors*:

X3.5.1 In this case chemical intake results from the inhalation of vapors in enclosed spaces. The chemical vapors originate from dissolved chemicals in ground water located some distance below ground surface. Here the goal is to determine the RBSL for the chemical dissolved in ground water which corresponds to the target RBSL for vapors in the breathing zone as given in Table X3.3. A target vapor concentration value other than the RBSL for inhalation (as discussed in X3.2.2) may be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Table X3.3.

X3.5.2 A conceptual model for the transport of chemicals from ground water to indoor air is depicted in Fig. X3.2. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the relationship between enclosed-space air and dissolved ground water concentrations is represented in Table X3.3 by the "volatilization factor" $VF_{gw,esp}$ [(mg/cm^3-air)/(mg/cm^3-water)] defined in Table X3.4. It is based on the following assumptions:

X3.5.2.1 A constant dissolved chemical concentration in ground water,

X3.5.2.2 Equilibrium partitioning between dissolved chemicals in ground water and chemical vapors at the ground water table,

X3.5.2.3 Steady-state vapor- and liquid-phase diffusion through the capillary fringe, vadose zone, and foundation cracks,

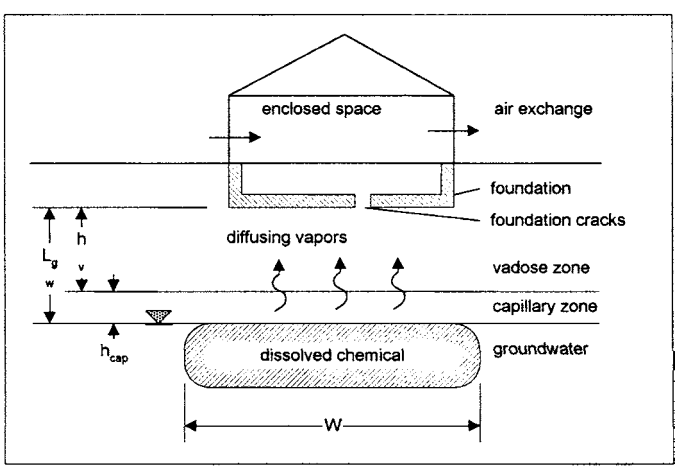


FIG. X3.2 Volatilization from Ground Water to Enclosed-Space Air

X3.5.2.4 No loss of chemical as it diffuses toward ground surface (e.g., no biodegradation), and

X3.5.2.5 Steady, well-mixed atmospheric dispersion of the emanating vapors within the enclosed space, where the convective transport into the building through foundation cracks or openings is negligible in comparison with diffusive transport.

X3.5.3 Should the example $RBSL_{gw}$ exceed the pure component solubility for any individual component, "S<" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario.

X3.6 *Surficial Soils-Ingestion, Dermal Contact, and Vapor and Particulate Inhalation*:

X3.6.1 In this case it is assumed that chemical intake results from a combination of intake routes, including: ingestion, dermal absorption, and inhalation of both particulates and vapors emanating from surficial soil.

X3.6.2 Equations used to estimate intake resulting from ingestion follow guidance given in Ref. **(15)** for ingestion of chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and intake rates remain constant over the exposure duration. Other values for exposure parameters (that is, child exposure or age-adjusted exposure) should also be considered for ingestion of soil.

X3.6.3 Equations used to estimate intake resulting from dermal absorption follow guidance given in Ref. **(15)** for dermal contact with chemicals in soil. For this route, it has been assumed that surficial soil chemical concentrations and absorption rates remain constant over the exposure duration. Other values for exposure parameters (that is, child exposure or age-adjusted exposure) should also be considered for dermal contact with soil.

X3.6.4 Equations used to estimate intake resulting from the inhalation of particulates follow guidance given in Ref. **(15)** for inhalation of airborne chemicals. For this route, it has been assumed that surficial soil chemical concentrations, intake rates, and atmospheric particulate concentrations remain constant over the exposure duration.

X3.6.5 Equations used to estimate intake resulting from the inhalation of airborne chemicals which have volatilized from surficial soils follow guidance given in Ref. **(15)** for inhalation of airborne chemicals.

X3.6.6 A conceptual model for the volatilization of chemicals from surficial soils to outdoor air is depicted in Fig. X3.3. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the relationship between outdoor air and surficial soil concentrations is represented in Table X3.3 by the "volatilization factor" VF_{ss} [(mg/cm^3-air)/(mg/g-soil)] defined in Table X3.4. It is based on the following assumptions:

X3.6.6.1 Uniformly distributed chemical throughout the depth range of 0-L_{ss} (cm) below ground surface,

X3.6.6.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X3.6.6.3 Diffusion through the surficial soil layer,

X3.6.6.4 No loss of chemical as it diffuses toward ground surface (e.g., no biodegradation), and

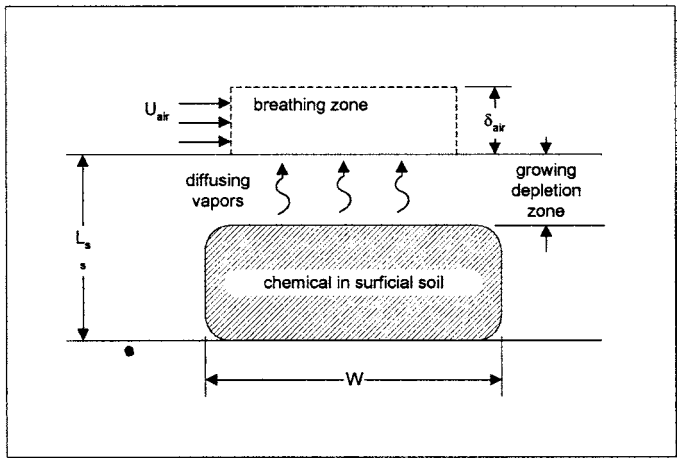


FIG. X3.3 Volatilization from Surficial Soils

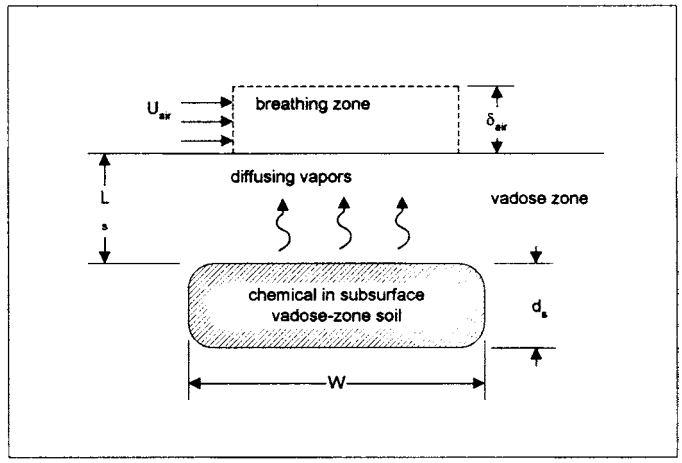


FIG. X3.4 Volatilization from Subsurface Soils to Ambient Air

X3.6.6.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X3.6.7 In the event that the time-averaged flux exceeds that which would occur if all chemical initially present in the surficial soil zone volatilized during the exposure period, then the volatilization factor is determined from a mass balance assuming that all chemical initially present in the surficial soil zone volatilizes during the exposure period.

X3.6.8 Equations for calculating the apportionment of chemical from this presumed combination of surficial soil intake routes, including ingestion, dermal absorption, inhalation of particulates, and inhalation of vapors emanating from surficial soil, are specified in Table X3.3. The calculated values are included in Table X3.1.

X3.7 *Subsurface Soils-Inhalation of Outdoor Vapors*:

X3.7.1 In this case chemical intake is a result of inhalation of outdoor vapors which originate from chemicals contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for outdoor vapors in the breathing zone, as given in X3.2. A target vapor concentration other than the RBSL for inhalation (as discussed in X3.2.2) may be substituted for the $RBSL_{air}$ parameter appearing in the equations given in Table X3.3.

X3.7.2 A conceptual model for the transport of chemicals from subsurface soils to ambient air is depicted in Fig. X3.4. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the relationship between outdoor air and soil concentration is represented in Table X3.3 by the "volatilization factor", $VF_{s,amb}$ [(mg/cm^3-air)/(mg/g-soil)], defined in Table X3.4. It is based on the following assumptions:

X3.7.2.1 A constant chemical concentration in subsurface soils.

X3.7.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X3.7.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone to ground surface,

X3.7.2.4 No loss of chemical as it diffuses toward ground surface (that is, no biodegradation), and

X3.7.2.5 Steady well-mixed atmospheric dispersion of the emanating vapors within the breathing zone as modeled by a "box model" for air dispersion.

X3.7.3 Should the example RBSL exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated, $C_{sat,soil}$ [mg/kg-soil] (see Table X3.4 for calculation of this value), "Rs" is entered into the table to indicate the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X3.7.4 No mass balance is imposed on the volatilization factor $VF_{s,amb}$.

X3.7.4.1 If the depth of the affected subsurface soil layer, d_s, can be specified, a mass balance can be imposed.

X3.7.4.2 In the event that the time-averaged flux exceeds that which would occur if all the chemical initially present in the affected subsurface soil layer volatilized during the exposure period, then the volatilization factor can be determined from a mass balance assuming that all chemical present in the subsurface soil layer volatilizes during the exposure period.

X3.8 *Subsurface Soils-Inhalation of Enclosed-Space (Indoor) Vapors*:

X3.8.1 In this case chemical intake is a result of inhalation of enclosed-space vapors which originate from chemicals contained in subsurface soils located some distance below ground surface. Here the goal is to determine the RBSL for subsurface soils that corresponds to the target RBSL for indoor vapors, as given in Table X3.3. A target vapor concentration other than the RBSL for inhalation (as discussed in X3.2.2) may be substituted for the $RBSL_{air}$ parameter appearing in Table X3.3.

X3.8.2 A conceptual model for the transport of chemicals from subsurface soils to enclosed spaces is depicted in Fig. X3.5. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the relationship between indoor air and soil concentrations is represented in Table

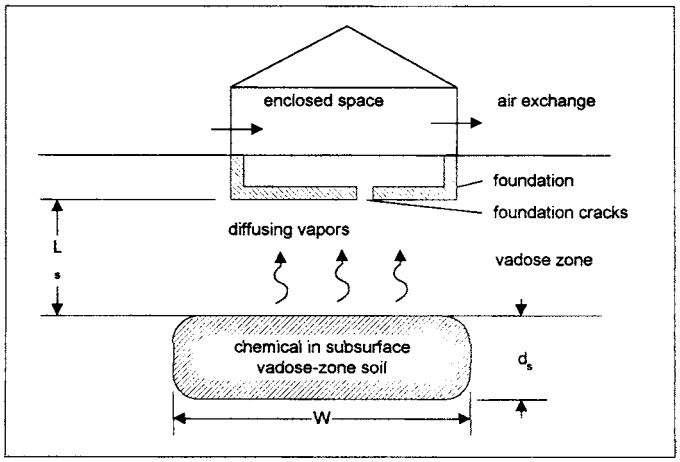


FIG. X3.5 Volatilization from Subsurface Soils to Enclosed-Space Air

X3.3 by the "volatilization factor", $VF_{s,esp}$ [(mg/cm^3-air)/(mg/g-soil)], defined in Table X3.4. It is based on the following assumptions:

X3.8.2.1 A constant chemical concentration in subsurface soils,

X3.8.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X3.8.2.3 Steady-state vapor- and liquid-phase diffusion through the vadose zone and foundation cracks,

X3.8.2.4 No loss of chemical as it diffuses toward the indoor space (that is, no biodegradation), and

X3.8.2.5 Well-mixed atmospheric dispersion of the emanating vapors within the enclosed space.

X3.8.3 Should the example RBSLs exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated, $C_{sat,soil}$ [mg/kg-soil] (see Table X3.4 for calculation of this value), "Rs" is entered into the table to indicate the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X3.8.4 No mass balance is imposed on the volatilization factor $VF_{s,esp}$.

X3.8.4.1 If the depth of the affected subsurface soil layer, d_s, can be specified, a mass balance can be imposed.

X3.8.4.2 In the event that the time-averaged flux exceeds that which would occur if all the chemical initially present in the affected subsurface soil layer volatilized during the exposure period, then the volatilization factor can be determined from a mass balance assuming that all chemical present in the subsurface soil layer volatilizes during the exposure period.

X3.9 *Subsurface Soils-Leaching to Ground Water*:

X3.9.1 In this case chemical intake is a result of chemicals leaching from subsurface soils, followed by inhalation of enclosed-space vapors, inhalation of outdoor vapors, or ingestion of ground water as discussed in X3.1 through X3.3. Here the goal is to determine the RBSL for subsurface soils that correspond to the target RBSLs for the inhalation or ground water ingestion routes. A target ground water concentration other than an RBSL for ground water (as discussed in X3.2.2), may be substituted for the $RBSL_{gw}$ parameter appearing in the equations given in Table X3.3.

X3.9.2 A conceptual model for the leaching of chemicals from subsurface soils to ground water is depicted in Fig. X3.6. Values for the parameters listed in this figure are specified in Table X3.2. For simplicity, the ratio between total soil concentration and ground water concentration is represented in Table X3.3 by the soil/ground water "leaching factor", LF_{sw} [(mg/cm^3-water)/(mg/g-soil)], defined in Table X3.4. This factor is based on the following assumptions:

X3.9.2.1 A constant chemical concentration in subsurface soils,

X3.9.2.2 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and vapor phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X3.9.2.3 Steady-state leaching from the vadose zone to ground water resulting from the constant leaching rate I [cm/s],

X3.9.2.4 The contribution of vapor- and liquid-phase diffusion through the vadose zone is negligible in comparison to the transport due to infiltration,

X3.9.2.5 No loss of chemical as it leaches toward ground water (e.g., no biodegradation), and,

X3.9.2.6 Steady well-mixed dispersion of the leachate within a ground water "mixing zone".

X3.9.3 Should the example RBSLs exceed the value for which the equilibrated vapor and dissolved pore-water phases become saturated (see Table X3.4 for calculation of this value), "Rs" is entered in the table to indicate that the selected risk level or hazard quotient cannot be reached or exceeded for that compound and the specified exposure scenario (even if free-phase product or precipitate is present in the soil).

X3.9.4 In some regulatory programs, "dilution attenuation factors" (DAFs) are currently being proposed based on fate and transport modeling results. A DAF is typically defined as the ratio of a target ground water concentration divided by the source leachate concentration. This is identical in definition to the ground water/soil pore water leaching factor, $LF_{pw,gw}$,

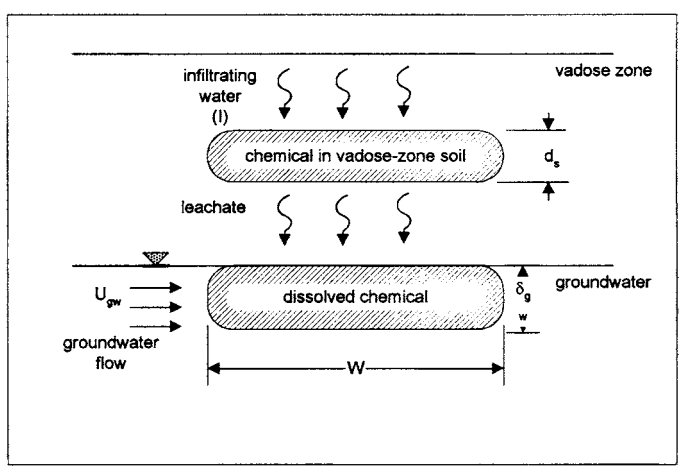


FIG. X3.6 Leaching from Subsurface Soils to Ground Water

defined in Table X3.4 as a component of the soil/ground water leaching factor, LF_{sw}.

X3.9.5 No mass balance is imposed on the leaching factor, LF_{sw}.

X3.9.5.1 If the depth of the affected subsurface soil layer, d_s, can be specified, a mass balance can be imposed.

X3.9.5.2 2 In the event that the time-averaged leaching rate exceeds that which would occur if all the chemical initially present in the affected soil layer leached during the exposure period, then the leaching factor can be determined from a mass balance assuming that all chemical present in the soil layer leached to ground water during the exposure period.

X3.10 *Free-phase Liquid Migration in Unsaturated Soils*:

X3.10.1 In this case our concern is in the further migration of nonaqueous phase liquid (NAPL) chemical in unsaturated soil, from a source zone toward the water table and on towards a potential receptor, or from a source zone toward a building basement, sump, or utility conduit, and on towards a potential receptor.

X3.10.2 The presence of a pure-chemical NAPL may be estimated using the equation for $C_{sat,soil}$ and K_{sw} in Table X3.4 with parameters for unsaturated soil. For mixtures of chemicals, $C_{sat,soil}$ is irrelevant for predicting the presence or absence of a NAPL. The presence or absence of a NAPL consisting of a liquid mixture of immiscible chemicals may be estimated using calculations presented by Johnson et al. **(22)**, Mott **(23)**, or Mariner **(24)**.

X3.10.3 A NAPL may be present in unsaturated soil, but immobile. The mobility of a NAPL is not governed by thermodynamic properties, but by capillary, viscous, and gravity forces acting on the bulk NAPL phase. Wilson and Conrad **(25)**, Conrad et al. **(26)**, and Cohen and Mercer **(27)** have compiled experimental data on measured levels of immobile NAPL for a range of chemicals and soil types. This immobile NAPL level is specified as residual saturation, S_r, which is the fraction of available soil pore volume taken up by the immobile NAPL.

X3.10.4 We calculate an example $RBSL_s$ for pure chemicals using the equation specified in Table X3.3. It is based on the following assumptions:

X3.10.4.1 A specified value of S_r consistent with sandy soil conditions and the prior references (X3.10.3),

X3.10.4.2 A local measurement of chemical concentration in soil,

X3.10.4.3 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, vapor, and immiscible phases, where the partitioning is a function of constant chemical- and soil-specific parameters.

X3.10.4.4 A pure chemical immiscible phase,

X3.10.4.5 Displacement of the air-phase soil void volume by the NAPL volume, and,

X3.10.4.6 The pure chemical is presumed to be a liquid at standard conditions of temperature and pressure.

X3.10.5 The $RBSL_s$ value is not applicable for chemicals which are infinitely miscible in water. No NAPL will exist in such a case.

X3.10.6 For mixtures of chemicals, the pure chemical $RBSL_s$ value is not relevant.

X3.10.6.1 The $RBSL_s$ value for a chemical mixture may be estimated using calculations presented by Johnson et al. **(22)**, Mott **(23)**, or Mariner **(24)**, and a specified residual saturation level, S_r or,

X3.10.6.2 The equation specified in Table X3.3 may be conservatively simplified, using the bulk density of the liquid chemical mixture, and neglecting the sorbed, dissolved, and vapor phase contribution to soil concentration.

X3.10.7 The calculated $RBSL_s$ value is intended to be conservative with respect to presumed conditions.

X3.10.7.1 The applicable value of S_r may be smaller for soils which are more course grained (for example, gravel) than the presumed sandy soil. The applicable value of S_r may be much greater for soils which are finer grained (for example, silt and clay) than the presumed sandy soil.

X3.10.7.2 The selected S_r value is intended to be conservative with respect to chemical type and properties. A larger S_r value may be applicable (for example, with some non-Newtonian fluids).

X3.10.8 Site characterization is a necessary component of determining the mobility or immobility of a NAPL in unsaturated soils. More information on estimating the presence and mobility of a NAPL is given in API **(28)** and USEPA **(29)**.

X3.10.9 Use of the example RBSL concentrations in this appendix for leaching from soils to ground water (X3.9) presumes that further migration of NAPL in unsaturated soil from a source zone toward the water table is insignificant.

X3.10.10 The example RBSL concentrations in this appendix regarding inhalation of indoor or outdoor vapors (X3.7 and X3.8) originating from soils are conservative with respect to the presence or absence of a NAPL phase, unless that NAPL phase has migrated near or into a building basement, sump, or utility conduit that may shorten the diffusive vapor transport pathway.

X3.11 *Free-phase Liquid Migration in Saturated Soils*:

X3.11.1 In this case our concern is in the further migration of non-aqueous phase liquid (NAPL) chemical in saturated soil, from a source zone toward a potential receptor.

X3.11.1.1 The presence of a NAPL may be detected or confirmed through the use of ground water monitoring wells.

X3.11.1.2 The presence of a pure-chemical NAPL may be estimated using the equation for $C_{sat,soil}$ and K_{sw} in Table X3.4 using parameters for saturated soil, including $\theta_w = \theta_T$. For mixtures of chemicals, $C_{sat,soil}$ is irrelevant for predicting the presence or absence of a NAPL. The presence or absence of a NAPL consisting of a liquid mixture of immiscible chemicals may be estimated using algebraic calculations presented by Johnson et al. **(22)**, Mott **(23)**, or Mariner **(24)**.

X3.11.2 As for unsaturated soils (X3.10.3), a NAPL may be present in saturated soil, but immobile. The mobility of a NAPL is not governed by thermodynamic properties, but by capillary, viscous, and gravity forces acting on the bulk NAPL phase. Wilson and Conrad **(25)** and Conrad, et al., **(26)** have measured levels of immobile NAPL at values of residual saturation, S_r, which are generally greater than that for similar unsaturated soils.

X3.11.3 We may calculate an example $RBSL_s$ for pure chemicals in saturated soil using the equation specified in Table X3.3. This is based on the following assumptions:

X3.11.3.1 A specified value of S_r consistent with sandy soil conditions and the prior references (X3.10.3),

X3.11.3.2 A local measurement of chemical concentration in soil,

X3.11.3.3 Linear equilibrium partitioning within the soil matrix between sorbed, dissolved, and immiscible phases, where the partitioning is a function of constant chemical- and soil-specific parameters,

X3.11.3.4 A pure chemical immiscible phase,

X3.11.3.5 Displacement of the water-phase soil void volume by the NAPL volume, and,

X3.11.3.6 The pure chemical is a liquid at standard conditions of temperature and pressure.

X3.11.4 The $RBSL_s$ value is not applicable for chemicals which are infinitely miscible in water. No NAPL will exist in such a case.

X3.11.5 For mixtures of chemicals, the pure chemical $RBSL_s$ value is not relevant.

X3.11.5.1 The $RBSL_s$ value for a chemical mixture in saturated soil may be estimated using calculations presented Johnson et al. **(22)**, Mott **(23)**, or Mariner **(24)**, and a specified residual saturation level, S_r or,

X3.11.5.2 The equation specified in Table X3.3 may be conservatively simplified, using the bulk density of the liquid chemical mixture, and neglecting the sorbed and dissolved phase contribution to soil concentration.

X3.11.6 The calculated $RBSL_s$ value is intended to be conservative with respect to presumed conditions.

X3.11.6.1 The applicable value of S_r may be smaller for soils which are more course grained (for example, gravel) than the presumed sandy soil. The applicable value of S_r may be much greater for soils which are finer grained (for example, silt and clay) than the presumed sandy soil.

X3.11.6.2 The selected S_r value is intended to be conservative with respect to chemical type and properties. A larger S_r value may be applicable (for example, with some non-Newtonian fluids).

X3.11.7 Site characterization is a necessary component of determining the mobility or immobility of a NAPL in saturated soils. More information on estimating the presence and mobility of a NAPL is given in API **(28)** and USEPA **(29)**.

X3.11.8 Use of the example RBSL concentrations in this appendix for ingestion of ground water (X3.3) or inhalation of indoor or outdoor vapors (X3.4 and X3.5) originating from ground water presumes that further migration of NAPL in saturated soil from a source zone toward a potential receptor is insignificant.

X3.12 *Parameter Values*:

X3.12.1 The equations in Table X3.3 refer to intermediate parameters (volatilization factors, leaching factors, dispersion factors, and so forth). Equations for these intermediate parameters are specified in Table X3.4. The chemical-specific calculated values for these intermediate parameters are given in Table X3.1.

X3.12.2 The IRIS- and HEAST-referenced slope factor and reference dose values, the OSHA PEL-TWA and ACGIH TLV-TWA concentration values, and the Federal MCL values cited in Table X3.1 are the most recently updated values available prior to the writing of this appendix. They are cited at their last revised date.

X3.12.3 Table X3.2 lists exposure parameters used to calculate the example RBSLs (Table X3.1). All values given are based on adult male exposures only. With the exception of the dermal exposure parameters (SA, M, and RAF_d), the values given are reasonable maximum exposure (RME) values presented in Ref. **(30)** and are either upper bound estimates or average estimates for each individual exposure parameter, as appropriate. Other values for exposure parameters (that is, child exposure or age-adjusted exposure) may be selected and substituted for the parameters appearing in the equations given in Tables X3.3 and X3.4.

X3.12.4 The skin surface area, SA = 3160 cm^2/day, is based on the seasonally-averaged surface area of the head, hands, and forearms for adult males given in Ref. **(30)**. The soil-to-skin adherence factor, M [mg/cm^2], and dermal relative absorption factor, RAF_d [mg-absorbed/mg-applied], are based on guidance issued by Ref. **(31)**. Other values for skin surface area (that is, child or age-adjusted values) may be selected and substituted for the parameters appearing in the equations given in Tables X3.3 and X3.4.

X3.12.5 Soil properties are based on typical values for sandy soils and are consistent with values given in Ref. **(32)**. With respect to chemical vapor and aqueous transport through the soil matrix, RBSL values calculated for assumed sandy soil conditions will lead to overpredictions of actual exposure in cases where the actual soil texture is finer grained than the presumed sandy soil (e.g. for loam or clay).

X3.12.6 Physical dimensions are consistent with the scale of a moderate-sized chemical release site (approximately 0.5 acre).

X3.12.7 Particulate emission rates were estimated by the approach presented by Cowherd, et al. **(33)**. It was assumed that the mode of the surficial soil size distribution was 2 mm, the erosion potential was unlimited, there was no vegetative cover or non-erodable elements, and the mean annual wind speed was 4 m/s.

X3.12.8 The chemical-specific parameters used are defined in Table X3.2. Values are specified in Table X3.1.

X3.12.8.1 Linear equilibrium partitioning between soil pore water, soil pore air, and soil sorbed phases is presumed at soil pore vapor concentrations below the saturated vapor limit, $C_{sat,vap}$, defined in Table X3.4, and at pore water concentrations below the aqueous solubility limit, S, defined in Table X3.2. Under these conditions volumetric fractions of a chemical partitioned between each of these phases within the soil matrix are defined through mass and species conservation by the following equations:

$$FRAC_{vapor}\left[\frac{cm^3-vapor}{cm^3-soil}\right] = \frac{H_{eff}\cdot\theta_a}{H_{eff}\cdot\theta_a + K_d\cdot\rho_s + \theta_w} \quad (X3.5)$$

$$\mathrm{FRAC_{water}}\left[\frac{\mathrm{cm^3-water}}{\mathrm{cm^3-soil}}\right]=\frac{\theta_w}{H_{eff}\cdot\theta_a+K_d\cdot\rho_s+\theta_w} \quad (X3.6)$$

$$\mathrm{FRAC_{sorbed}}\left[\frac{\mathrm{cm^3-sorbed}}{\mathrm{cm^3-soil}}\right]=\frac{K_d\cdot\rho_s}{H_{eff}\cdot\theta_a+K_d\cdot\rho_s+\theta_w} \quad (X3.7)$$

Parameters in these equations are defined in Table X3.2. For individual chemicals these fractions are plotted in Table X3.1 as a function of the soil saturation ratio, θ_w/θ_T. This series of plots illustrate the diverse range of partitioning behavior for the selection of chemicals presented in this appendix. Given a convective or diffusive driving force, those chemicals with a higher mass fraction in pore water or pore air are expected to be transported at a higher phase velocity through the soil matrix. Presumed vadose-zone conditions correspond to a single value of the soil saturation ratio, $\theta_w/\theta_T = 0.12/0.38$, on this plot. Saturated soil corresponds to a value of $\theta_w/\theta_T = 1$.

X3.12.8.2 Vapor- and liquid-phase diffusive transport through soils resulting in air emissions, under conditions of linear equilibrium partitioning between soil pore water, pore air, and soil sorption, is governed by a single group of chemical- and soil-specific terms as indicated in Table X3.4 for the volatilization factor for surficial soils to ambient air. This group of terms, $(H_{eff}\cdot D_{eff}/K_{sw}\cdot\rho_s)$ [cm^2/sec], is plotted in Table X3.1 as a function of the soil saturation ratio, θ_w/θ_T. This series of plots illustrate, for a single chemical, the sensitivity of diffusive transport to changes in soil moisture. Each of two terms for the effective diffusion coefficient (from Table X3.4) is plotted, illustrating the relative contribution of water- and air-phase diffusive transport. For the selection of chemicals presented in this appendix, the wide range in magnitude for $(H_{eff}\cdot D_{eff}/K_{sw}\cdot\rho_s)$ values illustrates the chemical-specific variation in diffusive transport through soils. Presumed vadose-zone conditions correspond to a single value of the soil saturation ratio, $\theta_w/\theta_T = 0.12/0.38$, on each of the plots.

X3.12.8.3 Chemical-specific water- and air-phase thermodynamic parameters are presumed consistent in definition, based on the equation:

$$H\left[\frac{\mathrm{atm-m^3}}{\mathrm{g-mol}}\right]=\frac{P_v\ [\mathrm{mm\ Hg}]\cdot MW\ [\mathrm{g/g-mol}]}{S\ [\mathrm{mg/L}]}\cdot\frac{\mathrm{atm}}{760\ \mathrm{mm\ Hg}}\cdot\frac{\mathrm{mg}}{\mathrm{g}}\ \frac{\mathrm{m^3}}{\mathrm{L}} \quad (X3.8)$$

Variability, especially for extremely low measured values of aqueous solubility, S, and vapor pressure, P_v, is expected. For ionic chemical species, the unionized fraction of chemical in water is used in the definition of Henry's law coefficient, H.

X3.12.8.4 The pure chemical aqueous solubility limit is an upper bound for most organic chemical concentrations dissolved in water. For chemicals which may form ions in water including acids, bases, and salts, the pure component aqueous solubility limit is not necessarily an upper bound solubility limit. For inorganic species in this appendix, the aqueous solubility limit will depend on the soil/water pH, the chemical oxidation state, and the solution matrix.

X3.12.8.5 The organic carbon/water partition coefficient, K_{oc}, is relatively insensitive to soil type for non-ionizing organic chemicals in moist soils. For organic chemicals which form ions within the normal soil pH range, including acids, bases, and salts, K_{oc} will vary with soil/water pH, the chemical oxidation state, and the composition of the soil matrix. The soil/water partition coefficient, K_d, for inorganic chemicals, including acids, bases, and salts, will vary with the soil/water pH, the chemical oxidation state, and the composition of the soil matrix.

X3.12.9 In this development, surficial soils are defined as those soils present within 1 m of ground surface. Subsurface soil RBSLs are based on assumed source depths of 1 m. Ground water is assumed to be located 3 m below ground surface.

X3.12.10 Once again, the reader is reminded that the parameter (and corresponding example RBSL) values and selected chemicals are presented here as examples only, and are not intended to be used as standards. At best, the parameters are reasonable values based on current information and professional judgment. The reader should review and verify all assumptions prior to using any of the example RBSLs as screening values.

X4. THE ROLE OF MATHEMATICAL MODELING IN THE RISK-BASED CORRECTIVE ACTION PROCESS

X4.1 *Introduction:*

X4.1.1 In the context of Risk-Based Corrective Action (RBCA), mathematical "models" are any of the calculations that are used in the various steps of the RBCA process ultimately to determine corrective action goals, for example, Risk-Based Screening Levels (RBSL), Site-Specific Target Levels (SSTL), and to develop a strategy for achieving these goals. These models are most typically associated with assessing the fate and transport of chemicals in the environment, that is, they are used to estimate the direction, rate, and extent of chemical migration. However, "models" are also used to estimate chemical uptake that result from environmental exposure and to interpret, interpolate, extrapolate, and assess the consistency of site characterization data, historical monitoring data, and toxicological information. Models may play an important role in the design of remedial action systems and monitoring programs (for example, well locations, density, and sampling frequency). Therefore, mathematical modeling is a valuable tool that can provide information to the RBCA process.

X4.1.2 Refer to Guide D 5880 and D 5718 for more information relative to the proper application of mathematical models used in fate and transport assessments.

X4.2 *Uses of Mathematical Modeling:*

X4.2.1 Mathematical model results play a key role in many phases of RBCA, including:

X4.2.1.1 Determining the potential urgency of response based on estimated migration and attenuation rates of chemical(s) of concern,

X4.2.1.2 Developing Tier 1 RBSL,

X4.2.1.3 Determining Tier 2 SSTL,

X4.2.1.4 Designing Remedial Action Systems,

X4.2.1.5 Designing Monitoring Programs.

X4.2.2 Examples of predictive modeling uses in the RBCA process include:

X4.2.2.1 The interpolation of site-specific data, as in the case of drawing contour maps for ground water concentrations and ground water elevations,

X4.2.2.2 The prediction of future chemical concentration distributions based on historical trend data, as in the case of ground water transport modeling,

X4.2.2.3 The recommendation of sampling locations and sampling frequency based on current interpretation and future expectations of the distribution of chemicals of concern, as in the design of ground water monitoring networks,

X4.2.2.4 The design of remedial action alternatives, as in the case of hydraulic control systems, and

X4.2.2.5 The calculation of exposures as in the development of RBSL and SSTL.

X4.2.3 Predictive modeling is not used in the RBCA process as:

X4.2.3.1 A substitute for actual site characterization or monitoring data.

X4.3 *Characteristics of Mathematical Models:*

X4.3.1 Mathematical models are, at best, approximations of the real processes (such as the movement of chemicals in the subsurface, or the ingestion of chemicals contained in drinking water) that they are used to represent. These models may be relatively simple, as in the case of some analytical solutions: they may also be complex, as is typically the case for numerical chemical migration models. Regardless of the model used certain key issues, specifically, the ability of the model to produce accurate and valid results, and the uncertainty in the results should be evaluated to determine how well these models represent the real world processes they describe.

X4.3.2 The "accuracy" of modeling predictions is judged based on how well the model predicts observed behavior, and is dependent upon a number of factors including:

X4.3.2.1 The approximations used when describing the real system by mathematical expressions,

X4.3.2.2 The input parameters used to generate the results, and

X4.3.2.3 The mathematical methods used to solve the governing equations (for example numerical solution methods, expansion approximations).

X4.3.3 Modeling results are always subject to some degree of uncertainty, due to variability and uncertainties in the input parameters. Variability represents true heterogeneity in the parameter while uncertainty represents ignorance (or lack of perfect knowledge) about poorly characterized phenomena or models. It is important to quantify this uncertainty when interpreting the results. Many times this is done with a "sensitivity" analysis in which the user quantifies the influence of changes in input parameters on the model results, and then identifies those parameters that most significantly influence the results. The use of probabilistic risk analysis (PRA), that is, use of statistical distributions in place of single point values is a useful alternative to account for both variability and uncertainty in input data.

X4.3.4 The "validation" of model results is dependent upon the model meeting pre-established objectives. This is usually accomplished by comparing model results with known solutions for simplified conditions. In some cases, for example, conservative Tier 1 assessments, exposure and risk may be overestimated as a means of addressing uncertainty. In this case one might say that the models are often valid but not accurate. However, the validation of model results, at any Tier, should be to ensure that these are consistent with real world expectations and when these differ, then the rationale for these differences should be explicitly stated.

X4.4 *Categories of Mathematical Models Used in the RBCA Process:*

X4.4.1 Mathematical models typically used in the RBCA process can be grouped into broad categories:

X4.4.1.1 Chemical fate and transport (migration) models,

X4.4.1.2 Exposure assessment models,

X4.4.1.3 Dose-response assessment models, and

X4.4.1.4 Remedial action system design models.

X4.4.2 The determination of Tier 1 RBSL, or Tiers 2 and 3 SSTL generally involves the use of the first three types of models.

X4.5 *Migration Models:*

X4.5.1 Chemical(s) of concern can both migrate (for example, by leaching, advection, dispersion) and transform (for example, by biodegradation, hydrolysis, photolysis) in the environment. Migration (that is, fate and transport) models estimate the movement of a chemical through soil, ground water, or air over time. Most models focus on specific phenomena (for example, ground water transport) and vary in complexity, depending on assumptions made during model development. In RBCA, simple screening-level migration models are utilized in Tiers 1 and 2. More complex models are typically used in Tier 3.

X4.5.2 Most screening level migration models have a simple mathematical form and are based on rough conceptual approximations of actual phenomena. For example, the travel time between the leading edge of a dissolved hydrocarbon plume and a ground water well can be approximated by:

$$\frac{\text{distance to well (ft)}}{\text{retarded flow velocity (ft/y)}} = \frac{1000\ \text{ft}}{100\ \text{ft/y}} = 10\ \text{years} \qquad \text{(X4.1)}$$

X4.5.3 *Migration Model Data Requirements*—Input data requirements are dependent on the phenomenon being described. For ground water migration models the most commonly required data for various screening level models include:

X4.5.3.1 Soil bulk density (can be estimated $\approx$ 1.7 g/cm^3),

X4.5.3.2 Total soil porosity (can be estimated $\approx$ 0.38 cm^3/cm^3),

X4.5.3.3 Soil moisture content can be conservatively estimated in many cases. It is approximately equal to the total soil porosity beneath the water table, and typically >0.05 cm^3-H_2O/cm^3-soil in the vadose zone; this can be a critical input

parameter in the case of diffusion models and may require site-specific determination unless conservative values are used,

X4.5.3.4 Fraction organic matter in soil particles (= 0.005 – 0.01: sandy soil is often conservatively assumed); this can also be a critical parameter requiring site-specific determination unless conservative values are used),

X4.5.3.5 Hydraulic conductivity (generally site-specific determination required),

X4.5.3.6 Ground water gradient and flow direction (requires site-specific determination),

X4.5.3.7 First-order decay-rate (generally requires site-specific calibration, as models are very sensitive to this parameter).

X4.5.4 Depending on the phenomenon being described or the models selected, or both, other information may be required. For example, if air dispersion of soil particulates is being described then values for parameters such as wind speed, precipitation, temperature, soil particle size distributions, and nearby building characteristics will be needed.

X4.5.5 In most cases, measurements of the attenuation (that is, decrease in concentration) of chemicals with distance away from the source area will be required to calibrate and verify the selected models. The amount of data required varies depending on:

X4.5.5.1 The models used,

X4.5.5.2 Their sensitivity to changes in model input parameters, and

X4.5.5.3 The contribution of the particular exposure pathway to the total incremental exposure.

X4.5.6 Generally, site-specific physical and chemical properties for the most sensitive parameters are required for migration models. However, in lieu of site-specific data, values selected from the literature may be used. These may take the form of conservative single point estimates or a range or distribution of values may be used as an alternative to account for variability and uncertainty in these parameters.

X4.6 *Exposure Models:*

X4.6.1 "Exposure models" are used to estimate the chemical uptake resulting from various exposure routes, such as ingestion, inhalation, and absorption.

X4.6.2 Typically, the models used to estimate uptake are simple algebraic expressions, such as those contained in Ref **(15)**. Application of these equations is illustrated in Appendix X3.

X4.6.3 Human exposure factors may be divided into receptor physiologic parameters (for example, body weight, skin surface area); contact rate (for example, consumption of water, soil ingestion rate); and time activity patterns (for example, time spent indoors/outdoors, time spent at work). Some of these variables, particularly the physiologic parameters, have been well characterized but others, such as time-activity patterns, are less well documented. All parameters are subject to variability (that is, true heterogeneity) and uncertainty (that is, ignorance about a measurement). Thus, a range of values may be available for any given parameter. The choice will depend to some extent on the site-specific circumstances and the level of conservatism desired. While point values are often selected for simplicity, statistical distributions for many of the exposure parameters are readily available for Tier 3 analyses. Typical sources for these parameters are the USEPA Exposure Factors Handbook (1997) **(30)** and the AIHC Exposure Factors Sourcebook (1994) **(34)**.

X4.7 *Dose-Response Models:*

X4.7.1 In general terms, the purpose of the toxicity assessment is to collect and weigh the available evidence regarding the potential for particular chemical(s) of concern to cause adverse effects in exposed individuals and to provide an estimate of the relationship between the extent of exposure to a chemical and the increased likelihood and/or severity of adverse effects. Adverse effects are broadly characterized as carcinogenic (that is, resulting in tumor development or other forms of cancer) or non-carcinogenic (that is, all other forms of toxicity unrelated to cancer effects). Toxicity assessments combine dose-response data with models to identify a "safe dose" or a toxic level for a particular adverse effect. Most estimates of a "safe dose" or toxic level are based on animal studies. In some instances, human epidemiological information is available on a chemical.

X4.7.2 For non-carcinogenic effects, toxicity criteria are developed based on the concept that there is a "safe" (that is, threshold) level of material to which humans can be exposed without adverse effects. These criteria are often derived for chronic exposures (usually over a lifetime) by applying safety or uncertainty factors, or both, to intake levels observed to have little or no effects in human or animal studies. These are typically expressed as an acceptable daily intake, that is, a reference dose (RfD) or a reference concentration (RfC).

X4.7.3 The threshold value for a chemical is often called the no observed adverse effects level (NOAEL). Scientists usually estimate NOAELs from animal studies. An important value that typically results from a NOAEL or LOAEL (lowest observed adverse effect level) value is the reference dose (RfD). A reference dose is an estimate (with an uncertainty typically spanning an order of magnitude) of a daily exposure (mg/kg/day) to the general human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious effects during a lifetime of exposure. The RfD value is derived from the NOAEL or LOAEL by application of uncertainty factors (UF) that reflect various types of data used to estimate RfDs and an additional modifying factor (MF), which is based on a professional judgment of the quality of the entire database for the chemical. The oral RfD, for example, is calculated from the following model:

$$\mathrm{RfD} = \frac{\mathrm{NOAEL}}{\mathrm{UF} \times \mathrm{MF}} \tag{X4.2}$$

X4.7.4 The first step in evaluating potential carcinogenic materials is determining if the material is a carcinogen based on human or animal studies, or both. The USEPA currently has a 5 tier (A-E) classification scheme.

X4.7.5 Depending on mode of action, carcinogenic materials may be divided into genotoxic (that is, having the ability to mutate genetic material and eventually initiate tumors, also

referred to as mutagenic) or non-genotoxic (that is, non-mutagenic). It is generally accepted that whereas non-genotoxic materials may exhibit a threshold limit, any exposure to genotoxic materials may eventually lead to tumor formation. For materials classified as carcinogenic, a determination of an "acceptable" (genotoxic) or "safe" (non-genotoxic) exposure level is driven by the mode of action that produces the carcinogenic effect.

X4.7.6 Thus, for non-genotoxic materials, a "safe" level may be derived from no (or lowest) observed adverse effect levels, that is, NOAEL or LOAEL (typically from animal studies) combined with safety and uncertainty factors. The process is comparable to that used for non-cancer effects. This general approach has not traditionally been used by the USEPA until recently (1996) when the USEPA proposed its new cancer guidelines which take a more mechanistic approach (that is, taking into account how the specific cancer is formed).

X4.7.7 For genotoxic materials (where it is assumed that no threshold exist), extrapolation methods are often used to calculate a sufficiently low level that is "acceptable." USEPA typically use a mathematical modeling method (for example, one-hit, linear multi-stage) to calculate this value, often expressed numerically as a slope factors (SF) or unit risk factor (URF).

X4.7.8 Toxicity values are generally obtained from a standard set of reference tables (for example, USEPA's *Integrated Risk Information System*(**8**), IRIS, or the *Health Effects Summary Assessment Tables*, HEAST (**9**)). It is important to note that the information in IRIS has typically only been peer-reviewed within the EPA and may not always have support from the external scientific community. Whereas the information in IRIS has been subject to agency-wide data quality review, the information in the HEAST tables has not. The user is expected to consult the original assessment documents to appreciate the strengths and limitations of the data in HEAST. Thus, care should be exercised in using the values in HEAST. Some state and local agencies have toxicity factors they have derived themselves or preferences for factors to use if neither IRIS nor HEAST lists a value.

X4.7.9 It is important to note that in extrapolating the information obtained in animal studies to humans, a number of conservative assumptions are made.

X4.7.9.1 For noncarcinogens, a system of default safety and uncertainty factors, as discussed above, (in multiples of 10) is used to convert observation in animals to estimates in humans.

X4.7.9.2 For carcinogens, some of the most important assumptions include:

X4.7.9.2.1 The results of the most sensitive animal study are used to extrapolate to humans,

X4.7.9.2.2 In general, chemicals with any carcinogenic activity in animals are assumed to be potential human carcinogens, and

X4.7.9.2.3 No threshold exists for carcinogens (see section X4.7.6).

X4.7.10 The uncertainty in the RfD and SF values are often neglected in deference to single point values which are then typically summarized in databases such as IRIS and HEAST and are used subsequently as absolute estimates of risk. Further, many of these conservative assumptions described above are technical policy decisions made by the USEPA. These assumptions are not explicitly defined and may obscure the conservatism in the safe dose estimate. Thus, care must be exercised in interpreting results which have as a basis these conservative toxicity evaluations.

X4.8 *Remedial Action System Design Models:*

X4.8.1 Models may be used in the design of remedial action systems, such as those used to assess flow and removal rates from vapor extraction systems, or drawdown versus pumping rate behavior for pump and treat systems. Remedial system practices generally also contain economic (cost) models.

X5. RISK-BASED CORRECTIVE ACTION FOR PROTECTION OF ECOLOGICAL RESOURCES (ECO-RBCA)

X5.1 Due to the success of the risk-based corrective action (RBCA) program for petroleum release sites, there is a great deal of interest and need for applying the RCA process to assess risks to ecological resources. In response, ASTM Subcommittee E50.04 on Performance Standards Related to Environmentally Regulated Programs has initiated development of a standardized approach to RBCA for protection of ecological resources (Eco-RBCA).[8] As developed in the human health-based approaches at petroleum release and chemical release sites, the new Eco-RBCA standard guide describes a logical sequence of activities and decisions to be followed from the time a chemical release is discovered until no further action is achieved. The Eco-RBCA standard guide outlines an approach for managing chemical release sites by integrating site assessment, ecological risk assessment, risk management, and corrective action into a technically defensible framework.

X5.2 The Eco-RBCA standard guide provides a technically defensible process for achieving no further action when appropriate. The Eco-RBCA process encourages user initiatives and stakeholder involvement in the development of a RBCA program for a site. The Eco-RBCA standard guide *(1)* helps direct risk based corrective action at a site, *(2)* compliments but does not supersede federal, regional, or state regulations, and *(3)* can be employed where there may not be a regulatory framework for corrective action, or where agency guidance for such actions does not exist, or where the user wishes to conduct corrective action such as sites in voluntary cleanup programs or under Brownfields initiatives. In addition, it can also be used as a unifying framework where several different agency programs affect the site.

X5.3 The Eco-RBCA standard guide outlines a tiered approach for conducting ecological evaluations as part of

[8] When ASTM publishes the Eco–RBCA standard guide, the information in that guide supercedes the information in this appendix.

risk-based corrective actions taken at sites impacted by a chemical release. The RBCA process employs a tiered approach that optimizes resources (for example, time, financial, and professional) while making scientifically sound risk management decisions. Tiers are groupings of evaluations that start simple and proceed to more complex evaluations when site conditions warrant. Each tier represents a level of effort that determines whether risk based corrective action is appropriate and which alternative action will eliminate or achieve an acceptable level of risk to relevant ecological receptors and habitats. In early tiers, environmentally conservative assessments are used to compensate for the uncertainty of using limited data and qualitative site information. In later tiers, site specific evaluations are used to develop more realistic exposure estimates, and the evaluation is refined by focusing on relevant ecological receptors and habitats and chemicals identified in previous tiers.

X5.4 The Eco-RBCA is divided into three tiers of evaluation. The Tier 1 Evaluation includes the Tier 1 Ecological Risk Assessment and the Tier 1 decision point (Steps 3 and 4, respectively). Likewise, the Tier 2 Evaluation includes the Tier 2 Ecological Risk Assessment (Step 5) and the Tier 2 decision point (Step 6) and the Tier 3 Evaluation includes the Tier 3 Ecological Risk Assessment (Step 7) and the Tier 3 decision point (Step 8). Before initiating an Eco-RBCA evaluation, an initial site assessment is conducted.

X5.4.1 *Step 1 - Initial Site Assessment (Planning and Scoping)*—At this first step it is determined whether or not an Eco-RBCA evaluation is appropriate for a site. This step includes the development of a site conceptual model and consideration of appropriate regulatory requirements, technical policy decisions, screening criteria, and the technical need for an assessment of site conditions. No further action is appropriate if there are no complete or potentially complete exposure pathways to relevant ecological receptors and habitats. Stakeholders should be identified in Step 1 and decisions regarding the above issues should include these stakeholders.

X5.4.2 *Step 2 – Decision Point: Response Action Evaluation*— The decision to proceed in Step 2 depends on the technical policy decisions and the regulatory requirements (for example, screening criteria identified in Step 1) and actual site conditions. The decision point may lead to a no further action decision (Step 10), a Tier 1 Evaluation (Step 3), or an evaluation of the need for initial response actions. Initial response actions may be required before thoroughly evaluating risks to relevant ecological receptors and habitats in Step 3. Such actions may be driven by any or all of the need to reduce immediate threats to identified receptors, existing regulatory requirements (for example, based on National Contingency Plan (NCP) - Oil Spill Response, Clean Water Act (CWA) - impact on migratory waterfowl), or approaches used successfully at similar sites. The user returns to Step 1 if response actions are implemented. If response actions are not required but further evaluation is appropriate, then the user proceeds to the Tier 1 Evaluation in Step 3, which includes the Tier 1 Ecological Risk Assessment (ERA).

X5.4.3 *Step 3 - Tier 1 ERA*—The Tier 1 ERA consists of two phases: an Exposure Pathway Analysis and a Generic Screening Evaluation. The Tier 1 Exposure Pathway Analysis involves refinement of a site conceptual model (defined by the sources, potential transport pathways, and potential relevant ecological receptors and habitats) and deciding if the potential exposure pathways need to be evaluated further. If no potentially complete exposure pathways exist, a no further action decision should result. If further evaluation is appropriate, a generic screening evaluation should be conducted. This could include a screening evaluation using relevant ecological screening criteria (RESC), other relevant measurable criteria (ORMC), multiple lines of evidence, site observations (for example, site walk, sketch diagram, written discussion, checklist), or other information.

X5.4.4 *Step 4 - Tier 1 Decision Point*—Following the Tier 1 Ecological Risk Assessment a decision is made as to whether site conditions meet the Tier 1 corrective action goals. This decision should be based on consideration of the Tier 1 Evaluation results, technical policy decisions, applicable regulations, site owner management plans, land use and controls, community values, and other stakeholder issues. Implications of this decision may need further discussion in terms of values and flexibility. If comparison of the site conditions meet the corrective action goals, then the user proceeds to Step 10 to determine whether no further action is appropriate. If it is determined in Step 4 that the site may not meet the corrective action goals, then either interim remedial action, remedial action based on applicable corrective action goals (Step 9), or further tiered evaluation is conducted (Step 5).

X5.4.5 *Step 5 - Tier 2 ERA*— The Tier 2 ERA is a site-specific refinement of the Tier 1 ERA. Tier 2 may include one or more of the following as necessary to support site-specific decisions: (1) further refinement of the site conceptual model in terms of relevant species and their exposure potential; (2) a simple food web model and a narrower focus on relevant ecological receptors and habitats and potentially complete exposure pathways; (3) measurements of species density and diversity; (4) site chemical concentration measurement and monitoring (for example, fate and transport modeling); (5) simple models (with site specific data) to be used in refining exposure estimates; and (6) other simple qualitative or quantitative evaluation methods.

X5.4.6 *Step 6 - Tier 2 Decision Point*—Following the Tier 2 ERA a decision is made as to whether site conditions meet the Tier 2 corrective action goals. The decision options for the Tier 2 evaluation will be the same as for the Tier 1 decision point described in Step 4. A decision is made as to whether to consider no further action (through Step 10), assess remedial alternatives (Step 9), or proceed with further evaluation in Step 7.

X5.4.7 *Step 7 - Tier 3 ERA*—The Tier 3 ERA is a refinement of Tier 2, and generally will involve a much greater expenditure of resources than a Tier 2 ERA. Tier 3 may include the use of probabilistic tools (for example, Monte Carlo or statistical models) and in-situ tests (for example, caged bivalves, substrate colonization). Numerical models, with detailed site monitoring, may be applicable for chemical fate and transport predictions.

X5.4.8 *Step 8 - Tier 3 Decision Point*—Following the Tier 3 ERA a decision is made as to whether site conditions meet the Tier 3 corrective action goals. Decision options for the Tier 3 decision point are essentially the same as the Tier 1 and Tier 2 decision points described in Steps 4 and 6. One notable exception is that further evaluation in another advanced tier is not an option. A decision is required as to whether to assess remedial alternatives (Step 9) or consider no further action (Step 10).

X5.4.9 *Step 9 - Implementing the Remedial Action Program*—The evaluation of potential remedial action alternatives is conducted in Step 9. The effectiveness, likelihood of success, and costs should be considered in evaluating, selecting, and implementing a remedial action program. The evaluation of the remedial action alternatives includes the probability of success in meeting the corrective action goals, costs, effectiveness of the remedial action in protecting relevant ecological receptors and habitats, long-term reliability, and the implementability and practicability of the remedial action. In addition, the risks of remedial action should be compared to the environmental benefits (for example, water table drawdown in hydraulic containment and effect on wetlands, soil removal in sensitive habitat) as part of the process. Following the selection and implementation of remedial action(s), the user proceeds to the Step 10 decision point to decide whether no further action or further monitoring is appropriate.

X5.4.10 *Step 10 - Monitoring Programs*—In this step monitoring tasks (for example, water well monitoring, biota monitoring, ecological surveys, confirmation of ground water concentration attenuation) and the requirements for establishing the effectiveness of the remedial action program are determined. Such measures are needed to evaluate whether site conditions are changing and if corrective action goals are met. This step requires an evaluation of performance objectives (that is, the corrective action goals) for their continued relevance (for example, exposure model remains applicable).

X5.5 The ASTM Eco-RBCA standard guide is under development and is currently organized as follows:

X5.5.1 Section 1 gives an overview of the process;

X5.5.2 Section 2 lists referenced documents;

X5.5.3 Section 3 defines terminology used;

X5.5.4 Section 4 describes the significance and use of this standard guide;

X5.5.5 Section 5 provides general information pertinent to the Eco-RBCA process; and

X5.5.6 Section 6 presents a description of the 10 steps of the Eco-RBCA process.

X5.6 The Eco-RBCA standard guide includes appendixes that are provided for additional information but are considered non-mandatory. The appendixes are as follows:

X5.6.1 Appendix X1 provides a brief description of the Guide for RBCA (Guide E 2081).

X5.6.2 Appendix X1 describes screening criteria and how they can be applied within the Eco-RBCA framework;

X5.6.3 Appendix X2 is a comparative analysis of ecological risk assessment regulatory approaches and guidance documents;

X5.6.4 Appendix X3 presents the development and selection of relevant ecological screening benchmarks;

X5.6.5 Appendix X4 includes examples of the application of the Eco-RBCA framework;

X5.6.6 Appendix X5 presents risk management issues; and

X5.6.7 Appendix X6 presents information on uncertainty and probabilistic tools.

X6. ACTIVITY AND USE LIMITATIONS, INCLUDING INSTITUTIONAL AND ENGINEERING CONTROLS

X6.1 Corrective action programs utilizing risk-based corrective action principles frequently rely on Activity and Use Limitations (AULs), including institutional and engineering controls, to achieve an "acceptable risk" or "no significant risk" level. For purposes of this appendix, "activity and use limitations" are those controls that can be utilized by responsible parties, voluntary parties and regulatory agencies in corrective action programs where, as a part of the program, certain levels of chemical releases may remain in soil or ground water. AULs provide a mechanism to ensure that exposures to remaining chemicals of concern are prevented or reduced to protect human health and the environment. The need for, implementability of, and enforceability of AULs should be considered early in the risk based corrective action process. Understanding the activity and land use are an integral part of the risk based corrective action process. A user may determine, based upon post-remedial action land or ground water use, or deficiencies in the AULs that may be available, that an AUL may not be feasible for the site. The user also needs to identify who will be responsible for the long-term enforcement and maintenance of any AULs that are used at a site.

X6.2 Because of the importance of this issue to the long-term success of risk-based corrective action, the ASTM E50.04 Subcommittee has initiated the development of a separate standard guide concerning the use of AULs, including institutional and engineering controls.[9] The AUL standard guide will explain how AULs need to be considered during the risk based corrective action process. The guidance document will also describe the types of AULs that are commonly available, including proprietary controls (for example, "deed restrictions," restrictive covenants, easements, equitable servitudes); state and local government controls (for example, zoning, building permits, well drilling prohibitions, water and

[9] When ASTM publishes the activity and use limitations standard guide, the information in that guide supercedes the information in this appendix.

well use advisories); statutory enforcement tools (for example, permits and consent orders); and informational devices (for example, deed notices, notice to government agencies, record notice, registry act requirements, transfer act requirements). Finally, the standard guide will discuss implementation considerations, such as identifying the need for, reliability of, and implementability of AULs early in the corrective action process; whether there are available state and local authorities to implement an AUL; enforceability considerations; changes in land use; and stakeholder participation issues.

X6.3 The purpose of this appendix is to provide basic review information about AULs typically used in corrective action programs.

X6.4 The types of AULs discussed in this appendix are as follows:

1. Deed restrictions, or restrictive covenants;
2. Use restrictions (including well restriction areas);
3. Access controls;
4. Compliance monitoring;
5. Notice, including record notice, actual notice, and notice to government authorities;
6. Registry act requirements;
7. Transfer act requirements;
8. Contractual obligations and agreements and
9. Restrictive zoning.

X6.5 AULs vary in both form and content. Agencies and landowners can invoke various authorities and enforcement mechanisms, both public and private, to implement any one or a combination of the controls. For example, a state could adopt a statutory mandate (see X6.6) requiring the use of deed restrictions (see X6.7) as a way of enforcing use restrictions (see X6.8) and posting signage (a type of access control, see X6.9) along with compliance monitoring (X6.10). Thus, a number of AULs are often used as overlapping strategies.

X6.6 *Statutory Mandates*:

X6.6.1 Some states' emergency response programs mandate post-remedial action AULs and impose civil penalties for non-compliance. These programs impose obligations on landowners to use one or more AULs described in this appendix.

X6.7 *Deed Restrictions*:

X6.7.1 Deed restrictions place limits and conditions on the use and conveyance of land. They serve two purposes: informing prospective owners and tenants of the environmental status of the property and ensuring long-term compliance with the AULs that are necessary to maintain the integrity of the remedial action over time. Certain legal rules must be satisfied in order to make a deed restriction binding and enforceable, as described below.

X6.7.2 The following four factors are required for a promise in a deed restriction (also called a "restrictive covenant") to be held against current and subsequent landowners: *(1)* a writing, *(2)* intention by both original parties that particular restrictions be placed on the land in perpetuity, *(3)* "privity of estate," and *(4)* the restriction must "touch and concern the land."

X6.7.2.1 The first requirement is that of a writing. Conveyances of land are legally required to be documented in a writing. This legal rule also holds true for deed restrictions affecting land. Ideally, a deed restriction used as an AUL would be written with particularity and then recorded in the local land records office, similar to the documentation and recording of a sale of land. Parties may also encounter the requirement that the deed restriction be executed "under seal," a legal formality that has been abandoned in most states.

X6.7.2.2 The second requirement that must be satisfied for a deed restriction to be legal and binding is that the deed restriction should be precisely reflect the parties' intentions in regard to the scope and the duration of the restrictions. Explicitly stating in the deed restriction that the parties intend the restriction to "run with the land" (that is, last forever and bind subsequent owners) is strongly recommended.

X6.7.2.3 The third requirement, privity of estate, means that only persons with a certain relationship to the land should be able to enforce a deed restriction. Normally, deed restrictions are promises between buyer and seller or between neighbors, therefore, the state or a third party may not enforce a deed restriction. Privity of estate, however, should not be a barrier to state enforcement of the deed restriction if the proper steps are taken. Even in states that require privity of estate, this concern can be addressed if the landowner takes the land with knowledge that the restrictions exist and might be enforced by these third parties. Thus, it is strongly recommended that the deed restriction explicitly state that the state's environmental authority may enforce the restriction. Recording of the deed restriction serves as notice to anyone who later purchases or acquires an interest in the land.

X6.7.2.4 Finally, a deed restriction is only enforceable if the promise "touches and concerns the land." This means that any deed restriction used as an AUL should be written so that it centers on the land and use of the land. One fact to consider when deciding if the promise" touches and concerns the land" is whether the landowner's legal interest in the land is decreased in value due to the deed restriction. If the land is devalued in this way, then the restriction could be said to "touch and concern the land." Note that the focus of the inquiry is on the land itself; promises that are personal in nature and only concern human activities that happen to take place on the land are least likely to be enforceable.

X6.7.3 Deed restrictions or restrictive covenants may be difficult, at best, for some states to enforce. Due to the potential difficulties encountered by a governmental agency in enforcing a deed restriction, it may be appropriate for an individual state to seek statutory and regulatory amendments to ensure that such authority exits in regard to all deed restrictions for environmental purposes. Specific legal advice should be sought with respect to the validity of restrictive covenants or deed restrictions in a particular state.

X6.7.4 Remedies for noncompliance with deed restrictions comes in two forms: *(1)* persons or agencies may sue to obtain a court order (injunction) requiring compliance or *(2)* if the state statute allows for it, the state's attorney general can seek enforcement of civil penalties, such as fines, for non-compliance.

X6.7.5 A state program can require a landowner to continue monitoring activities and to allow state environmental officials access to the site to monitor compliance with AULs. These arrangements may need to be placed in a deed restriction in order to run with the land from owner to owner, but responsible parties or voluntary parties may also be required to sign a contract making these promises. Additionally, it should be noted that almost every state has authority to issue administrative orders to accomplish some or all of the above.

X6.7.6 The above arrangements can also set out procedures that will be followed if some emergency requires that the site be disturbed. If, for example, underground utility lines must be repaired, the landowner would follow this protocol for handling the soil and alerting the state authority.

X6.8 *Use Restrictions*:

X6.8.1 Use restrictions are usually the main component of a deed restriction. Use restrictions describe appropriate and inappropriate uses of the property in an effort to perpetuate the benefits of the corrective action and ensure property use that is consistent with the applicable corrective action goals. Such techniques also prohibit any person from making any use of the site in a manner that creates an unacceptable risk to human health or environment from exposure to the residual chemical releases.

X6.8.2 Use restrictions may address uses that could disturb a containment cap or unremediated soils. A prohibition of drinking on-site ground water (or off-site ground water by means of well restriction areas) may also be appropriate. Well restriction areas can be a form of AUL by providing notice of chemicals of concern in ground water, and by prohibiting or conditioning the construction of wells in that area. As an example, a program may allow a restriction of record to include one or more of the following:

1. Restriction on property use;
2. Conditioning the change of use from nonresidential to residential on compliance with all applicable corrective action goals for a residential property;
3. Restriction of access; or
4. Restriction of the disturbance of agency approved remedial actions on the land.

X6.8.2.1 This technique preserves the integrity of any ground water remedial action by prohibiting or conditioning the placement and use of any or all types of wells within the area.

X6.8.2.2 Well restrictions of this nature would be subject to agency approval, public notice and may include the restriction on constructing or locating any wells within a particular designated area. Notice of the well restriction is recorded on the land records and with various health officials and municipal officials. The restrictions can only be released upon a demonstration that the chemicals of concern in the well restriction area meet the corrective action goals.

X6.9 *Access Controls*:

X6.9.1 Another subset of AULs is the control of access to any particular site. Access can be controlled by measures such as fencing and gates, security, posting or warnings. Consideration of the way in which the site and adjacent land are used help to determine the appropriate level and means of access controls. For example, it should be noted whether the site is located in a residential or mixed neighborhood; whether sensitive land use areas, such as playgrounds, day care centers, or schools are within close proximity; or if the site provides a pathway that is frequently traversed by neighbors. These factors could increase the potential for and intensity of exposures to the chemicals of concern.

X6.9.2 Access controls require continued maintenance and custodial care for the length of time the AULs are to be in-place. Therefore, planning must occur for these activities, including the financial responsibility for such up-keep.

X6.10 *Monitoring Programs*:

X6.10.1 Monitoring programs may be needed to ensure that conditions do not deteriorate and result in unacceptable risks to human health or the environment either on or off-site. For example, monitoring programs may be needed to ensure that chemical migration is not occurring at an unacceptable rate or intensity.

X6.10.2 Monitoring may be conducted at scheduled intervals, as necessary, during the period of time that the AULs are in-place.

X6.10.3 Monitoring programs could include sampling ground water monitoring wells located on-site, downgradient of the site; sampling air from air monitoring stations on- and off-site; and monitoring discharges to nearby surface water bodies.

X6.10.4 Monitoring programs requires continued maintenance, custodial care and data collection and evaluation for a length of time. Therefore, planning must occur for these activities, including the financial responsibility for such up-keep.

X6.11 *Notice*:

X6.11.1 Regulations of this type generally provide notice of specific location of chemical releases on the site, and disclose any restrictions on access, use, and development of part or all of the impacted site to preserve the integrity of the remedial action. Three types of notice are described below *(1)* record notice; *(2)* actual notice; and *(3)* notice of governmental authorities.

X6.12 *Record Notice:*

X6.12.1 Some states require that sites having releases of hazardous waste file a notice on the land records providing to any subsequent purchaser of the property information regarding the past or current activities on the site.

X6.12.2 The record notice requirement may be broad; the program may require any property subject to a response action to obtain a professional opinion and then prepare and record a Grant of Environmental Restriction that is supported by that opinion.

X6.12.3 The record notice requirement can be ancillary to a transfer act (see X6.16), in which case recording of an environmental statement is only required in conjunction with a land transaction.

X6.13 *Actual Notice:*

X6.13.1 States may require direct notice of environmental information to other parties to a land transaction. These laws protect potential buyers and tenants, and they also help ensure that use restrictions and other AULs are perpetuated.

X6.13.2 Actual notice of an environmental defect or failure to provide notice may give a party the right to cancel the transaction and result in civil penalties. For example, landlords and sellers who do not give notice as required by the state may be liable for actual damages plus fines. Nonresidential tenants who fail to notify landowners of suspected or actual hazardous substance releases can have their leases canceled and are subject to fines.

X6.14 *Notice to Government Authorities*

X6.14.1 Parties to a land transaction may also be required to file the environmental statement with various environmental authorities. Notice to the government may be required before the transaction takes place.

X6.15 *Registry Act Requirements*:

X6.15.1 Some states have registry act programs that provide for the maintenance of a registry of hazardous waste disposal sites and the restriction of the use and transfer of listed sites.

X6.15.2 A typical registry act provides that the state environmental agency establish and maintain a registry of all real property which has been used for hazardous substance disposal either illegally or before regulation of hazardous waste disposal began in that state.

X6.15.3 The state agency is responsible for investigating potential sites for inclusion on the registry. The registry includes the location of the site and a listing of the hazardous wastes on the property, and may also include a classification of the level of health or environmental hazards presented by the conditions on the property. The state agency may be required to perform detailed inspections of the site to determine its priority relative to other sites.

X6.15.4 Owners of sites proposed for inclusion on the registry have rights of hearing and appeal, and owners of sites on the registry have rights to modify or terminate their listing. In some cases, the owner of a site proposed for inclusion on the registry may obtain the withdrawal of the proposed registration by entering into a consent agreement with the state. Such a consent agreement establishes a timetable and responsibility for remedial action.

X6.15.5 When a site appears on the state registry, the owner must comply with regulatory requirements in regard to use and transfer of the site. The use of a site listed on the registry may not be changed without permission of the state agency. In negotiations for a conveyance of a registered site, the owner may be obligated to disclose the registration early in the process, and permission of the state agency may be required to convey a registered property. Under other schemes, permission to convey is not required, but the seller must notify the state agency of the transaction.

X6.15.6 Finally, registry acts require that the listing of a property on a hazardous materials site registry be recorded in the records of the appropriate locality so that the registration will appear in the chain of title.

X6.16 *Transfer Act Requirements*:

X6.16.1 Some states have transfer act programs that require full evaluation of all environmental issues before or after the transfer occurs. It may be that within such a program, AULs can be established by way of consent order, administrative order, or some other technique that establishes implementation and continued responsibility for AULs.

X6.16.2 A typical transfer act imposes obligations and confers rights on parties to a land transaction arising out of the environmental status of the property to be conveyed. Transfer acts impose information obligations on the seller or lessor of a property (see X6.16.3). That party must disclose general information about strict liability for corrective action costs as well as property-specific information, such as presence of hazardous substances, permitting requirements and status, releases, and enforcement actions and variances.

X6.16.3 Compliance with transfer act obligations in the manner prescribed is crucial for ensuring a successful conveyance. Sometimes the transfer act operates to render a transaction voidable before the transfer occurs. Failure to give notice in the required form and within the time period required or the revelation of an environmental violation or unremediated condition will relieve the transferee and the lender of any obligation to close the transaction, even if a contract has already been executed. Moreover, a violation of the transfer can be the basis for a lawsuit to recover consequential damages.

X6.17 *Contractual Obligations and Agreements*:

X6.17.1 One system for ensuring the future restriction on use of a site, or the obligation to conduct corrective action on a site, is to require private parties to restrict use by contract. While this method is often negotiated among private parties, it will be difficult, if not impossible, to institutionalize some control over that process without interfering with the abilities and rights of private parties to freely negotiate these liabilities.

X6.17.2 Another avenue is for the landowner or responsible party to obligate itself to the state by contract. The state may require a contractual commitment from the party to provide long-term monitoring of the site, use restrictions, and means of continued funding for corrective action (including active remedial action).

X6.18 *Restrictive Zoning*

X6.18.1 Local land use control jurisdictions may provide for restrictive or "overlay" zoning that prohibits certain activities or land uses. Such AULs are difficult to establish for individual sites. For many sites located in the same local planning jurisdiction which have undergone RBCA analysis, a restrictive "zone" may be more practical. This "overlay" might prevent certain exposures to chemicals of concern as an effective means of establishing a number of AULs with one regulatory action.

X7. RISK-BASED CORRECTIVE ACTION CASE EXAMPLES

X7.1 *Introduction*—This appendix illustrates the critical features of the risk-based corrective action process through presentation of several case examples, including an agricultural chemical formulation and distribution facility (X7.2) and an operating industrial facility (X7.3). Both cases are hypothetical. The decisions made in each example case are not necessarily generally applicable; they are a function of pertinent technical policy decisions (discussed in Appendix X1), concurrence of all involved parties, and compliance with federal, state, or local laws and regulations. The examples cover a range of situations and include illustration of the Tier 1 screening process, site conditions & initial response actions the Tier 2 assessment, and corrective action selection. Methods and decisions used in these steps are briefly summarized.

X7.2 *Agricultural Chemical Formulation and Distribution Facility*:

X7.2.1 *Initial Site Assessment*—Components of the initial site assessment are discussed in X7.2.2 to X7.2.10. A plan view of the site and surrounding area, with important features illustrated, is given in Fig. X7.1.

X7.2.2 *Site Description*—The site consists of a two-acre tract in a predominately agricultural area. The adjacent land use is both agricultural and residential. The nearest residence is at a distance of 400 ft from the property boundary. The site is not currently subject to any federal, state, or local enforcement actions.

X7.2.3 *Site Ownership and Activity*—The current business on the site is engaged in sales and distribution of prepackaged pesticides, prepackaged fertilizers and soil amendments, and bulk aqueous liquid fertilizers. In addition to the present site use, prior activities at the site included on-site mixing and formulation of bulk pesticides. The site includes an enclosed office and warehouse for storage of prepackaged materials, a tank farm for storage of bulk liquid fertilizer, several loading and material transfer areas, and several waste storage areas. The business has been in operation on the present site for forty years, with four changes in ownership over the same time period. The site surface is unpaved, with a gravel parking area and a concrete-paved wash pad area.

X7.2.4 *Past Releases or Potential Source Areas*—Potential spill or leak areas on the site include the current fertilizer tank farm area, a fertilizer loading rack area, a truck wash pad, a burn barrel area, and a used pesticide container and used oil storage area. The area which had formerly been used for formulation of bulk liquid pesticides is identifiable by the remaining equipment foundations; this has also been identified as a potential leak or spill area. Stained soil was observed in the vicinity of the truck wash pad area and the used oil storage area.

X7.2.5 *Regional and Site Hydrogeologic Conditions*:

X7.2.5.1 The climate in the region is subtropical, with a warm, dry winter season and a hot, wet summer season. Agricultural crops in the adjacent farm fields are watered using drip irrigation during the summer months.

X7.2.5.2 The regional topography is complex, with the site located in an alluvial mountain valley drained by a single continuously flowing small creek. United State Geological Survey (USGS) topological maps indicate the creek is fed by springs along its length, both upstream and downstream from the site. The site itself is gradually sloped towards an open drainage ditch which is seasonally dry. The drainage ditch enters the creek 200 ft from the site boundary. Two low areas are evident on the site. These low areas evidently pond with water during wet weather periods.

X7.2.5.3 The site hydrogeological investigation has included soil borings, collection of ground water samples, and characterization of geological structure and hydrogeological conditions. The first three to six feet of soils on the site consist primarily of sandy loam, going to poorly sorted sandy gravel at depths below ground surface (BGS) between six to twenty feet, and to poorly sorted gravelly sand at depths greater than twenty feet BGS. First encountered ground water in the region is found at a seasonally varying mean depth BGS of 24 to 30 ft. Ground water gradient, determined from four installed on-site piezometers, is in the direction of the creek. Ground water velocity has been estimated from the measured gradient and the observed soil characterization. A basalt layer is encountered in the vicinity of the site at depths of between 100 to 120 ft. Municipal and residential drinking water in the vicinity is generally produced from wells at a depth of 80 to 100 ft BGS.

X7.2.6 *Beneficial Use Summary and Receptor Survey*:

X7.2.6.1 The site is in a rural agricultural area. Drinking water for on-site use is supplied from a well screened at a depth BGS of 100 ft. The nearest off-site residence, at a distance of approximately 400 ft downgradient from the site, is supplied from a well screened at a depth of 90 ft BGS. Six wells are within one-half mile of the site. Three of the wells are used for residential drinking water and the remaining wells are used for agricultural irrigation. Ground water is the sole drinking water supply source within this local mountain-valley area and the state has a ground water classification scheme that identifies ground water in this area as Class II. In the absence onsite exposure points, the point of exposure for Class II ground water is assumed to be the facility boundary.

X7.2.6.2 The site itself is considered a commercial/industrial property. Access to the warehouse, tanks, loading racks, and other potentially impacted areas is restricted by a fence and locked gate.

X7.2.7 *Ecological Assessment Summary*—There is no obvious impact to vegetation on the site. For the preliminary site visit, during the late summer, green vegetation was found only in the vicinity of the creek boundary or in the adjacent irrigated fields. The creek is considered a relevant ecological receptor and habitat; there was no obvious impact to the creek or adjacent drainage ditch due to site activities.

X7.2.8 *Exposure Scenario Evaluation Flowsheet*—An exposure scenario flowsheet for this site is given in Fig. X7.2. This flowsheet is based on information discussed in X7.2.2 to X7.2.7.

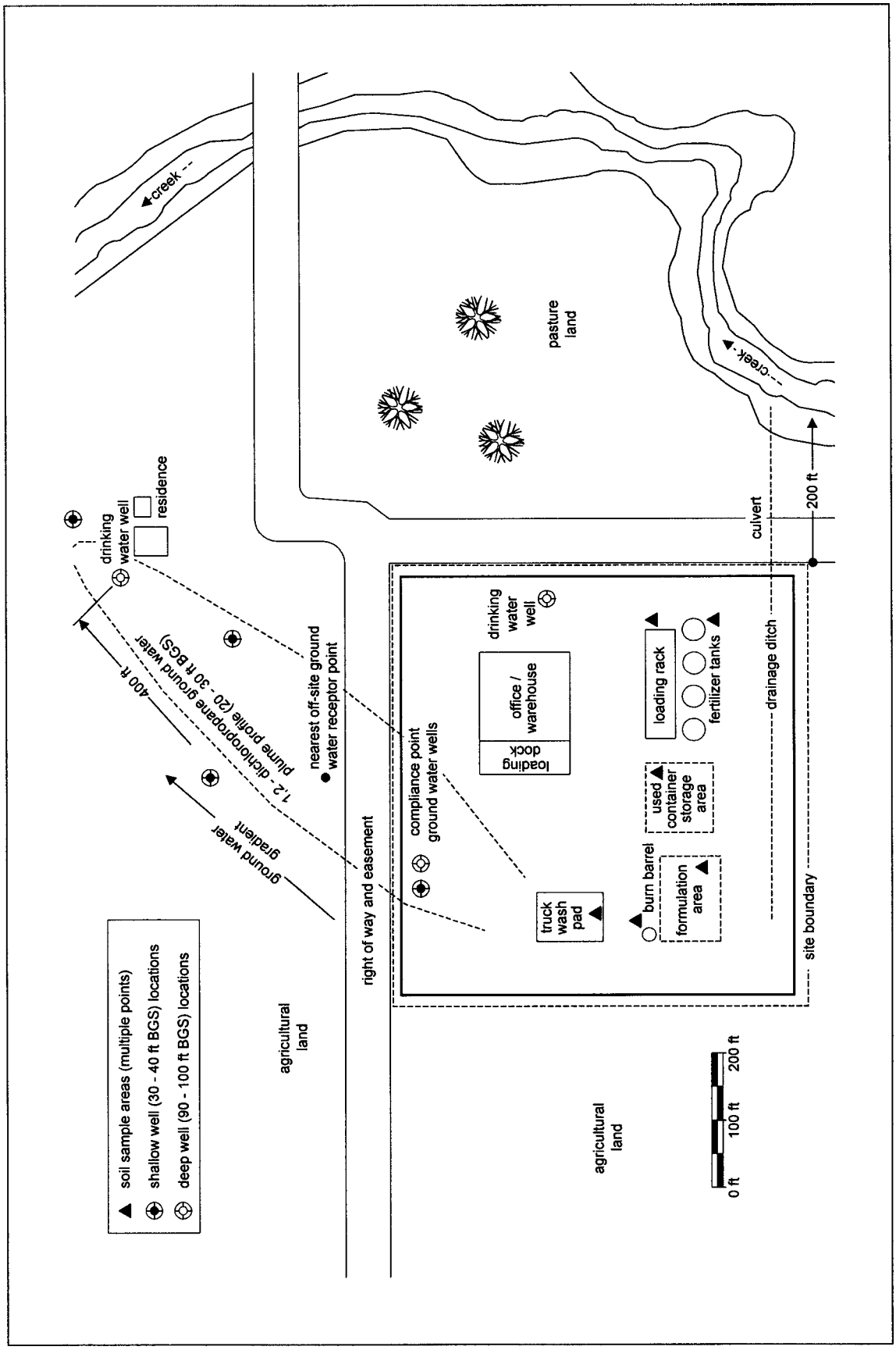


FIG. X7.1 Plan View of Agricultural Chemical Formulation and Distribution Facility and Surrounding Area.

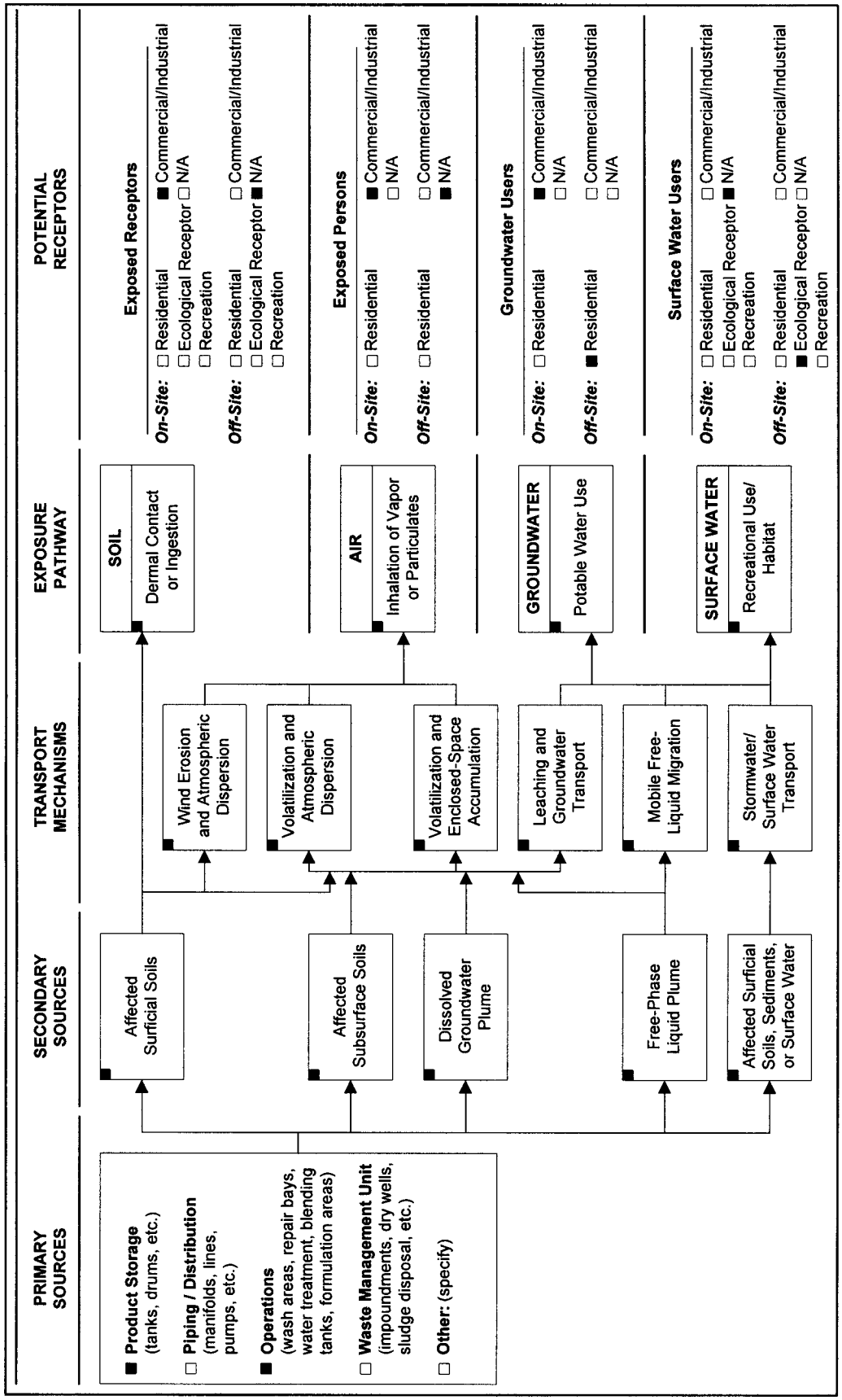


FIG. X7.2 Exposure Scenario Evaluation Flowchart for Agricultural Chemical Formulation and Distribution Facility.

X7.2.8.1 Commercial/industrial exposure to on-site impacted surficial soils, through direct contact, is both a current and potential future exposure pathway at this site. Inhalation of vapors evolved from impacted soils, both indoors and outdoors, is also a current or potential future exposure pathway for on-site commercial/industrial receptors.

X7.2.8.2 Migration of non-aqueous phase liquids, leaching of soluble constituents to ground water, and migration of soluble chemicals of concern via ground water transport to residential water ingestion are viable exposure pathways for this site, both under current land use and for any viable future use of the site.

X7.2.8.3 The potential also exists at this site for surface water or sediment migration to an off-site creek, in addition to potential migration of any soluble ground water plume to the creek. The creek is considered habitat.

X7.2.9 *Site Conditions and Initial Response Actions*—Based on a qualitative evaluation of the information collected in the initial site assessment, no immediate threat to human health, safety, or environmental receptors has been identified, and no immediate response action is warranted for the site (see Table 1, Site Conditions and Initial Response Actions). If an immediate threat was identified, it would be addressed forthwith, site conditions are evaluated and revised as additional information on the site becomes available.

X7.2.10 *Site Sampling Activities - Initial Site Investigation*:

X7.2.10.1 In the initial site investigation, soil samples were taken from the identified potential spill or leak areas. This included both surficial soil and samples taken at geometrically increasing depth increments to the water table, which on site was found at a depth BGS of approximately 28 ft. In addition, surficial soil samples were taken from several locations along the dry drainage ditch.

X7.2.10.2 The selected soil analyses were based on chemicals of concern identified from previous and current site use. In areas where pesticide impacts were suspected, samples were analyzed for organochlorine pesticides, organophosphate pesticides, and carbamate pesticides. Soil samples were analyzed for nitrate and ammonia in the areas potentially impacted by spilled fertilizer. In the used oil area, the soil chemical analyses included volatile and semi-volatile organic compounds, as well as total petroleum hydrocarbons reported by carbon number range.

X7.2.10.3 Half the soil borings were extended into the region of the upper water table, and shallow ground water samples (30 to 40 ft BGS) were taken from temporary sampling points. These ground water samples were analyzed for both pesticides and nitrate. Several composite water samples were taken from the flowing off-site creek, both upstream and downstream from the dry ditch outflow location. Ground water samples were also taken from existing wells in the vicinity of the site, as available, during the preliminary on-site investigation.

X7.2.10.4 Sampling and chemical analysis procedures appropriate for use in a quantitative risk assessment were used in the site investigation. The method quantification limits for the chemicals of potential concern, in nearly all cases, were below the most stringent applicable Tier 1 risk-based screening-level (RBSL) concentrations. Where this was not the case, it was judged that such chemicals were either not likely to be the sole chemicals present in a sample, or were not very likely to have been used at the site or in the site vicinity. The resulting data set was reviewed and judged to be reliable, accurate, and verifiable.

X7.2.11 *Analytical Data and Screening-Level Comparison-Tier 1*:

X7.2.11.1 Site conditions have been compared to the generic conditions used in deriving Tier 1 RBSL concentrations for soil and ground water, and based on the site soil type and identified site characteristics, the Tier 1 RBSL concentrations are considered to be conservative with respect to actual site conditions.

X7.2.11.2 The analyzed soil and ground water samples showed non-detectable concentrations for most potential chemicals of concern, in most samples. Given that the analytical method quantification limits were at or below the applicable RBSL concentrations, and that all identified potential source areas were sampled, no further investigation of the non-detected chemicals in soil or ground water was warranted.

X7.2.11.3 No generic Tier 1 Relevant Ecological Screening Criteria (RESC) concentrations are available for impacts to surface water as a relevant ecological receptor and habitat. The quantitative assessment of surface water impacts is deferred to a site-specific Tier 2 assessment. No site chemicals of concern were detected in the creek water samples and no pesticides were detected in surficial soil samples taken from the dry drainage ditch. Nitrate was detected in the drainage ditch at concentrations below any available Tier 1 RBSL criteria (based on leaching to ground water and exposure to surficial soil).

X7.2.11.4 The detected soil concentrations have been compared to the available and applicable Tier 1 RBSL concentrations. The soil concentrations in the following source areas for the indicated chemical and exposure pathways were above the corrective action goals:

Former pesticide formulation area.
- *Lindane:*
  - *leaching to ground water and surficial soil exposure.*
- *1,2-Dichloropropane:*
  - *leaching to ground water and indoor air inhalation.*

Truck wash pad.
- *Lindane:*
  - *leaching to ground water and surficial soil exposure.*
- *Toxaphene:*
  - *leaching to ground water, surficial soil exposure, indoor air inhalation.*

Fertilizer loading rack area and tank farm area.
- *Nitrate:*
  - *leaching to ground water.*

Additional investigation was focused on the chemicals for which the concentrations were above the Tier 1 RBSL. For those chemicals which were not above any applicable Tier 1 RBSL, no further investigation has been pursued.

X7.2.11.5 In the used oil storage area, concentrations of benzene, ethylbenzene, toluene, and xylenes, as well as polycyclic aromatic hydrocarbons were not above the RBSL for soils, but a relatively high total petroleum hydrocarbon concentration was measured. On a carbon number basis, this petroleum hydrocarbon was shown to consist of constituents with a boiling point greater than n-pentadecane ($C_{15}H_{32}$). In

this range, the chemicals of concern are expected to be relatively immobile. No migration of the petroleum hydrocarbons beyond a 2 ft. depth was detected. No aesthetic concerns were noted.

X7.2.11.6 In ground water, measured concentrations were compared against the applicable and available Tier 1 RBSL criteria on a point-by-point basis. Most chemicals of potential concern were either not detected in ground water, or did not exceed the most stringent applicable Tier 1 RBSL concentration in any analyzed sample. Where this was the case, no further investigation of the screened chemicals was warranted. Those chemicals which were above a Tier 1 RBSL concentration for ground water included toxaphene and 1,2-dichloropropane, for both the risk-based ground water ingestion criteria and the ORMC, which are the State drinking water maximum contaminant levels (MCLs) for Class II ground water. The nitrate in ground water concentrations were above the State drinking water MCL for Class II ground water. Toxaphene concentrations, in addition, were above the RBSL ground water criteria based on indoor air inhalation.

X7.2.11.7 Ground water samples taken from existing water wells in the vicinity of the site have been compared against Tier 1 RBSL ground water ingestion criteria. This included samples from the on-site drinking water well and the nearest downgradient drinking water well, 400 ft from the property boundary. None of the samples from the drinking water wells were above the Tier 1 corrective action goals for drinking water. Nitrate in upgradient, downgradient, and on-site drinking water wells was detectable at low levels, but were not above the Tier 1 corrective action goal (the State drinking water MCL).

X7.2.12 *Refined Screening-Level Comparison - Tier 1*:

X7.2.12.1 As a refinement on the point-by-point comparisons of site data with applicable Tier 1 RBSL concentrations, the areas where chemicals of concern were found to be above the corrective action goals were examined in greater detail. This comparison provides a means for determining potentially complete exposure pathways based on site data, and for expediting the choice of any needed remedial action.

X7.2.12.2 For those samples which were above the Tier 1 RBSL surficial soil criteria (lindane and toxaphene), further refinement of the point-by-point screening-level assessment showed that all of the samples which were above this Tier 1 RBSL criteria were taken at depths BGS greater than 10 ft, except for two samples (toxaphene) in the truck wash pad area, which were taken at a depth BGS of 1 ft. These shallow soil samples were above the Tier 1 RBSL surficial soil criteria for toxaphene by a wide margin.

X7.2.12.3 For the indoor air inhalation exposure pathway, with both 1,2-dichloropropane and toxaphene, no samples were above the indoor air RBSL criteria for soil either within a distance of 25 ft from a currently occupied building or within 15 ft of the ground surface, except for toxaphene in the vicinity of the truck wash pad area (where no current occupied buildings exist). For points where the concentrations at a depth greater than 15 ft (for either soil or ground water) were above the Tier 1 RBSL indoor air inhalation, no shallower samples taken in the same bore-hole were above the Tier 1 RBSL indoor air inhalation criteria for soil, indicating that the indoor air vapor transport predicted with the generic and conservative Tier 1 models is not confirmed by observation, and is not found to be a currently completed exposure pathway at this site.

X7.2.12.4 For the exposure pathway of leaching to ingested ground water, concentrations in different potential source areas were above the Tier 1 RBSL criteria for lindane, 1,2-dichloropropane, toxaphene, and nitrate. For 1,2-dichloropropane, toxaphene, and nitrate, the leaching potential was confirmed by on-site concentration measurements in ground water above the respective Tier 1 RBSL ground water ingestion criteria. The areas of ground water impacts at concentrations above the Tier 1 RBSL ground water ingestion criteria was adequately delineated for toxaphene in the preliminary site investigation. For 1,2-dichloropropane and nitrate, the ground water plumes above the Tier 1 RBSL ground water ingestion criteria extend beyond the on-site sampled area covered in the preliminary site investigation.

X7.2.13 Site Conditions & Initial Response Actions - Given the additional site information, the site condition analysis (Table 1, Example Site Conditions and Initial Response Actions) was repeated.

X7.2.13.1 Based on the initial site investigation, and estimated chemical of concern travel times, the potential exists for impact to an off-site domestic water supply well within approximately a two-year ground water travel time for both the nitrate and 1,2-dichloropropane plumes. In response, an interim remediation system was installed as a hydraulic stabilization measure to minimize off-site migration of impacted ground water. Sentry monitoring wells have been installed at the site between the source zones and the existing off-site drinking water wells to evaluate the effectiveness of the interim system. These sentry monitoring wells were completed in both the same zone (90–100 ft. BGS) as the drinking water wells, and at shallower levels (30–40 ft. BGS). A quarterly ground water monitoring program was initiated at the site, along with further ground water investigation (a Tier 2 investigation, discussed below).

X7.2.13.2 No current impact is seen in the existing off-site drinking water wells. By negotiation and agreement between the involved parties, the site will be re-evaluated and response action will be taken if two quarters of compliance point well monitoring data are above the applicable Tier 2 site-specific target level (SSTL) concentrations (discussed below). This response action is intended to eliminate the potential risk prior to any actual exposure to impacted drinking water.

X7.2.13.3 No impact is evident in the off-site creek, but the site is within 500 ft of this environmental receptor. The drainage ditch leading from the site to the creek provides an inappropriate transport conduit for site surface water run-off. As a interim response action, containment and control of surface water run-off to this ditch from the site has been implemented. This response action interrupts the identified exposure pathway. At the same time, the site was regraded to eliminate the two low areas on the site which may pond during wet weather periods.

X7.2.13.4 A final item of concern in the Tier 1 analysis is the toxaphene found in surficial soil at the truck wash pad above Tier 1 RBSL surficial soil criteria. This soil is within the

access-controlled area of the site. As an interim response, this site access control will be maintained. Other responses were deferred until a decision on final corrective action for the site was reached. This deferral requires continued commitment by the current business operator to control access to the site, and to inform any individuals with access to the controlled area of the discovered chemicals and the hazards associated with these chemicals.

X7.2.14 *Evaluation of Tier 1 Results*—A series of decisions, based on urgency and relative costs and benefits, were made between interim remedial action, remedial action, or further tier evaluation at this point, for each instance where the site conditions did not meet the Tier 1 corrective action goals.

X7.2.14.1 Interim action was initiated in cases where it was justified by site conditions, as discussed in X7.2.13.

X7.2.14.2 For soils, the Tier 1 analysis of X7.2.11 and X7.2.12 has been sufficient; no recalculation of Tier 1 RBSL concentrations for soils using site-specific data is justified.

X7.2.14.3 For ground water, a Tier 2 assessment and evaluation is justified.

X7.2.15 *Tier 2 Investigation*—The Tier 2 investigation has focused on delineating the off-site nitrate and 1,2-dichloropropane ground water plumes, and in establishing a measure of the plume stability (growing, steady-state, shrinking) over time. The Tier 2 site investigation has included collection of additional ground water concentration data, measurement of saturated soil properties, and estimation of site-specific parameters including ground water velocity and direction. Simple mathematical models for ground water transport have been used to check and validate the internal consistency of the measured site data and the attenuation of detected chemicals with distance from the source zone. Well placement in this investigation has been optimized to define the near-centerline plume concentrations with distance from the source, and to determine the maximum downgradient extent of the plume.

X7.2.16 *Tier 2 Assessment*:

X7.2.16.1 Measured aqueous concentrations of nitrate and 1,2-dichloropropane in shallow (30 to 40 ft. BGS) wells, both onsite and offsite, were found to be nearly stable with time. Measured and modeled attenuation rates of these chemicals along the near-centerline of the ground water plumes have been used to establish Tier 2 site-specific target level (SSTL) concentrations for nitrate and 1,2-dichloropropane. By negotiation and agreement between the involved parties, the chosen ground water receptor point was located just beyond the downgradient edge of the property boundary and adjacent public road easement. This was judged to be the nearest viable location for a future off-site ground water well. It is upgradient of the nearest existing ground water well. Screening level ground water concentrations were fixed at the Tier 1 RBSL ground water ingestion levels for the selected receptor point; the calculated Tier 2 SSTL compliance concentrations for the compliance point monitoring well locations (upgradient from the receptor point) are higher than the Tier 1 RBSL ground water ingestion concentrations, and include derived factors which account for the observed attenuation rates in ground water with increasing distance from the source area.

X7.2.16.2 The Tier 2 site investigation has shown that the nitrate ground water plume meets the Tier 2 SSTL compliance point concentration for the applicable compliance point sentry monitoring well. The measured soluble nitrate plume is reasonably stable or shrinking with time. Both upgradient and downgradient wells screened in the upper aquifer (30 to 40 ft BGS) show low but detectable nitrate levels, most likely due to the adjacent land use. No nitrate above Tier 1 RBSL ground water ingestion criteria were detected in monitoring wells screened at the depths similar to that used for drinking water wells (90–100 ft BGS) near the site.

X7.2.16.3 The 1,2-dichloropropane plume has been found to exceed the Tier 2 SSTL compliance point concentration for the applicable sentry monitoring well at shallow depth (30 to 40 ft BGS). Modeling and data show that this shallow plume extends off-site, and beyond the nearest possible future off-site ground water well, at levels greater than the Tier 1 RBSL ground water ingestion concentration. This shallow plume has also been shown to intercept the location of an existing off-site drinking water well. The drinking water well is completed in a deeper zone than the region where the chemicals of concern have been identified, and the drinking water well is not currently impacted. No 1,2-dichloropropane is detectable in any monitoring wells screened at depths of 90 to 100 ft, or at the depths similar to that used for drinking water wells near the site. The measured 1,2-dichloropropane plume is relatively stable over time.

X7.2.16.4 No chemicals of concern have been detected in the off-site creek. An estimate of potential surface water chemical concentrations in the creek has been made using a combination of the estimated volume of impacted ground water seepage into the creek and a geometric mean average water flow for the creek. This estimate of surface water chemical concentration is below analysis detection limits, and is also below any applicable freshwater aquatic toxicity criteria (selected as a relevant ecological screening criteria, or RESC) or human health-based criteria levels. Since surface water run-off has been contained on-site as part of a interim response action, water run-off is no longer a relevant transport pathway to the creek for this site. The interim response action has interrupted the identified exposure pathway.

X7.2.17 *Site Conditions and Emergency Response*—Additional information from the Tier 2 investigation and assessment has warranted a re-classification of the site (Table 1, Example Site Conditions and Initial Response Actions), based on better knowledge of site conditions and the measured extent of the chemical of concern ground water plumes. The off-site 1,2-dichloropropane ground water plume not being captured by the interim system has been shown to intercept the location of an existing residential drinking water well. This drinking water well is completed in a deeper zone than the plume, and is not impacted. The potential for vertical migration of the chemical of concern plume due to pumping at this existing drinking water well location has been investigated and found to be of concern. As an interim response, a point-of-use water treatment system has been provided for this ground water user. The previously implemented ground water monitoring program is also continuing at the site.

X7.2.18 *Final Corrective Action*:

X7.2.18.1 As a final corrective action, the interim system will become the final system with modifications appropriate to continue ground water treatment to levels achievable by the best available technology, and to hydraulically stabilize the plume to minimize offsite migration. The final system will continue operating until 1,2-dichloropropane concentrations are reduced below the Tier 2 RBSL or involved parties agree that is technically impracticable to continue system operation. In selection of this final corrective action, continued commercial/industrial use of the site is presumed. No everlasting use restrictions are intended to be placed on adjacent property use or off-site ground water use based on offsite plume stability and calculated attenuation rates. The continued commercial/industrial site description implies that a use restriction, using applicable and available methods (described in Appendix X6), has been placed on the site, and that this use restriction is acceptable to the involved parties. This use restriction includes limitations for impacted on-site ground water use as a drinking water supply, and appropriate limitations on site activity (for example, no residential use, no deep excavation without appropriate worker protection).

X7.2.18.2 For soils, final corrective action has included removal of affected soils in the truck wash pad area from the surface to a depth of 3 ft, appropriate disposal of the impacted soil, and replacement with clean soil fill material. All other issues regarding soils have been addressed in interim corrective action or in the refined assessment. The interim actions for soils have included elimination of a potential surface runoff transport pathway to a surface water body, and site grading to eliminate the potential for on-site ponded water (and the associated water-head driven aqueous infiltration).

X7.2.18.3 Remediation of the 1,2-dichloropropane ground water plume to the applicable Tier 2 SSTL levels, by any existing and available methodology is technically impracticable. Remediation to asymptotic levels by the best available technology is estimated to take up to three years until it would be technically impracticable to continue system operation.

X7.2.18.4 During the remediation period, to prevent unintended exposure to the affected ground water, off-site use restrictions for ground water in the immediate vicinity of the ground water plume were put in place. This use restriction, during the remediation period, is based on concurrence of all affected parties. Given the beneficial use of ground water in the local area as a sole drinking water supply source, the ultimate goal has been to return to unrestricted use of the off-site ground water as quickly as is technically possible. We note that the Tier 2 assessment has already established that the 1,2-dichloropropane ground water plume is relatively stable over time, and, at least, the present situation is not worsening. System operation is expected to reduce the overall time to reduce the 1,2-dichloropropane concentration to a level where monitored natural attenuation can continue as the selected final corrective action until the Tier 2 SSTL is achieved.

X7.2.18.5 The ground water plume is fed from a aqueous leachate source in on-site unsaturated soils. Lowering the on-site aqueous infiltration rate, through site grading, has been estimated to proportionately lower the total mass transport rate of leached 1,2-dichloropropane to ground water. Given literature-identified attenuation mechanisms of hydrolysis and biodegradation for 1,2-dichloropropane, and the lowered aqueous-leachate plume source loading, recession of the plume with time was predicted.

X7.2.18.6 After 2 additional years of quarterly ground water monitoring subsequent to system deactivation, seasonal fluctuations in ground water concentrations were seen, but a general downward trend in concentration was evident. At this point an annual monitoring program was implemented. After 6 additional years, the general downward trend was shown to continue, and the 1,2-dichloropropane plume was shown to decrease below the Tier 2 SSTL compliance point concentration for the applicable sentry monitoring well. No compliance point concentrations were above the SSTL within an additional year-long period of monitoring.

X7.2.18.7 Based on prior agreement between the involved parties, meeting all appropriate Tier 2 SSTL concentrations for the applicable sentry monitoring wells, over a 1 year time period, has been sufficient demonstration that the site meets all remaining conditions with respect to the site use restrictions discussed in X7.2.18.1. A "no further action" letter, consistent with the continued restricted commercial/industrial site use, has been issued. The off-site ground water use restrictions discussed in X7.2.18.4 have been lifted.

X7.2.18.8 If, over the period of monitoring, decreases in monitored ground water concentrations did not meet expectations, the corrective action plan for ground water would have been reviewed and modified. During the period of monitoring, site conditions and additional data were used to continuously monitor the site classification conditions and the appropriateness of the corrective action response.

X7.2.18.9 If a specific regulatory requirement of, for example, a ground water restoration goal is applicable as an ORMC, then this would be included in the corrective action goals.

X7.2.19 No further action for this site is based on restricted commercial/industrial site use. If less restrictive site use (residential use, for example) is desired by the property owner, a re-assessment of the property would be needed.

X7.2.20 Again, the decisions made in this hypothetical case example are based on presumed technical policy decisions, concurrence of all involved parties, and compliance with federal, state, or local laws and regulations.

X7.3 *Operating Industrial Facility*:

X7.3.1 *Initial Site Assessment*—Components of the initial site assessment are discussed in X7.3.2 to X7.3.10. A plan view of the site and surrounding area, with important features illustrated, is given in Fig. X7.3.

X7.3.2 *Site Description*—The property consists of a 3-acre city block in a zoned light industrial area. The adjacent land use is mixed light industrial, commercial, and residential. The immediate neighboring properties are all commercial and industrial; the nearest residences are at a distance of 400 ft from the property boundary. The site is not subject to any federal, state, or local enforcement actions.

X7.3.3 *Site Ownership and Activity*—There are two businesses currently operating on the site. The first is a commercial

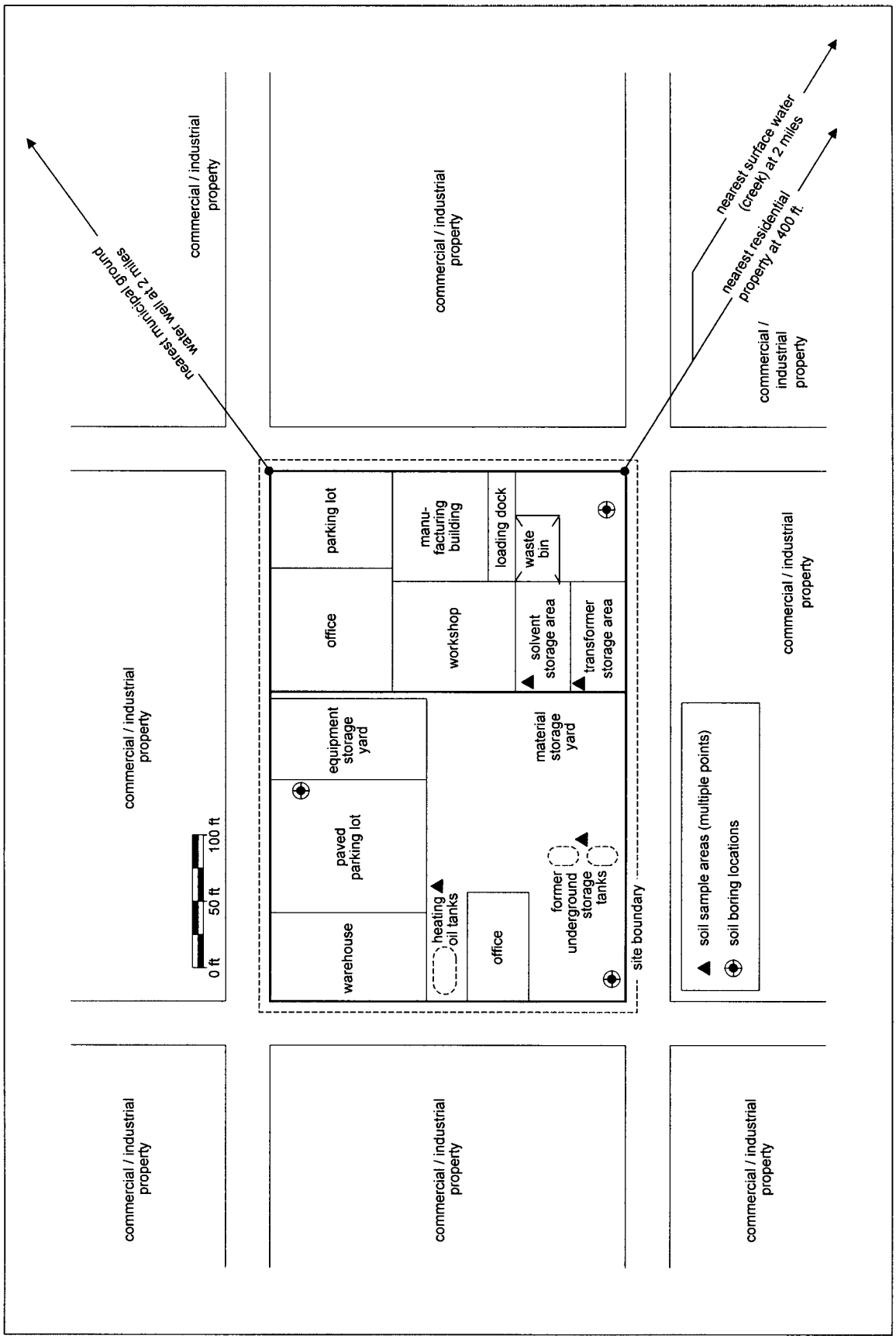


FIG. X7.3 Plan View of Operating Industrial Facility and Surrounding Area.

construction contractor, and includes an office building and warehouse, an asphalt-paved parking lot, and a gravel-paved equipment and materials storage yard. The second business is an electric motor rebuilding facility which includes an office, a workshop, a manufacturing building, a storage area, a used solvent tank location, and an asphalt-paved parking lot. Both businesses have been in operation at the present site for over twenty-five years.

X7.3.4 *Past Releases or Potential Source Areas*—Potential spill or leak areas on the site include a former underground gasoline storage tank, since removed; a diked concrete-paved solvent storage area; two former outdoor above ground heating oil tanks, since removed; an electrical equipment and transformer storage area; and a former sludge and used solvent storage tank area.

X7.3.5 *Regional and Site Hydrogeologic Conditions*:

X7.3.5.1 The site hydrogeological investigation has included soil borings, collection of ground water samples, and characterization of geological structure and hydrogeological conditions. The site surface topography is generally flat with a 15 ft variation over the 3-acre site. The regional topography is also relatively flat; surface elevation changes within 2 miles of the site are less than 50 ft. No permanent surface water features or low spots are present on the site. No permanent surface water features are present in the vicinity of the site. Surface water runoff from the site drains to a municipal stormwater sewer and treatment system. The site is not in a flood plain.

X7.3.5.2 The first five to eight feet of soils on the site consist primarily of fill material including sand, silt, and clay. The fill material is generally underlain by a layer of up to 10 ft of silty loam, followed by a layer of clayey silt to a depth of 40 ft. The water table in the vicinity of the site is found at an average depth of 60 to 80 ft, and generally exceeds the USEPA drinking water criteria for total suspended particulate, iron, and manganese. Municipal drinking water used in the area is produced from either wells at depths of 200 to 250 ft, or supplied from a local river.

X7.3.6 *Beneficial Use Summary and Receptor Survey*:

X7.3.6.1 The site is within an industrialized urban area. All businesses and residences within five miles of the site are served by municipal water and sewer utilities. The municipal water is supplied from a local river and from ground water wells, the nearest being two miles upgradient from the site, and producing from a depth of 220 ft. No producing ground water wells or well setback zones of any type are currently located closer than two miles from the site. A local ground water use restriction is in place (as described in Appendix X6) to prevent installation of drinking water wells within the urban area. The intent of this local use restriction has been to prevent ingestion of impacted ground water within the urban area.

X7.3.6.2 The site itself is zoned light industrial, is presently operating with commercial/industrial tenants, and by all likelihood, land use will continue in the future as commercial/industrial. All neighboring properties adjacent to the site are currently either light industrial or commercial. The nearest residential properties are 400 ft. from the property boundary.

X7.3.7 *Ecological Assessment Summary*—There is no evidence of impact to vegetation on the site. There are no relevant ecological receptors and habitats on the site. Given the local industrial development and urban activity, there is a low likelihood that the site will be returned to an undeveloped, pristine condition. The surface water nearest to the site is a creek which, at closest, passes within 2 miles of the site. No impacts to ecological receptors or habitat are anticipated in the future due to this site, and, by agreement of the involved parties, no further study of ecological impacts is planned.

X7.3.8 *Exposure Scenario Evaluation Flowsheet*—An exposure scenario flowsheet for this site is given in Fig. X7.4. This flowsheet is based on information discussed in X7.3.2 to X7.3.7.

X7.3.8.1 Commercial/industrial exposure to on-site impacted surficial soils, through direct contact, is both a current and potential future exposure pathway at this site. Inhalation of vapors evolved from subsurface impacted soils, both indoors and outdoors, is also a current or potential future exposure pathway for on-site commercial/industrial receptors.

X7.3.8.2 Leaching of soluble constituents to ground water, or migration of non-aqueous phase liquids, are viable transport pathways at this site, but ingestion of impacted ground water by residents in the vicinity of this site is not of concern, given the local ground water use restriction.

X7.3.8.3 Surface water or sediment exposure pathways are not present and therefore not applicable at this site. Volatilization of chemicals of concern from ground water is not likely to be of concern because of the depth to the water table.

X7.3.9 *Site Conditions and Initial Response Actions*—Based on a qualitative evaluation of the information collected in the initial site assessment, no immediate threat to human health, safety, environmental receptors, or habitat has been identified, and no immediate response action is warranted for the site (Table 1, Example Site Conditions and Initial Response Actions). If an immediate threat was identified, it would be addressed forthwith. Site condition analysis is repeated and revised as additional information on the site becomes available.

X7.3.10 *Site Activities - Preliminary Site Investigation*:

X7.3.10.1 In the preliminary site investigation, soil samples were taken from the identified potential spill or leak areas. This included both surficial soil and samples taken at geometrically increasing depth increments to 25 ft. The selected soil analyses have been based on chemicals of concern identified from previous and current site use at each of the potentially impacted areas.

X7.3.10.2 Three soil borings to a depth of 80 ft were taken near the site boundaries to map soil stratigraphy, the depth to ground water, and the approximate local ground water flow direction. Temporary ground water sampling points were installed at these three locations and ground water samples were collected to determine ground water quality and to determine the presence of chemicals of concern, including any non-aqueous phase liquids.

X7.3.10.3 Sampling and chemical analysis procedures appropriate for use in a quantitative risk assessment were used in the site investigation. The method quantification limits for the chemicals of potential concern, in all cases, were below the

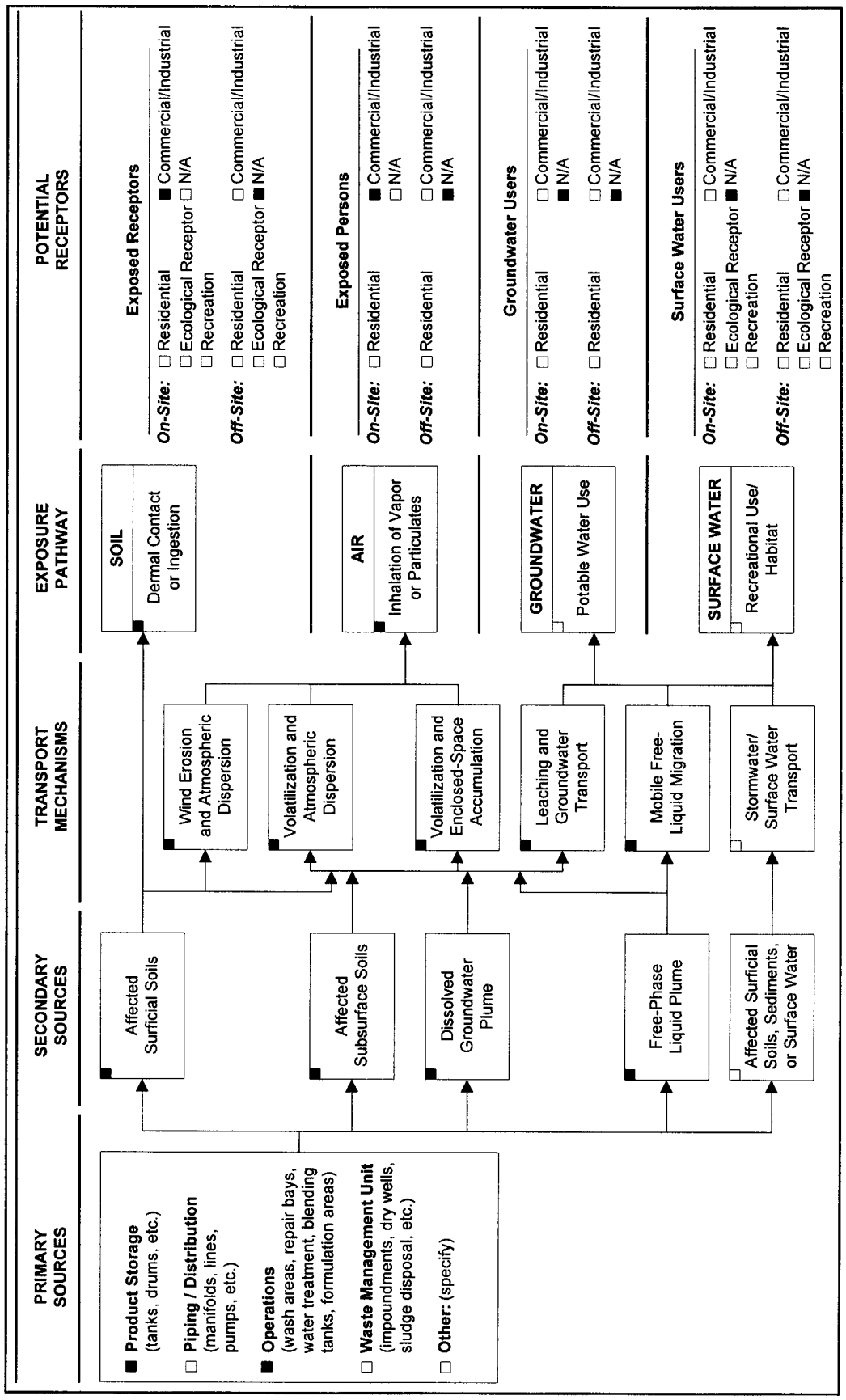


FIG. X7.4 Exposure Scenario Evaluation Flowchart for Operating Industrial Facility.

most stringent applicable risk-based screening-level concentrations. The resulting data set was reviewed and judged to be reliable, accurate, and verifiable.

X7.3.10.4 For those samples taken in an area where the potential existed for a mobile, non-aqueous phase liquid plume, the soil samples were analyzed for total petroleum hydrocarbons (TPH), with measured values reported by equivalent carbon number range.

X7.3.11 *Analytical Data and Screening-Level Comparison-Tier 1*:

X7.3.11.1 Site conditions have been compared to the generic conditions used in deriving Tier 1 risk-based screening-level (RBSL) concentrations for soil and ground water, and based on the site soil type and identified site conditions, the Tier 1 RBSL concentrations are considered to be conservative with respect to actual site conditions.

X7.3.11.2 The analyzed soil and ground water samples showed non-detectable concentrations for most potential chemicals of concern in all samples. Given that the analytical method quantification limits, in all cases, were below the most stringent applicable Tier 1 RBSL concentrations, no further investigation of these non-detected chemicals was necessary.

X7.3.11.3 The preliminary screening of the site data consisted of point-by-point comparisons of all site soil analytical data to the applicable RBSL. All measured values showed concentrations which were below the screening criteria except for benzene and trichloroethene (TCE), with respect to the indoor air inhalation exposure pathway; and poly-chlorinated biphenyls (PCBs), with respect to the surficial soil exposure pathway.

X7.3.11.4 No measured values of TPH in soil were great enough to indicate that free-phase organic liquid migration in soils would be of concern for any source region of this site. For TCE, all measured concentrations were below the residual soil concentration level calculated for Tier 1 soil assumptions; no free-phase liquid was found.

X7.3.11.5 The TCE was detected at concentrations below the calculated Tier 1 RBSL concentration in a single downgradient ground water sample, but above the Federal drinking water MCL concentration value. No measured free-phase liquids were evident in any of the ground water samples. With a local use restriction in place to prevent the use of ground water wells for drinking water in the vicinity of this site, there will be no ingestion exposure to impacted ground water. By agreement of the involved parties, no further investigation of ground water is planned.

X7.3.12 *Refined Screening-Level Comparisons - Tier 1*:

X7.3.12.1 As a refinement of the point-by-point comparison of site data with applicable Tier 1 RBSL concentrations, the areas where concentrations of chemicals of concern were noted to be above the corrective action goals were examined in greater detail.

X7.3.12.2 For the PCBs, concentrations greater than the Tier 1 RBSL screening-level values were confined to the area of the electrical equipment and transformer storage area. Of four surficial soil samples in this area, two showed low but quantifiable levels of PCBs, while two showed non-detected concentrations. No PCBs were detected at depth. In refinement of the Tier 1 screening-level assessment, an arithmetic average PCB surficial soil concentration was calculated, using a weighted average of the two detected soil concentrations and half the detection limit for the remaining two samples. This averaged surficial soil PCB concentration was then compared to the Tier 1 RBSL concentration for surficial soil; the average concentration was above the Tier 1 RBSL surficial soil criteria.

X7.3.12.3 For the benzene and TCE, site soil concentrations that were above the Tier 1 RBSL concentrations were confined to the area of the used solvent storage tank area. In refinement of this point-by-point screening-level assessment, it was noted that the only values exceeding the Tier 1 RBSL indoor air inhalation soil concentration were for soil samples taken in the depth range of 18 ft to 25 ft BGS; shallower samples taken in the same borings at depths of 4 ft to 12 ft were lower, and did not, in any case, exceed this screening level. In addition, no soil samples taken within 25 ft of any existing building were above any Tier 1 RBSL indoor air soil criteria. Based on this analysis, we can conclude that the observed soil concentrations do not confirm vapor transport to the surface at levels great enough to exceed the applicable Tier 1 RBSL concentration along any existing complete transport pathway, or at any actual point of exposure for indoor air inhalation.

X7.3.13 *Site Classification and Initial Response*

X7.3.13.1 Based on the preliminary investigation, and comparison with classification scenarios (Table 1, Example Site Classification and Response Actions), the site could best be described as posing no demonstrable long-term threat to human health, safety, relevant ecological receptors, or habitat.

X7.3.13.2 Management of the on-site businesses have been informed that the site concentrations were above the commercial/industrial surficial soil criteria for PCBs in the region of the electrical equipment and transformer storage area. As an interim response, signs were posted and access to this area of the site was limited by an installed fence and locked gate, pending the selection of a final corrective action for the site. This interim response requires continued commitment by the current business operators to maintain the fence and gate, and to inform any individuals with access to the controlled area of the discovered chemicals and the hazards associated with these chemicals.

X7.3.14 *Evaluation of Tier 1 Results*—A series of decisions, based on urgency and relative costs and benefits, were made between interim remedial action, remedial action, or further tier evaluation at this point, for each instance where the site conditions did not meet the Tier 1 corrective action goals.

X7.3.14.1 Interim action was initiated in cases where it was justified by the site conditions.

X7.3.14.2 For soils, the Tier 1 analysis of X7.3.11 and X7.3.12 has been sufficient; no recalculation of Tier 1 RBSL concentrations for PCBs in soil using site-specific data is needed.

X7.3.14.3 For ground water, no exposure pathway is present and no further analysis is justified.

X7.3.14.4 No Tier 2 investigation has been necessary for this site.

X7.3.15 *Final Corrective Action*:

X7.3.15.1 In selection of final corrective action, continued commercial/industrial use of the site is presumed.

X7.3.15.2 For soils, final corrective action has included removal of surficial soils in the electrical equipment and transformer storage area, replacement with clean fill material, and concrete paving.

X7.3.16 Since the assessment is based on the assumption of continued commercial/industrial site use, the future use of the site has been restricted, by agreement of the involved parties, through administrative controls (discussed in Appendix X6), to commercial/industrial (non-residential) use.

X7.3.17 The administrative controls will remain in effect unless actions are taken at a later date to re-access the site using the more conservative assumptions of a residential screening criteria, and, if needed, corrective actions sufficient to meet the residential site use criteria are implemented.

X7.3.18 Finally, the decisions made in this hypothetical case example are based on presumed technical policy decisions, concurrence of all involved parties, and compliance with federal, state, or local laws and regulations.

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