Alabama Department of Environmental Management

# ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL

## Revision 3.0

## February 2017

## NOTICE

**This document has been prepared to assist individuals in understanding the minimum necessary elements of conducting an environmental risk assessment. It is not intended as a substitute for the regulations and should not be used as such. Mention of trade names or commercial products does not constitute endorsement or recommendation for use. The hyperlinks and citations provided in this document are for helpful reference and may be used in the development of a facility's risk assessment plans, reports, etc. It should be noted that use of the provided hyperlinks and citations alone does not ensure Departmental approval/acceptance of such risk evaluations, plans, reports, etc.**

**September 2005**
**Revised April 2008**
**Revised February 2017**

**The Alabama Department of Environmental Management does not discriminate on the basis of race, color, national origin, sex, religion, age, or disability.**

## APPENDICES

## FIGURES

# 1.0
# BACKGROUND AND INTRODUCTION

## 1.1 INTRODUCTION

The Alabama Department of Environmental Management (ADEM), hereafter referred to as "the Department", has the responsibility for overseeing soil and groundwater cleanups which are managed under a variety of different regulatory programs. These include sites regulated under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) Program, the Brownfield Redevelopment and Voluntary Cleanup Program, the Underground Storage Tank (UST) Program, the Resource Conservation and Recovery Act (RCRA) Program, the Dry Cleaners Trust Fund, the Solid Waste Program, and other sites being addressed through state statutory authority. The Department's objective is to establish a consistent risk-based decision making process for all sites, through which soil, sediment, surface water and groundwater corrective action decisions are made. The evaluation of the cumulative risk present at a site accompanied by the development of **Risk-Based Target Levels (RBTLs)** is a consistently protective approach for the management of a wide variety of impacted sites. The risk-based corrective action process has been accepted and well documented by the **United States Environmental Protection Agency (USEPA)**. Certain cleanup programs (e.g., UST, RCRA, CERCLA) may have additional specific requirements or regulations for risk assessment and cleanup criteria. This guidance may not be used as a substitute for such requirements and regulations, although it may be used in conjunction with such requirements and regulations.

The **Alabama Risk-Based Corrective Action (ARBCA)** Guidance Manual has been developed to provide the risk-based approach for the assessment of the cumulative risk at a site, the development of RBTLs and selection of appropriate **Regional Screening Levels (RSLs)** for contaminated sites. Site concentrations are first compared to RSLs. If the site concentrations exceed RSLs or if the indoor air vapor inhalation pathway is complete and there is an exceedance of the **Vapor Intrusion Screening Levels (VISLs)**, **Risk Management-1 (RM-1) Levels**, or **Risk Management-2 (RM-2) Levels** are then calculated. The procedure for development and comparison of site **chemicals of concern (COC)** concentrations with appropriate RBTLs is also provided. The most current version of the **Alabama Environmental Investigation and Remediation Guidance (AEIRG)** should be utilized for site investigation requirements. Program specific guidance is also available for certain programs (*i.e.*, UST program). Evaluators should be aware of additional guidance in performing assessment and remediation activities. Emergency Response actions shall be conducted in accordance with the requirements of the ADEM Emergency Response Program (contact ADEM Field Operations Division for applicable information).

This ARBCA process recognizes and balances the following: (i) the need to protect public health, water resources, and the environment of the State, (ii) differences in site-specific characteristics, (iii) the existing laws and regulations of the State, and (iv) resource limitations. Appropriate risk- and exposure-assessment practices suggested by the U. S. EPA and the ASTM E1739-95 Standard have been integrated into the process for USTs. State-specific default values have been selected which are appropriate for sites located in Alabama.

The Department recognizes that, as of the effective date of this guidance document, there will be a number of ongoing risk assessments based on the April 2008 ARBCA or the November 2001, *ARBCA: Alabama Risk-Based Corrective Action for Underground Storage Tanks Guidance Manual, Revision 1.0.* Those risk assessments which have been requested and approved by the Department or submitted to the Department by the effective date of this guidance will continue to be processed using the previous guidance. However, risk assessments requested after the effective date of this guidance shall follow the guidance contained herein and any applicable, revised, program-specific guidance. Those sites which have corrective action limits accepted by the Department prior to the date of this guidance may continue to utilize those corrective action limits as their cleanup goals. However, if new information arises at such a site and is cause for revised site or area evaluation, as determined by the Department, the most-current guidance should be utilized.

This guidance was developed for use by individuals with existing technical expertise and skill in the area of hydrogeological investigations, risk assessments, and risk management issues. Certain submissions required by the Department involve the practice of engineering as those terms are defined in Code of Alabama 1975, as amended § 34-11-1 to 34-11-37; and/or the practice of geology, as that term is defined in Code of Alabama 1975, as amended § 34- 41-1 to 34-41-24. Any person preparing or submitting such submissions has the responsibility to ensure compliance with these laws and any regulations promulgated there under, as may be required by the State Board of Registration for Professional Engineers and Land Surveyors and/or the Alabama Board of Licensure for Professional Geologists. All submissions, or parts thereof, which are required by State law to be prepared by a licensed engineer, land surveyor, or geologist, must include the engineer's, land surveyor's, and/or geologist's signature and/or seal(s), as required by the applicable licensure laws.

## 1.2 APPLICABILITY

The intent of this document is to establish a consistent procedure for initially evaluating a site using a screening process and for those exceedances, determining the cumulative risk at a site. In the case that the risk at a site exceeds appropriate risk values, this document will guide the user though the development of RBTLs that are protective of the current and future (i) human health, (ii) environment, (iii) emergency situations, and, (iv) nuisance conditions. The RBTLs are developed to be applied by the user as a guide or goal during the remediation process to aid the site in the achievement of appropriate cumulative risk levels protective of human health and the environment. This document provides a technically defensible procedure for estimating cumulative risk and establishing risk management levels at impacted sites. This document is not intended as a detailed guide to every aspect of the risk assessment practice. It is intended for use by competent professionals with adequate knowledge of environmental risk assessment principles. Prior experience and/or training will be necessary for an individual to correctly conduct and implement the risk assessment as part of the overall site management process.

This guidance is not intended to address risk at a site due to radionuclides. Radionuclides, whether covered under the Atomic Energy Act or Technically Enhanced Naturally Occurring Radioactive Material (TENORM), are not covered under the ARBCA Guidance Manual. If radionuclides are believed to be present at a site, the Department should be contacted for guidance. Additionally, this guidance is not intended to address worker safety issues which are administered under the Occupation Safety and Health Administration (OSHA).

Acronyms used in this document may have a different meaning than the same acronyms used in other documents or regulatory programs.

## 1.3 COORDINATION WITH OTHER STATES

Facilities have the responsibility to coordinate with other state environmental agencies to address any requirements above and beyond Alabama requirements if there is the potential for transboundary groundwater or surface water impacts to occur. This is of particular concern when surface water forms the boundary between two states.

# 2.0
# TARGET CONCENTRATIONS

ADEM Admin. Code ch. 335-7-2 provides **Maximum Contaminant Levels (MCLs)** for drinking water for select lists of contaminants. The MCLs are also reflected in the RSLs and should be used as established corrective action limits. Please note that these promulgated values are subject to change and an owner/operator or consultant should verify that the values are current. The RSLs are updated semi-annually and generally should contain the most current values. Please refer to the ADEM Administrative Code for the current MCL values or these values may also be found on USEPA's Groundwater and Drinking Water website.

The ARBCA process establishes a site-specific evaluation process that include the RSLs, VISLs (if the indoor inhalation pathway exists) Risk-Management-1 (RM-1) levels, and Risk-Management-2 (RM-2) levels. Refer to the subsequent chapters for details. When correctly applied, evaluation/remediation activities utilizing target levels generated from RSLs, VISLs, RM-1 levels, or RM-2 levels should satisfy the target cumulative risk level requirements established by the Department. Chemical-specific, risk-based, target levels will be developed for soil, groundwater, and soil vapor. The RSLs and VISLs selected or the RM-1 levels or RM-2 levels developed will depend on site-specific conditions such as complete exposure pathways, land use, and fate-and-transport parameters. The specific process used to determine and apply the target concentrations and to evaluate the site-specific cumulative risk at a site is described in subsequent sections of this document.

# 3.0
# OVERVIEW OF THE ARBCA PROCESS

## 3.1 INTRODUCTION

The ARBCA process (Figure 3-1) includes a range of site-specific activities that begin with the first notice of a suspected release. This process continues until the Department determines that the site-specific concentrations are protective of human health and the environment. Upon completion of this process, the Department will indicate that the corrective action performance standards have been attained and may terminate the corrective action process provided that (i) the ARBCA process has been correctly implemented, (ii) the future use of the site is consistent with the assumptions used in the ARBCA Evaluation, and (iii) the requirements related to environmental covenant(s) per ADEM Admin. Code div. 335-5 are met, if applicable.

The ARBCA process integrates the elements of site characterization, exposure assessment, risk calculations, and risk-management activities (including corrective action and risk communication) to determine site-specific cumulative risk protective of human health and the environment. Each element of the process is important and must be correctly applied for the adequate protection of human health and the environment.

The ARBCA process is applicable at all sites irrespective of the current phase of activities being conducted. Since the ARBCA process can begin at any point subsequent to the confirmation of the release, sites currently under assessment should be carefully evaluated to ensure that a sufficient quality and quantity of data is available or has been collected. Although certain sections or tables contained within this guidance may be used following the confirmation of a release, in order to accurately determine the cumulative risk at the site, the site should be fully characterized, and a Conceptual Site Model (CSM) should be developed prior to a cumulative-risk evaluation. The CSM should be considered a dynamic document and updated as new information arises.

Risk management is an important part of the ARBCA process. Risk-management activities may include active or passive engineered corrective-action systems as well as owner-imposed institutional controls. Institutional controls include, but are not limited to, land-use restrictions such as an environmental covenant, receptor removal or relocation, and communication with potentially affected parties. Risk-management issues are discussed in detail in Section 10.0.

## 3.2 TIERED APPROACH AND RISK-BASED TARGET LEVELS

The ARBCA process utilizes a tiered approach, with each subsequent tier being more site-specific. The process includes three tiers of evaluation: Regional Screening Level (RSL) Evaluation, Risk Management-1 (RM-1) Level, and Risk Management-2 (RM-2) Level as discussed below. Figure 3-1 contains a comparison of the different tiers used in the ARBCA process. In the RM-1 and RM-2 Levels, site-specific, cumulative risks are calculated and, if exceeded, then site-specific Risk-Based Target Levels (RBTLs) (concentrations) are calculated. A brief discussion of the types of RBTLs utilized in this process is presented in the following paragraphs.

The Maximum Contaminant Level (MCL) is the maximum permissible level of a contaminant in drinking water which is delivered to any user of a public-water system. With respect to groundwater, certain chemicals have established MCLs, therefore, Regional Screening Level (RSL) Evaluations use the MCLs.

In the absence of an MCL, the following process should be used to determine the values appropriate to evaluate groundwater:

- In the absence of an MCL, the tapwater values from the RSL table should be first consulted. For non-carcinogens, the RSL value in the table using a target hazard quotient of 0.1 should be used.
- For compounds with neither an MCL nor an RSL tap-water value, a risk-based concentration should be calculated based on the ingestion of water and the inhalation of vapors during domestic use of water in accordance with the equations presented in Appendix E or from another source (any other sources should be approved by the Department prior to use). The calculated concentration is referred to as the Direct Ingestion of Groundwater Concentration (DIGC).
- If no MCL, RSL, or the necessary information needed to calculate a DIGC for a COPC is available, an approved Lifetime Health Advisory or Secondary Drinking Water standard may be utilized. The Department should be contacted for other COPCs for which information is not readily available.

RSLs are risk-based concentrations developed with the Department of Energy (DOE) Oak Ridge National Laboratory (ORNL) under an Interagency Agreement as an update of the U. S. EPA, Region-3, Risk-Based Concentrations table; the U. S. EPA, Region-6, Human-Health, Medium-Specific Screening Levels table; and the U. S. EPA, Region-9, Preliminary Remediation Goals table. The RSLs are generic, risk-based concentrations derived without the use of site-specific data. These concentrations may be applied during the early phase of site assessment and in environmental site assessments where the representative site concentrations (see Appendix B) and the source area(s) have been adequately identified and characterized. Site characterization should be conducted in accordance with the current *Alabama Environmental Investigation and Remediation Guidance (AEIRG).*

RM-1 concentrations are media-, receptor- and pathway-specific concentrations calculated using default assumptions and parameters presented in the most current Regional Screening Levels – User's Guide.

The Risk Management-1 (RM-1) target concentrations are calculated using the models presented in Appendix E. RM-1 concentrations will vary from site to site. An RM-1 Evaluation may be performed if the site has been (i) satisfactorily characterized, and (ii) the site data indicates that the input-parameter values used to develop the RM-1 levels are reasonably applicable. The RM-1 Evaluation is further discussed in Section 8.0.

Risk Management-2 (RM-2) target concentrations are site-specific concentrations based on site-specific data. These concentrations are based on cumulative risk and are back calculated to assist with cleanup objectives. An RM-2 Evaluation requires the collection of site data as discussed in Section 5.0 of this document. Adequate soil and groundwater data is necessary as discussed in the most current version of the AEIRG. The RM-2 concentrations are calculated using the models in Appendix E unless alternate models have been approved by the Department through submittal of an RM-2 work plan. It is necessary to calculate RM-2 concentrations only if the cumulative-risk levels exceed the Department-approved target-risk levels for one or more receptors. An RM-2 work plan should be developed and approved by the Department as discussed in Section 9.0.

## 3.3 THE OVERALL INVESTIGATION PROCESS WITH ARBCA

Figure 3-1 presents a simplified flowchart that illustrates the ARBCA process. As shown in Figure 6-1, the ARBCA process is a combination of data collection and data evaluation based on the receptors, complete exposure pathways, and site-specific concentrations appropriate for the site.

The ARBCA process begins with the acquisition of initial site data by performing a Preliminary Investigation (PI), a Closure Site Assessment (CSA), or an Environmental Assessment (EA). As an initial screen, maximum soil and groundwater concentrations are compared to existing RSLs. If the concentrations exceed the RSLs, or if there are sensitive receptors at or near the site, additional site data should be collected through a Secondary Investigation (SI). Site assessments should be performed to obtain sufficient technically defensible and reliable data for a site-specific, risk-based evaluation. A description of the type of data which should be obtained is listed in Sections 5.0 and 6.0

After an adequate site characterization has been performed (see Sections 5.0 and 6.0), a comparison of site concentrations to RSLs is conducted. Should the representative concentrations exceed the RSLs for any complete pathway, or if site characteristics significantly differ from the assumptions used to develop RSLs, then additional data may have to be collected to perform an RM-1 Evaluation. Note, at most sites, RSLs may be accepted as the remedial target levels without determining the cumulative risk at the site. The Department may provide the site with an indication that corrective action performance standards have been attained after the RSLs have been achieved.

For sites that proceed to an RM-1 Evaluation, the CSM must be developed and include all current and reasonable future receptors and all complete routes of exposure. RM-1 cumulative risks should then be calculated and compared to the allowable risk standards. If the allowable risk is exceeded, target concentrations should be calculated and compared to representative concentrations. After performing an RM-1 Evaluation, one of four options are usually available: (i) corrective action performance standards attained with conditions (an environmental covenant per ADEM Admin. div. 335-5 may be appropriate), (ii) remediation to meet RM-1 concentrations and a re-evaluation of the cumulative risk present at the site, (iii) monitoring, or (iv) an RM-2 Evaluation.

RM-2 concentrations can be calculated at any stage of the ARBCA process after adequate site characterization has been done and sufficient monitoring data has been obtained. Prior to performing the RM-2 risk calculations, the CSM must be updated and include all current and reasonable-future receptors and all complete routes of exposure. RM-2 cumulative risks are then calculated and compared to the allowable risk standards. If the allowable risk is exceeded, the target concentrations should be calculated and compared to representative concentrations for each receptor, for each decision unit/exposure domain for each chemical of concern. The comparison of representative concentrations to the calculated RM-2 concentrations should only be performed after sufficient monitoring data has been collected. If the site's representative concentrations do not exceed the calculated RM-2 calculations, the final process necessary would be to calculate the site-specific cumulative risk to ensure that the cumulative risk thresholds have been met.

After the completion of an RM-2 Evaluation, the Department may indicate that corrective action performance standards have been attained if the RM-2 cumulative risks do not exceed the target-risk levels, or the Department will require remediation and/or risk-management activities to achieve RM-2 target risks. Site-specific risk-management activities may include an environmental covenant developed and recorded in the Judge of Probate's Office in accordance with ADEM Admin. Code div. 335-5. Where risk management takes the form of remediation to target concentrations, cumulative risks and hazard indices may need to be recomputed using current representative site concentrations to ensure that risk levels are not exceeded before an indication that corrective action performance standards have been attained is provided.

The ARBCA process is a progressive approach which allows for additional site-data collection to support a site-specific, risk-based evaluation without compromising the protection of human health and the environment.

## 3.4 THE ARBCA PROCESS STEP BY STEP

Figure 3-1 shows a detailed view of the ARBCA process. Please note that this flowchart provides general guidelines. In summary, the ARBCA process begins with the discovery of a release followed by the performance of an adequate site assessment, the performance of initial-abatement measures as needed, RSL, RM-1, and/or RM-2 Evaluations, site remediation when warranted, confirmation of site remediation through monitoring, and the issuance of a letter indicating that corrective action performance standards have been met. Such a letter may require that land-use controls remain in place such as an environmental covenant developed in accordance with ADEM Admin. Code div. 335-5.

## 3.5 ANTICIPATED IMPACTS ON SITE COSTS

As the process moves from the RSL Evaluation to the RM-1 and possibly RM-2 Evaluations, the cost of data collection and risk evaluation will most likely increase. However, the cost of remediation is likely to decrease due to the probability that the site-specific RBTLs generally increase. Despite the difference among the three tiers (refer to Figure 3-1), there is one very significant similarity. Each tier will result in an equally acceptable level of protection for the site-specific, human and environmental receptors, where the acceptable level of protection is defined by the Department.

## 3.6 ARBCA-EVALUATOR QUALIFICATIONS

Implementation of RM-1 and RM-2 Evaluations requires the evaluator to be experienced in the concepts and procedures of risk assessment and risk management.

The Department will require that the ARBCA reports are signed by either an Alabama Licensed Professional Geologist or an Alabama Registered Professional Engineer. In addition, all reports or plans should be signed by a responsible corporate officer, the general partner or the proprietor, a principal executive officer or ranking elected official, or a duly authorized representative of one of the previous persons. Any person signing such a document should make the following certification:

*"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision according to a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."*

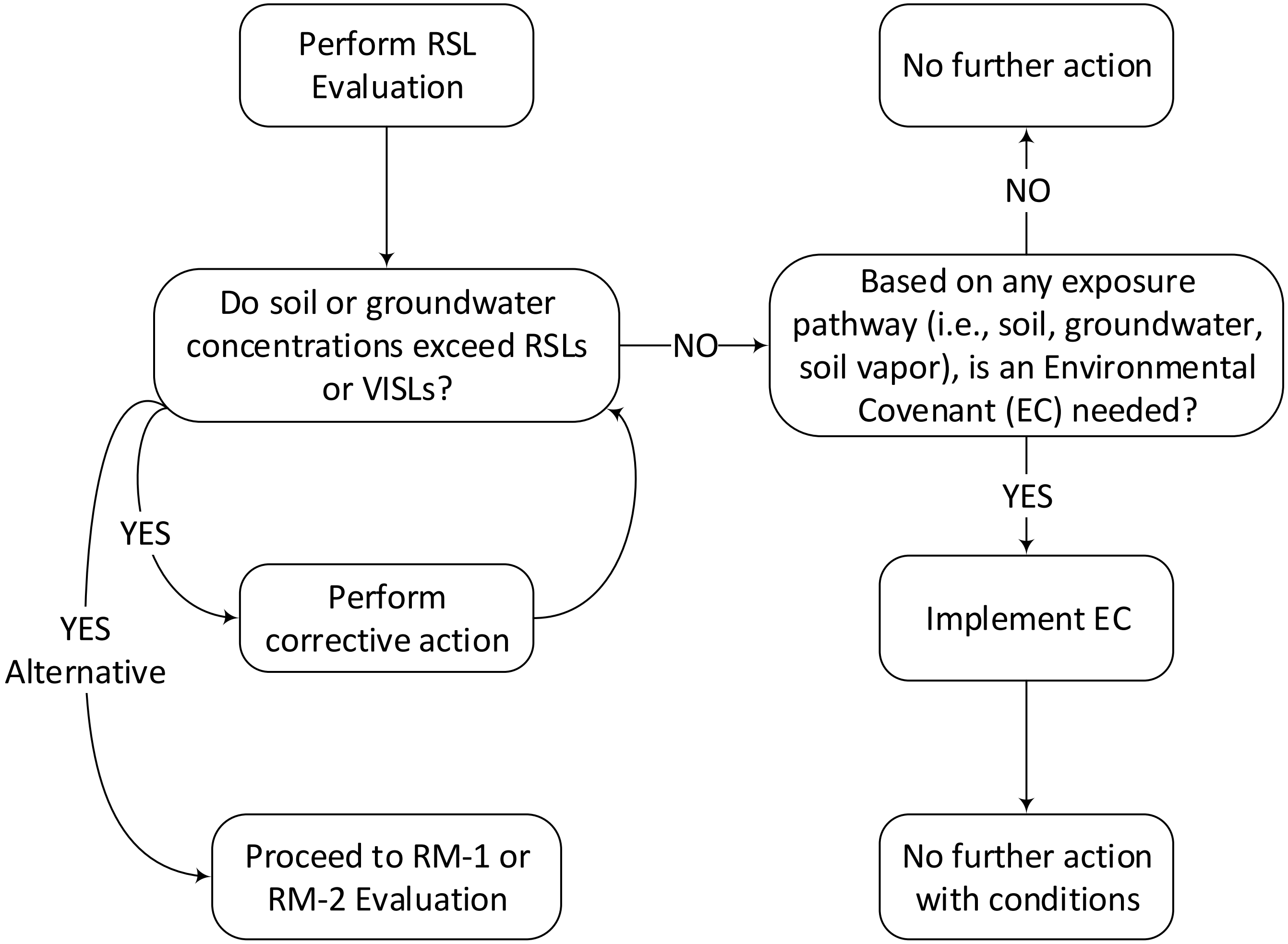


**Figure 3-1.** (a) Flow Diagram of the ARBCA Process for RSL Evaluation

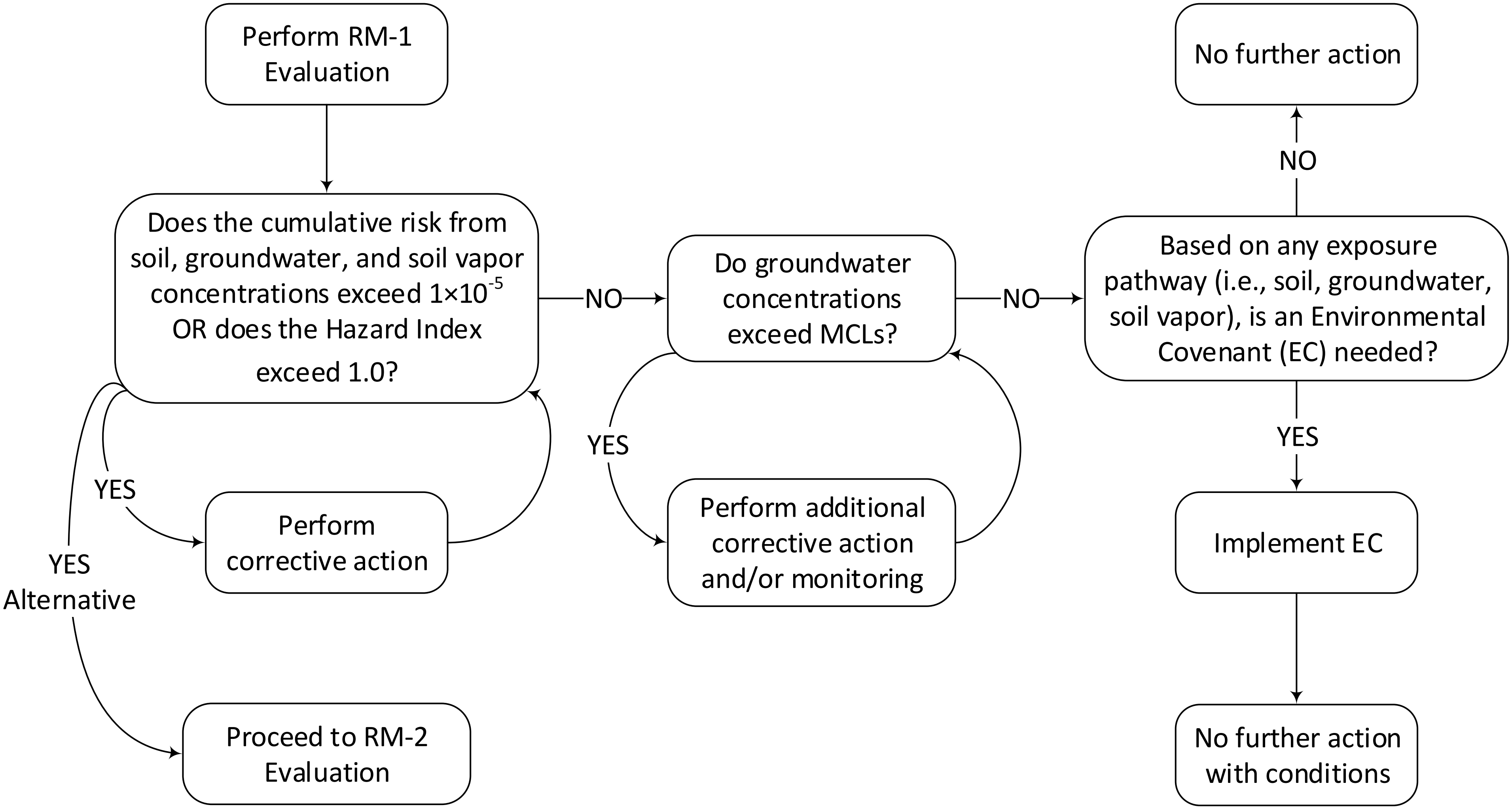


**Figure 3-1.** (b) Flow Diagram of the ARBCA Process for RM-1 Evaluation

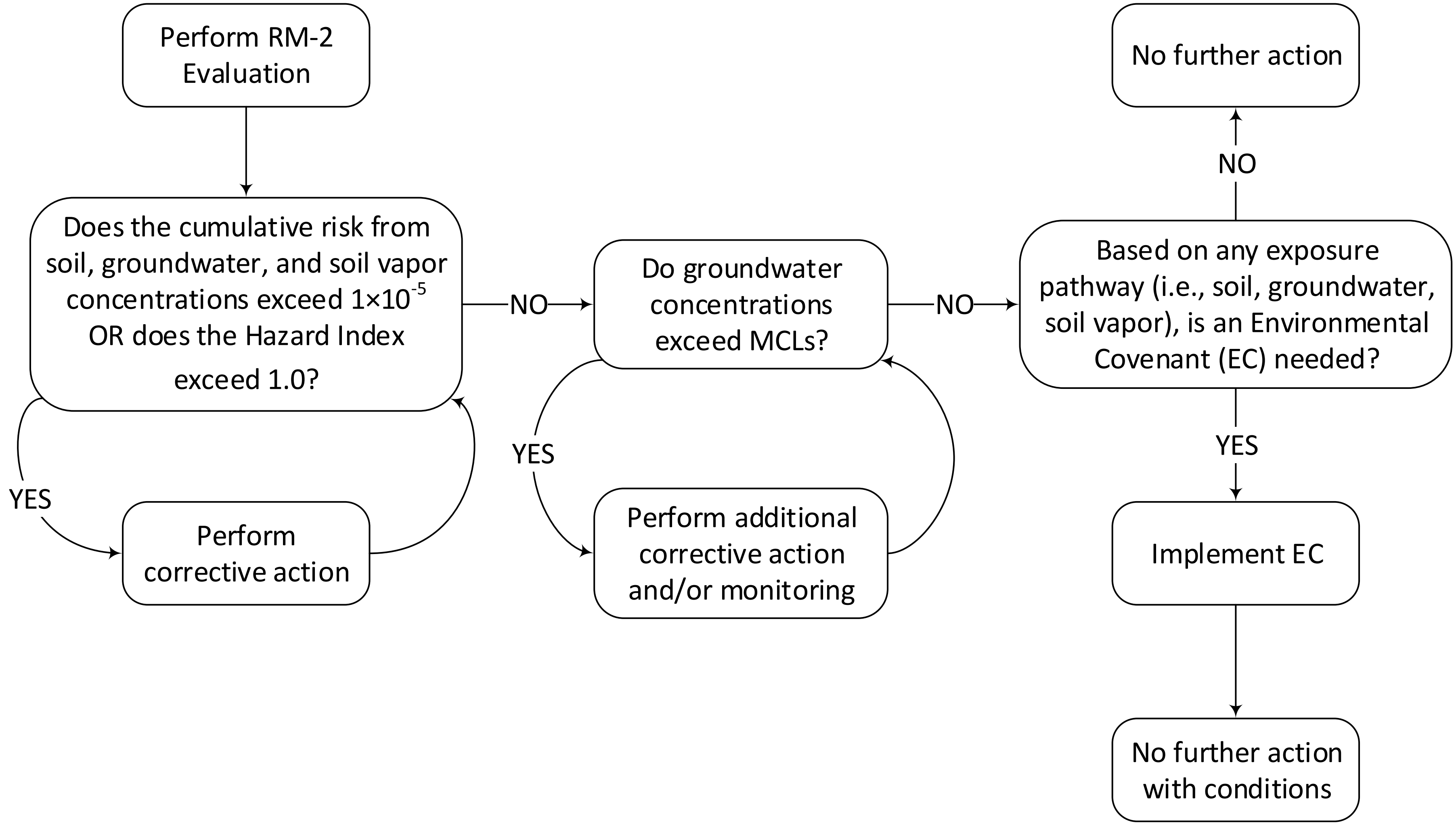


**Figure 3-1.** (c) Flow Diagram of the ARBCA Process for RM-2 Evaluation

# 4.0
# INITIAL-RESPONSE ACTIONS

## 4.1 SELECTING THE TYPE OF INITIAL RESPONSE

Determination of the appropriate initial-response action at a site involves the collection of appropriate site data and remedial action to reduce/eliminate any vapor problems or threat to public or domestic water supplies. Notification of appropriate personnel is critical in order to provide for an effective response to a public-safety threat. Public-safety offices such as the Fire Department and Emergency Management offices should be notified in the event of a public-safety threat.

To determine whether or not a site is located within a designated Source Water Assessment Area I or II, contact the local water-system operator for the area of interest.

The US Geological Survey Water-Resources Investigations Reports entitled *Geohydrology and Susceptibility of Major Aquifers to Surface Contamination in Alabama; Areas 1 -13* (U. S. Geological Survey, 1989) should be referenced to determine if a site is classified as a G.1 site. These reports indicate areas susceptible and highly susceptible to surface contamination. These documents are available from the Department or the Geological Survey of Alabama.

Initial-response actions should be used to reduce or eliminate the threat of exposure. These actions are not substitutes for regulatory requirements or other actions necessary at a later date to protect human health or the environment. Appropriate site-specific actions should be performed to protect human health and the environment. Additional information on initial response actions is located in the current AEIRG.

## 4.2 FREE-PRODUCT REMOVAL

The requirement to remove free product remains a component of the site corrective action. Risk evaluation (RM-1 or RM-2) may be conducted at sites with free product. However, the site must continue to undergo free-product removal. Furthermore, groundwater monitoring will be necessary during and after the free-product removal to verify that site conditions do not pose an unacceptable level of risk, and that free product has been removed, and its absence is not due to a temporary change in water table.

Appendix B includes information regarding how to account for free product in the development of representative concentrations for soil and groundwater.

## 4.3 THREATS TO UTILITIES

The potential for degradation of water-supply lines, the movement of vapors into storm and sanitary sewers, and damages to underground gas, phone, and electrical utilities must be evaluated as part of the ARBCA process. While the threats to these utilities cannot be easily quantified, an evaluation must be made which delineates the presence and location (and depth) of various utilities on and adjacent to the site where the release occurred.

This section highlights key aspects of the site-assessment process and the data required to perform an ARBCA evaluation. The most current version of the AEIRG includes guidance for performing a site investigation.

This section discusses several investigation components necessary to perform a technically defensible ARBCA Evaluation.

## 5.1 CHEMICALS OF POTENTIAL CONCERN (COPCs)

While evaluating a site impacted by a release, the Department focuses on Chemicals of Potential Concern (COPCs) (Note: The meaning of the term COPCs used in this manual may differ from its use in other programs and documents). Each facility will have a unique set of chemicals of potential concern (COPCs) based on past activities that have occurred over the years at the site. A thorough historical investigation should commence at the initiation of the COPCs determination process. If the past activities are unknown at a site, the complete list of constituents located in ADEM Admin. Code r. 335-14-2-Appendix VIII – Hazardous Constituents should be considered in the site analysis.

Each of the COPCs has unique physical and chemical properties and behave differently within the environment (mobility, persistence, and inter-media transport) and present different adverse environmental and human-health effects. Affected environmental media should be sampled and analyzed for the appropriately determined COPCs and compared to the RSLs. The RSLs are conservative, chemical-specific screening levels for soil, vapors, and groundwater for industrial and unrestricted land uses. These values are presented in the RSL Table available online with the link provided below. The appropriate RSLs should be selected based on the current land use and the most likely future land use (see Section 6.1). In addition, the Department may grant a corrective action performance standards attained letter if the maximum site concentrations for each medium do not exceed any medium-specific RSLs and the VISLs. The recommended laboratory analytical methods for determining the concentrations of the COPCs are found in SW-846. Please note that although SW-846 contains a method for Total Petroleum Hydrocarbons (TPH) - Gasoline Range Organics (GRO) and -Diesel Range Organics (DRO) (Method 8015), and the RSLs do contain several TPH screening levels for the different number of carbons, neither Method 8015 nor the TPH RSLs are acceptable for site and/or risk assessment purposes. However, TPH, GRO, and DRO can be very useful during the initial assessment of a site to provide information regarding where the contamination may be located. These methods should be utilized unless specific authorization has been granted by the Department to utilize an alternate analytical method. During the RSL Evaluation, the maximum site concentration of each COPC should be compared with the respective RSL and/or VISL. The COPCs whose maximum concentration does not exceed the RSL are eliminated. The remaining chemicals form the list of Chemicals of Concern (COCs), which are further evaluated under the RM-1 and RM-2 process. Note, the lists of COCs considered in both RM-1 and the RM-2 evaluations are identical. Following the determination of COCs, the cumulative risk should be determined and RBTLs developed for each COC as necessary to assist in guiding remediation activities.

## 5.2 SITE ASSESSMENT AND PRELIMINARY INVESTIGATION

Details regarding these types of assessments are in the most current AEIRG. These assessments are generally geared towards detecting a release or determining if soil and/or groundwater has been affected by a release. The assessment activities are performed to determine if soil and/or groundwater have been affected in the likely source areas and to determine the extent to which soil and/or groundwater have been affected. At this stage of the site-evaluation process, little information is known about the site. Since very little site data are collected as a part of the Site Assessment (SA) or Preliminary Investigation (PI), it is appropriate to use these conservative limits as screening levels such as the RSLs.

### 5.2.1 Site Assessment (SA)

With the ARBCA process, a site owner/operator may choose to utilize RSLs to evaluate the results of a SA. This will require the collection of samples and analysis of the samples for the COPCs from the most likely source areas. The frequency and number of samples are based on site-specific factors – additional guidance is located in the most current AEIRG.

### 5.2.2 Preliminary Investigation (PI)

The PI should be performed to obtain the necessary soil and groundwater COPC data, to obtain land-use information, and to develop the Conceptual Site Model (CSM) for the ARBCA process as discussed in more detail within Section 6.0. When performing a PI where soil and groundwater samples are collected, concentrations can be compared to the RSLs.

## 5.3 COMPREHENSIVE INVESTIGATION (CI)

The CI should be performed to (i) obtain adequate data to classify each site to determine initial-response actions, (ii) obtain adequate information to perform an RM-1 and an RM-2 Evaluation at the release site, and (iii) determine the full lateral and vertical extent of soil and groundwater contamination.

The primary guidance recommended for use to perform investigations such as the CI is the most current version of the AEIRG – Section 3.0. The CI is geared towards defining the lateral and vertical extent of contamination and determining the site-specific soil properties, hydraulic conductivity, stratigraphy, and land use of the site necessary to perform an RM-1 and an RM-2 Evaluation.

The key components of the CI are:

- Identification of the soil and groundwater areas impacted by COPCs appropriate to the type of waste released so that accurate representative soil and groundwater concentrations can be determined.

- Identification of the lateral and vertical extent of impacts to soil and groundwater. Unless otherwise directed by the Department, the extent of impact should be delineated by comparing the sampled concentrations to the RSLs. An ARBCA Evaluation requires that a thorough assessment of source areas be performed to ensure that representative concentrations of chemicals are detected at the site. The extent of soil contamination in the source area must be adequately delineated. An adequate assessment of the extent of the groundwater plume must be performed prior to performing the ARBCA Evaluation. When appropriate, future downgradient groundwater concentrations may be estimated using appropriate models.

- Installation of groundwater-monitoring wells for assessment, monitoring, and to determine background levels of COPCs.

- Determination of the hydraulic properties of the site including depth to groundwater, groundwater flow direction and rate, and hydraulic conductivity of the site.

- Identification of the current and future receptors, all appropriate exposure pathways, and any immediate and long-term hazards to human health and the environment.

The ARBCA process involves performing a site assessment to collect adequate data to calculate cumulative risks as required for an RM-1 or an RM-2 Evaluation. The assessment should be performed such that the lateral and vertical extent of impact is determined by comparing investigation data to the RSLs until desirable concentrations are reached. If it becomes apparent during the CI that the RSLs and VISLs will be met, then no additional information may be needed at the site. However, if the cumulative risks calculated per the RM-1 Evaluation are likely to exceed the acceptable risk levels or site conditions are significantly different than the RM-1 default values, the CI should include collection of all data necessary to perform an RM-2 Evaluation as expeditiously as possible.

## 5.4 REVIEW OF SITE CONDITIONS

An evaluation of the following site conditions is an integral part of the ARBCA process. The level of effort should be sufficient to accurately provide a technical basis for all determinations.

- Ground Surface Condition: Determine percentage of the site that is paved. Also note the general condition of the pavement.

- Land Use: Detailed survey and assessment of the current and likely future use of the land within 1,000 feet of the site should be performed. The survey should identify the current use of the properties as either unrestricted or other (*e.g.*, commercial, industrial, *etc*.). The most likely future use of the impacted or potentially impacted properties should also be determined (see Section 6.1).

- Receptors: Determine the human and ecological receptors present on and proximate to the site. Receptors include adults, children, construction workers, water-use wells, surface waters, *etc.* (see Section 5.5).

- Source History: Determine the history of the site. Evaluate the location(s) of previously installed USTs, Aboveground Storage Tanks (ASTs), dispensers, waste treatment, storage or disposal areas, above ground and below ground piping, *etc*. Determine if site structures influence any migration pathways at the site. Prepare a detailed map of the facility, made to scale, with a bar scale and north arrow, indicating the layout of past and current waste management areas, product storage or loading/unloading activities, piping, subsurface utilities, *etc*. The utilities should include buried phone lines, storm water sewers, sanitary-sewer systems, water supply lines, electrical lines, natural gas lines, and any other structures which might be present.

- Regional Hydrogeology: Review the regional hydrogeology to determine soil types and aquifer characteristics. Published literature and investigations previously conducted on proximate sites may yield important information for the hydrogeological characterization.

- Groundwater Use: Determine whether there is groundwater use for public water supply within a one-mile radius and for private domestic water supply within a 1,000-foot radius of the site. Determine if the site is in a Source Water Assessment Area.

- Surface Water: Locate surface-water bodies within 1,000 feet of the site which could potentially be affected by the release at the site.

- Review the facility files for any other pertinent environmental data.

## 5.5 PERFORMANCE OF A RECEPTOR SURVEY

The receptor inventory is a critical element of the ARBCA evaluation. Actual and potential receptors must be identified.

- Land Use: Within a 500-foot radius of the site, identify the following: schools, hospitals, residences, basements, day-care centers, nursing homes, and businesses. Also identify surface-water bodies, parks, recreational areas, wildlife sanctuaries, wetlands, and agricultural areas.

- Utility Survey: Identify the location and depth of all subsurface utilities and other subsurface pathways, which may serve as preferential conduits for migration of the contaminants. Identify the flow direction of the material (water, sewage, etc.) within the utility line.

- Water-Well Inventory: Locate all public water-supply wells within a 1-mile radius of the site and all private wells and well water use within a 1,000-foot radius. Information sources include the ADEM Water Supply Branch, the USGS, the Alabama Geological Survey, water-system operators, and interviews of local residents. A representative survey must be made and may require door-to-door interviews of businesses and residents. Identify existing potable and non-potable wells. The current use and status of all located wells should be noted.

- Surface Water: Locate surface-water bodies within 1,000 feet of the site which could potentially be affected by the release at the site.

- Ecological Receptors: The determination of ecological receptors within a 1,000-foot radius of the site is necessary. This includes, but is not limited to, the identification of wetlands, surface-water bodies, sensitive habitats, or the presence of endangered species. Any site where ecological receptors may be affected will undergo an RM-2 Evaluation utilizing USEPA's Ecological Screening Values.

Proper identification of potential receptors in the pre-assessment planning will facilitate appropriate initial responses which might include relocation of residents, supply of alternate drinking water, or performance of initial-abatement measures.

## 5.6 EVALUATION OF THREATS TO UTILITIES

Due to the potential for preferential flow of contaminated groundwater and vapors into underground utility lines/conduits, a thorough evaluation of potential and real impacts to underground utilities must be performed. A combination of site observations, general knowledge about buried utilities, and discussions with utility representatives and site owner(s) should reveal the locations of site utilities. The evaluation should include at a minimum:

- Locate all underground utility lines and conduits within the area of known or likely soil and groundwater impacts, for both on-site and any off-site properties, to which a release may have migrated or to which a release may migrate in the future (includes phone lines, water lines, sanitary sewers, storm sewers, and natural-gas lines).

- Determine the direction of flow in the utilities (water, storm water, and sewage).

- Identify the utility lines/conduits on a base map which also contains a diagram showing the extent and thickness of any free product that may be present and the impacts to soil and groundwater.

- Determine depth of the utility lines/conduits relative to the depth of groundwater. Seasonal fluctuations of the groundwater levels should be carefully evaluated. As appropriate, a cross-sectional diagram should be provided illustrating the depth to groundwater and the locations and depths of the lines/conduits.

- Determine the types of materials used for lines/conduits (i.e., PVC, terra-cotta, ductile iron, etc.).

- Determine any past impacts to utilities and any complaints that may have been previously filed with any local or State agency.

- As appropriate, sample the utilities and vaults using either explosimeters or by taking air samples. If explosive conditions are encountered, immediate emergency response is necessary.

- If free product is present, it should be remediated.

- Where dissolved contamination is present, an evaluation of the potential effects of dissolved contamination should be made.

Where a utility is threatened, or where an explosive situation exists, appropriate measures to eliminate fire, explosive, and vapor hazards must be undertaken. Additional assessment may be necessary to fully evaluate threats to utilities.

## 5.7 SUBSURFACE-DATA COLLECTION ACTIVITIES

The subsurface site investigation should be guided by the scope of work prepared during the PI planning stage; however, appropriate adjustments to the scope of work and modifications to the CSM should be made as data are collected, analyzed, and evaluated during site activities. The Geologist or Engineer performing the site assessment must remain flexible during the assessment procedure and evaluate the site information in the field to determine the most appropriate activity.

- Geologic Description: A continuous soil profile from at least one boring should be developed with detailed lithologic descriptions. Particular emphasis should be placed on characteristics that control chemical migration and distribution such as zones of higher or lesser permeability, changes in lithology, correlation between soil-vapor concentrations and different lithologic zones, obvious areas of soil discoloration, organic content, fractures, and other lithologic characteristics. Soil-boring logs should be submitted for each hole drilled at the site. The logs should indicate depth correlating with changes in lithology (with lithologic descriptions), soil- vapor analyses, occurrence of groundwater, total depth, visual and olfactory observations, and any other pertinent data. When a monitoring well is installed, as-built diagrams with depth to groundwater must be submitted for each well.

- Sampling for COPCs in Soil: The vertical and lateral extent of subsurface impacts should be defined during the site assessment. At a minimum, discrete samples should be collected within the surface soils (less than 12 inches in depth) and every five feet below ground surface (bgs) thereafter and should include samples from immediately above the saturated zone. These samples should be field screened using a properly calibrated field organic vapor analyzer such as a flame-ionization detector (FID) or a photo-ionization detector (PID). The sample obtained from immediately above the saturated zone and the sample reflecting the highest organic-vapor level should be submitted to the laboratory for analysis of appropriate COPCs. Additional samples may be necessary to fully characterize the soil chemical distribution and to quantify exposures for an RM-1 or RM-2 Evaluation or for the development of a corrective action plan. Please note that an incremental sampling methodology may be used rather than collecting discrete samples – please see Appendix C.2.1 of the most current AEIRG for additional guidance concerning acceptable sampling methods.

- Sampling for Physical Soil Properties: For those sites which need to move to an RM-1 or RM-2 Evaluation, site-specific soil physical properties should be obtained. These include porosity, water content, fractional organic carbon content, and dry soil bulk density. The sampling plan should be adequate to determine soil properties representative of (i) the source area, (ii) the soils through which the COPCs migrate to reach groundwater, (iii) the soils through which COPC vapors migrate to reach the surface, and (iv) the saturated soils for groundwater-contaminant migration evaluations. For further information refer to ASTM Standard D1587-08.

    - Fractional organic carbon ($f_{oc}$) samples must be determined using soil samples not affected by the release (*i.e.*, outside of the contaminated area). The sample does not have to be an undisturbed sample. Consideration must be given to collecting multiple samples if multiple lithologies are present which might affect transport of the COPCs, or if the COPCs are contained within multiple lithologies. Both a vadose zone fractional organic-carbon ($f_{oc}$) sample and a saturated zone, fractional organic-carbon ($f_{ocs}$) sample should be collected when it appears these two zones may differ at a site. See Section 5.10 for a discussion of laboratory methods.

    - Samples collected for porosity measurements should be undisturbed. Such a sample can be collected using a Shelby tube. Consideration must be given to collecting multiple samples if multiple lithologies are present which might affect transport of the COPCs, or if the COPCs are contained within multiple lithologies. Both a vadose-zone total porosity ($\theta_T$) and a saturated-zone total porosity ($\theta_{TS}$) should be collected when it appears these two zones may differ at a site. Generally, however, porosity will not be measured directly. Instead, porosity will be computed from the dry bulk density and the specific gravity using Equation 5-1 located in Section 5.10.

    - Samples collected for dry bulk density measurements should be undisturbed and can be collected using a Shelby tube. Consideration must be given to collecting multiple samples if multiple lithologies are present which might affect transport of the COPCs, or if the COPCs are contained within multiple lithologies. Both a vadose-zone dry bulk density and a saturated-zone dry bulk density should be collected when it appears the two zones may differ.

- Sampling for COPCs in Surface Water: Appropriate samples should be collected when COPC migration is known or suspected to affect a surface-water body. Water samples should be collected from both upstream and downstream of a groundwater-discharge point. An additional stream sample should be collected at the groundwater-discharge point.

- Sampling for COPCs in Groundwater: If the groundwater has been affected, temporary sampling points may be used to screen the levels of groundwater impacts and to assist in determining the optimal location (horizontally) of permanent monitoring wells and the depth of screen. A sufficient number of monitoring wells should be installed (a minimum of four for a Preliminary Investigation) to document COPC migration and groundwater flow. Well placement and design should consider:

- Concentration of COPCs in the source area
- Proximity of potential or impacted receptor(s)
- Occurrence of free product at the site
- Hydrogeologic conditions (water-table fluctuations, hydraulic conductivity, and flow directions)
- Groundwater use

## 5.8 SURFICIAL SOIL SAMPLING

The collection of surficial-soil data (0-1 ft bgs) is necessary where there is evidence of a surface spill or overfill and it is likely that surficial soils have been affected. These data are used to evaluate the exposure pathways associated with the surficial soil. These pathways include direct contact, ingestion of soil, or vapor and particulate inhalation. However, for a site where an assessment has already been performed, soil data at 0 to 1-foot bgs may not be available. In such cases, it is necessary to assess the site to determine if surficial samples should be collected. Care should be taken to collect a representative sample, especially for those volatile COPCs that have a Henry's Law Constant of $1 \times 10^{-5}$ atm-$m^3$/mole or greater and with a molecular weight of less than 200 g/mole.

## 5.9 REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

The performance of an RM-1 and/or an RM-2 Evaluation at a site requires the calculation of soil and/or groundwater representative concentrations and the calculation of cumulative risks. If the calculated cumulative risks exceed the Department-specified target-risk levels, the risk-based target concentrations can be developed. For site-specific risk-management decisions, it is necessary to compare these target levels with the representative soil, groundwater, and/or soil-vapor concentrations. The definition of the representative concentration is critical to determine if an unacceptable risk is present at the site and/or if remediation at a site is necessary. The representative concentration should be determined as per Appendix B.

## 5.10 RECOMMENDED LABORATORY ANALYTICAL METHODS

The site investigation should be conducted to obtain analytical data for COPCs and physical properties of soil. The acceptable analytical methods for determining concentrations of COPCs in soil, groundwater, and surface water are provided in the most current AEIRG. An RSL Evaluation assumes generic soil properties and does not use site-specific measurements. If an RM-1 or an RM-2 Evaluation is to be performed, site-specific soil data should be obtained. Acceptable laboratory methods for determining the following soil properties are listed as follows:

**Dry Bulk Density (g/cc)** is the dry weight of soil per unit volume of soil and considers both the solids and the pore space. The ASTM Method D2937-10, *Standard Test Method for Density of*

*Soil in Place by the Drive-Cylinder Method*, defines dry bulk density as the dry weight of a soil sample divided by the field volume of the soil sample. An accurate measurement of bulk density requires determining the dry weight and dry volume of an undisturbed sample. This method involves collecting a core of a known volume, using a thin-walled sampler to minimize disturbance of the soil sample, and transporting the core to the laboratory for (i) drying, (ii) estimation of the dry weight, and (iii) estimation of dry volume or volume of dry solids.

**Porosity (cc/cc-soil)** is the ratio of the volume of voids to the total volume of the soil sample. Many laboratories use dry bulk density and specific gravity data to determine porosity using the following:

$$n = 1 - \frac{\rho_s}{SG} \tag{5-1}$$

where,

$n$ = Porosity (cm$^3$/cm$^3$)
$\rho_s$ = Dry bulk density of soil (g/cm$^3$)
SG = Specific gravity or particle density (g/cm$^3$)

The ASTM Method D854-10, *Standard Test Methods for Specific Gravity of Soil Solids by Water Pycnometer*, may be used to determine specific gravity. If specific gravity is not available, then 2.65 g/cm$^3$ can be assumed for most mineral soils. If effective porosity is required for a particular fate-and-transport model, it should be estimated from a literature source.

**Volumetric Water Content/Moisture Content (cc/cc)** is the ratio of the volume of water to the volume of soil in a sample. The ASTM Method D2216-10, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, is a gravimetric oven drying method. The water content value used in most models is the volumetric water content. Hence a conversion may be necessary using the following:

$$\theta_{wv} = \theta_{wg} \times \frac{\rho_s}{\rho_l} \tag{5-2}$$

where,

$\theta_{wv}$ = Volumetric water content (cm$^3$-water/cm$^3$-soil)
$\theta_{wg}$ = Gravimetric water content (g-water/g-soil)
$\rho_s$ = Dry bulk density of soil (g-dry soil/cm$^3$-soil)
$\rho_l$ = Density of water (g/cm$^3$)

Refer to Section 1.4 of the method for special instructions on drying temperature and time for material containing significant amounts of hydrated (structural) water, such as clays. If the gravimetric water content is overestimated, dry bulk density measured with Method D2937-10 will be too small. Refer to Section 8 of Method D2937-10.

Further, if porosity is calculated using the equation in Todd (1980), Porosity = 1 – (dry bulk density/specific gravity × density of water), then porosity will be overestimated. In other words, if the gravimetric water content is wrong, dry bulk density and porosity will also be wrong.

**Fractional Organic Carbon Content in Soil (g-C/g-soil)** is the weight of organic carbon in the soil in the sample divided by the weight of the soil and is often expressed as a ratio.

Fractional organic carbon content can be estimated using the ASTM Method D2974-07a, *Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils.* This method measures the organic matter content of a sample. When using the ASTM Method D2974-07a, the result must be divided by 1.724 to get fractional organic carbon content (Page and others, 1982). If the laboratory results are reported as a percent, fractional organic carbon content is obtained by dividing the results by 100 and then dividing by 1.724.

The Walkley Black, rapid, dichromate-oxidation method for the determination of organic-carbon content (Page et al., 1982) should not be used.

**Hydraulic Conductivity (cm/sec)** is the discharge of water per unit area, per unit hydraulic gradient in a subsurface formation.

For some sites, it may be appropriate to use acceptable literature values. The reference used must be acceptable to the Department.

Site-specific values for hydraulic conductivity, if necessary, should be determined using accepted field test procedures. These include slug tests and/or pumping tests. Under certain circumstances, the Department may direct the site owner/operator to use an alternative method. One of these alternatives would be to perform a sieve test and estimate the hydraulic conductivity based on grain size distribution. Note that multiple tests for hydraulic conductivity should be obtained from various wells at the site to address the heterogeneity of the site.

# 6.0
# RISK-BASED EVALUATION: GENERAL CONSIDERATIONS

Several factors are common to ARBCA RM-1 and RM-2 Evaluations. RM-1 and RM-2 target levels are calculated when the cumulative risks exceed the acceptable risk levels (*i.e.*, IELCR = 1E-05 for carcinogenic risk and a HI = 1.0 for non-carcinogenic risk). There is not a requirement to calculate site-specific RM-1 or RM-2 target levels. RSLs and VISLs may be used as well. The advantage to RM-1 and RM-2 levels is that they allow for site-specific input parameters to be utilized for the development of the values and typically generate less conservative and more accurate target levels for a particular site. These issues are discussed in this section.

## 6.1 LAND USE

Characterization of the population and the activities near a release site is a critical component of the ARBCA process. The cumulative risks and target levels vary depending on whether the land use is unrestricted versus industrial, commercial, *etc.* Some sites may have multiple land uses. For such sites, the land use that yields the most conservative risk evaluation should be considered. Where multiple land uses exist for a site, such as a second-floor residence over a first-floor-commercial-use building, the site will be carefully evaluated and an appropriate risk evaluation will be applied based on site-specific data and available risk-management practices (*i.e.*, land use controls such as environmental covenant). The characterization of the population should initially be determined during the Site Assessment (SA) or the Preliminary Investigation (PI) and is modified as necessary during the development of the Conceptual Site Model (CSM) which is outlined in more detail in Section 6.5. If the information has not been obtained, the data must be obtained during the next phase of onsite work activities or prior to the initiation of the tiered, ARBCA Evaluation process.

With the ARBCA process, land use is categorized generally as either unrestricted or commercial. Of these, unrestricted land use generally results in lower target levels; thus, cleanup to unrestricted standards will usually allow unrestricted use. Examples of unrestricted and commercial land use as utilized in the ARBCA Evaluations are presented below.

- **Unrestricted**: Typically this refers to residential and includes, but is not limited to, schools, dwellings, homes, hospitals, child-care centers, nursing homes, playgrounds, recreation centers, and any other areas/structures with sensitive human activity. Groundwater may be used as a water supply at unrestricted sites.

- **Commercial**: Includes gas stations, industrial operations, stores, businesses, fleet operations, *etc.*, where employees work, but do not reside, on a continuing basis. Hotels, motels, and other transient activities are included in the commercial definition.

The current land use status should be clearly illustrated on maps submitted to the Department. A land use map with a radius of 1,000 feet should be prepared for most sites. If a site utilizes any land use other than an unrestricted use, an environmental covenant developed in accordance with ADEM Admin. Code div. 335-5 should be submitted for review and recorded in the Judge of Probate's Office. EPA's 2011 edition of the *Exposure Factors Handbook* can also be a helpful resource when determining land use considerations and potential impacts.

### 6.1.1 Determine Current Land Use

Current land uses and activities must be identified and evaluated to be protective of the existing receptors. Current land use refers to land use as it exists today. This can be readily determined by a site visit, and there should be no ambiguity about current land use.

A site reconnaissance should identify homes, playgrounds, parks, businesses, industries, or other land uses at the site of the release and in close proximity. Appropriate maps (zoning, insurance, topographic, land use, housing, *etc.*), state or local zoning boards, county property tax records, the U. S. Bureau of the Census, and aerial photographs can provide information for determining land use.

Undeveloped land should be characterized by the most likely future use of that property. If the undeveloped parcel is located in an area which is predominantly commercial, the commercial use classification may be appropriate which may require the appropriate land use controls (LUCs). However, if the setting is more rural and the land use is mixed, the undeveloped land should be considered unrestricted unless the owner is willing to impose the appropriate LUCs such as an environmental covenant developed in accordance with ADEM Admin. Code div. 335-5 to alter the land use classification to commercial.

### 6.1.2 Determine Most Likely Future Land Use

For all properties, both developed and undeveloped, the most likely future land use should be determined. The objective is to determine if any activities associated with the current land use are likely to be different in the future based on available information and the use of good professional judgment. Knowledge about the most likely future use of the site and adjacent properties is necessary to identify receptors, exposure points, exposure pathways, and exposure factors. Consideration of these pathways in the ARBCA process ensures that the site-specific decisions are as protective of future site conditions/uses as reasonably possible. The exposures to be evaluated in a human health or environmental risk assessment depend upon the activities that could occur under reasonable future uses of the land and groundwater at the site. Most likely future use and activities can be identified based on local zoning or other ordinances, knowledge of current land use and changing land use patterns, zoning decisions, community master plans, interviews with current property owners, commercial appraisal reports, proximity to wetlands, critical habitat, and other environmentally sensitive areas.

Careful consideration of future land and groundwater usage will reduce the possibility that the selected remedy will have to be re-evaluated due to changes in land use assumptions. It should be noted that, if cleanup is not based on unrestricted use, the future use of the property or groundwater will be limited to the usage scenario utilized for the calculation of the risks and cleanup goals and protected with LUCs such as an environmental covenant developed in accordance with ADEM Admin. Code div. 335-5

The user should consider all groundwater a potential drinking water source in the ARBCA process to ensure protectiveness of the remedy and to promote resource conservation. Final cleanup levels are based on-site-specific conditions, receptors, and current and most likely future land use. Future land and groundwater usage is uncertain and may be influenced by imposed LUCs such as an environmental covenant.

## 6.2 ON-SITE AND OFF-SITE

All ARBCA Evaluations must consider the impact of the chemicals to both the on-site receptors and off-site receptors. Thus, the CSM must clearly identify all complete pathways, routes of exposure, and receptors that may be impacted by Contaminants of Potential Concern (COPCs) located on-site and off-site. Within each area (on-site/off-site) there may be multiple land uses and multiple receptors. For example, a contaminated groundwater plume could migrate below an off-site, unrestricted land use area and a commercial area. In this case, both off-site unrestricted and commercial receptors have to be considered while developing the CSM. For simplification, the following definitions should be used:

- **On-site**: The property located within the legal property boundaries within which the source of the release is located. This includes the soil, groundwater, surface water, and air within those boundaries.

- **Off-site**: The property or properties located outside the property boundaries of the on-site property where the source of the release is located. This includes the soil, groundwater, surface water, and air located off-site.

The characterization of the release will include a determination of the on-site and off-site areas of impact. These areas are considered in determining the pathway-specific decision units or exposure domains (DUs/EDs) of the receptor(s). The DU/ED is the area over which the receptor may be exposed to the contaminated medium(s). Determination of the DU/ED is critical in developing representative concentrations separately for groundwater and soil for on-site and off-site properties. Appendix B provides details regarding the development of representative concentrations for on-site and off-site properties.

## 6.3 RECEPTORS

The objective of a risk assessment is to quantify the adverse health effects to the current receptors as well as the most-likely future receptors. For an ARBCA Evaluation, the human receptors to be considered should include persons who live or work within at least a 1,000-foot radius of the site boundary (and, at times, more depending on the source and hydrogeological conditions). For unrestricted-use receptors, the cumulative risks to both adults and children should be evaluated. Adults working at a commercial location or at construction-sites will be considered in the ARBCA Evaluation. A trespasser will generally have less exposure than residents and commercial workers; therefore, no specific quantitative analysis need be performed so long as the proper justification is provided within the ARBCA Report (*e.g.*, fencing and security exists to ensure that trespassers are unable to enter a property).

The most likely exposed human receptors that should be included in the ARBCA evaluation for a site are listed below; however, this should not be considered a complete list. The *2011 USEPA Exposure Factors Handbook* should be consulted to provide more site-specific activity-based information for potential receptors:

- Residential – Child
- Residential – Adult
- Commercial Worker – Adult
- Construction Worker – Adult

Surface water bodies such as creeks, rivers, springs, ponds, lakes, bays, *etc.*, should be identified within a minimum 1,000-foot radius of the site. Surface water bodies should be evaluated to determine the impacts of discharging groundwater or surface runoff from the release site. At a minimum, information to be evaluated should include the location, flow rates, depth, flow direction, and use classification from ADEM Admin. Code ch. 335-6-11. If the water body in question is not listed in Chapter 11, the ARBCA Evaluator should assume the Fish and Wildlife use classification. Typically, smaller streams will not be listed in Chapter 11.

On-site as well as off-site underground utilities and, specifically, their ability to serve as conduits should be fully evaluated. Adverse impacts may include degradation of water lines, degradation of sewer lines, vapors in storm and sanitary sewers, property damage to outer coatings of gas lines, and property damages to buried phone and electrical lines.

Where Chemical of Concern (COC) plumes extend, or likely to extend, beyond the site property boundary, any additional receptors should also be identified and their risk evaluated. In the absence of additional receptors, the ARBCA process requires the evaluation of the potential impact of COC plumes on groundwater resources beyond the legal site boundary. See Section 6.6 for the use of these criteria in selecting the location of the point of exposure.

There are certain sites such as conservation areas, sensitive resource areas, agricultural areas, *etc.*, where livestock or wildlife may be the potential receptors. In these areas, ecological exposure of wetlands, sensitive environments, wildlife and/or threatened and/or endangered species should be thoroughly evaluated. Section 6.13 addresses concerns regarding ecological risk evaluations. The potential risk to these types of receptors should be evaluated under an RM-2 Evaluation. The Department should be contacted to obtain additional guidance on these issues. More information is available in the document, *Ecological Risk Assessment Guidance for Superfund* (U.S. EPA, 1997).

Non-human receptors such as endangered species or other ecological receptors live in many types of areas that may be impacted by contamination and should be evaluated for potential ecological impacts. Source Water Assessment Areas (SWAAs) I or II should be identified and evaluated as necessary. A definition and a table describing SWAAs I and II are found in ADEM Admin. Code ch. 335-7-15. These types of areas should be evaluated under an RM-2 Evaluation.

## 6.4 HUMAN EXPOSURE PATHWAYS

A receptor comes in contact with COPCs through a complete exposure pathway. For a pathway to be complete, there must be (i) a source of chemical, (ii) a mechanism by which the chemical is released from the source, (iii) a medium through which a chemical travels from the point of release to the receptor's location, and (iv) a route of exposure by which the chemical enters the receptor's body and potentially causes adverse health effects. The source of a chemical depends on the nature of the site activities, the release, and the release area. Release mechanisms may cause chemicals to be released either in the air, on the ground surface, or in the subsurface. Potentially impacted media include air, surficial and subsurface soil, surface water, and groundwater. Routes of entry include ingestion of groundwater and soil particulates, indoor and possibly outdoor inhalation of vapors in the air, indoor and possibly outdoor inhalation of vapors from soil and groundwater, inhalation of soil particulates, dermal contact with soil, and leaching to groundwater from surficial and subsurface soils. Figure 6-1 is an example site conceptual exposure model that illustrates the relationships between the impacted media, transport mechanisms, exposure pathways, and potential receptors that comprise complete pathways. Items (i), (ii), and (iii) are critical in determining the exposure domain of the receptor(s). The Department has identified the most commonly encountered exposure pathways for which an evaluation must be conducted to determine whether a complete exposure pathway exists at the release site. These pathways are discussed below.

### 6.4.1 Pathways for Inhalation

For the inhalation pathway, the chemical intake occurs by the indoor inhalation of vapors or the outdoor inhalation of vapors and/or soil particulates at a site. In most cases, the outdoor inhalation of vapors pathway is not the critical pathway due to the extreme dilution of outside air and the fact that the sunlight degrades many COPCs. The Department considers a chemical to be a potential source for vapor intrusion if it has sufficient volatility and toxicity in the subsurface with sufficient mass or concentration to pose a possible inhalation risk within overlying buildings.

Further guidance on vapor intrusion related to petroleum and chlorinated compounds is available from the U.S. EPA in two guidance documents, *Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*.

Depending on the toxicity of the chemical, unacceptable exposures may occur at concentrations below the odor-threshold levels. In most cases, the source for these vapors is volatile chemicals in soil and/or groundwater. Chemicals that have migrated through subsurface soil to groundwater may volatilize from the soil and/or groundwater. The volatile COPCs may diffuse upward through the overlying capillary fringe, unsaturated zone, and cracks in the floor/foundation to indoor or outdoor air where the exposure may occur.

To quantitatively evaluate the vapor inhalation pathway, mathematical models are used to relate the allowable air and/or soil-vapor concentrations with the soil or groundwater concentrations. Risks from inhalation of vapors from soil or groundwater are calculated using actual concentrations in soil and groundwater and fate and transport models. If target risks (*i.e.*, IELCR = 1E-05 & HI = 1.0) are exceeded, target concentrations protective of indoor (and outdoor as necessary) inhalation are developed for RM-1 and RM-2 Evaluations. If the allowable risk is exceeded, then it may be appropriate to collect soil-vapor measurements, or it may be appropriate to proceed directly into remediation and/or mitigation. An evaluation should be performed to determine the necessity of collecting air and/or soil-vapor samples for comparison to the indoor/outdoor air and/or soil-vapor target levels which are located in the VISLs. Indoor-air measurements should not be performed at many sites due to technical difficulties associated with accurately measuring the indoor-air concentration contributed by soil and/or groundwater impacts. Rather, either models used to estimate indoor-air concentrations or the use of an empirical relation/attenuation factor to estimate indoor-air concentrations based on soil, groundwater, and soil vapor should be used. In the majority of cases, it is most appropriate to measure soil-vapor concentrations and compare these measured values with the VISLs.

If either the subsurface soil or groundwater indoor inhalation pathways are complete, the soil vapor pathways should be considered complete/potentially complete even if actual soil vapor measurements were not collected. The site conceptual exposure model should state that actual soil vapor measurements were not obtained and discuss why no representative concentrations for soil vapor are provided. If soil vapor data is available, the risk will be computed from actual soil vapor measurements, not from the soil and water concentrations.

For the RM-1 and RM-2 Evaluations, the guidance provided in the *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air*, the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*, and the *Risk Assessment Guidance for Superfund (RAGS) Part F* (EPA 2009) should be used to quantitatively determine either the risk or the Risk-Based Target Levels (RBTLs) associated with the outdoor inhalation of soil particulates.

Refer to Appendix B and the *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* for guidance on the methods for estimation of representative concentrations.

### 6.4.2 Pathways for Surficial Soils

Surficial soils are defined as soils extending from the surface to one foot below ground surface (bgs). The exposure pathways associated with affected surficial soil include the following:

- Ingestion of soil particulates
- Inhalation of soil particulates
- Outdoor inhalation of vapor emissions from soil
- Dermal contact with soil
- Leaching to groundwater, potential ingestion of groundwater, and migration to surface water

To evaluate these pathways, a representative number of surficial soil samples should be obtained from the affected area/exposure unit or domain. These measured concentrations are used to estimate the representative concentration(s) that are used to determine if the cumulative risks are acceptable. Refer to Appendix B for guidance on the methods for estimation of representative surficial soil concentrations.

Although surficial soil is defined as soils extending from the ground surface to one foot bgs, care should be taken not to dilute analytical results by sampling the entire 1-foot interval. In cases where clean fill has been placed on top of contaminated media, the surface soil samples should be collected within the zone of contaminated soils while avoiding collecting samples of the clean fill. In other cases where clean fill may not exist, but only a portion of the one-foot soil column is contaminated, the sampling of surficial soils should occur at the shallowest portion of the top one-foot where contamination is expected at higher concentrations.

Note: For construction workers, "surficial" soil is defined as the excavation depth. Thus, for the construction-worker receptor, the ARBCA Evaluator should define the depth to construction and use the soil concentration data over that depth range as the representative concentrations for the construction worker exposure domain or decision unit.

### 6.4.3 Pathways for Subsurface Soils

Subsurface soils are defined as soils located below one foot and extending to the water table. If an evaluator wishes to define subsurface soils differently, land use controls in accordance with ADEM Admin. Code div. 335-5 will be necessary. When evaluating potential, future, direct contact exposure pathways for a construction and/or commercial worker, subsurface soils may be defined to extend one foot below ground surface to 15 feet below ground surface. Fifteen feet below ground surface is a common nominal maximum depth, plus a safety factor, for construction activities. However, if it is anticipated that future excavation depths could exceed 15 feet below ground surface, the anticipated depth of excavation should be used to evaluate the risk to construction and/or commercial workers. The exposure pathways associated with subsurface soils include the following:

- Indoor inhalation of vapor emissions
- Outdoor inhalation of vapor emissions
- Leaching to groundwater, potential ingestion of groundwater, and migration to surface water
- Future potential ingestion of, inhalation of vapors and particulates from, and dermal contact with soil during excavation activities, as in 6.4.2, above.

To evaluate these pathways, a representative number of subsurface soil samples should be collected in the affected area. Representative subsurface soil concentrations are used to determine if the cumulative risks are acceptable. Refer to Appendix B for guidance on the methods for estimation of representative subsurface soil concentrations.

### 6.4.4 Pathways for Groundwater

Exposure pathways for the impacted groundwater include the following:

- Indoor inhalation of vapor emissions

- Outdoor inhalation of vapor emissions
- Ingestion of water on-site or off-site
- Future ingestion of water (groundwater resource protection)
- Impacts to surface waters (surface water protection)

To evaluate these pathways, representative groundwater samples should be obtained on-site and off-site. Representative groundwater concentrations are used to determine if the cumulative risks are acceptable. Refer to Appendix B for guidance on the methods for estimation of representative groundwater concentrations.

### 6.4.5 Other Pathways

Each of the above exposure pathways listed in Sections 6.4.1 to 6.4.4 must be evaluated as part of the exposure assessment; however, in some cases it may be determined that one or more of these exposure pathways are incomplete and will not be evaluated further.

Other significant exposure pathways, such as human consumption of food crops or fish and shellfish grown in impacted media or use of groundwater for irrigation of food crops for human consumption, should be evaluated if these pathways are complete. Refer to the *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual Part A* (U. S. EPA, 1989) for further guidance on evaluation of risk due to food intake. Additional references are available on the EPA RSL website.

## 6.5 CONCEPTUAL SITE MODEL (CSM)

The information obtained during the site assessment phase as described in Section 5.2 and the AEIRG is used to develop a CSM. The CSM is a general understanding or working hypothesis that depicts the relationship between the chemical source areas (contaminated soils and groundwater, non-aqueous phase liquids, *etc.*), transport mechanisms (leaching, groundwater transport, volatilization, *etc.*), receptors (residents, commercial workers, ecological, surface waters, *etc.*), and exposure routes (inhalation, ingestion, dermal contact, *etc.*). A detailed discussion regarding the CSM may be located in Section 2.4.3 of the ITRC's *Technical and Regulatory Guidance for the Triad Approach* – December 2003. The CSM requires a basic understanding of the following characteristics:

- The physical concentrations and distribution of the COPCs
- The factors affecting chemical transport
- The potential for a COPC to reach a receptor

When conducting the ARBCA Evaluation, a qualitative evaluation must be performed to identify the mechanisms by which COPCs will move from affected source media to the point of exposure (POE) where contact with the receptor occurs. If migration or contact is not possible (e.g., due to engineering controls such as a paved site that will prevent human contact with contaminated soil) under current and most likely future land use conditions, the site-specific COPC concentrations may not pose any risk, and the pathway(s) may be considered incomplete when constructing the site conceptual exposure model after all obligations to ensure the assumptions are met through an environmental covenant entered in the Judge of Probate's Office in accordance with ADEM Admin. Code div. 335-5. The exposure domains (EDs) or decision units (DUs) of all receptors must be considered. The ED or DU is the area over which the receptor may be exposed to the contaminated medium (surficial soil, subsurface soil, groundwater, and soil vapor). This area must be established for the on-site scenario as well as any off-site impacted or potentially impacted properties. Appendix B provides a detailed discussion on developing representative soil and groundwater concentrations, which requires identification of the ED or DU.

A CSM is required for RSL, RM-1, and RM-2 Evaluations. At some sites with multiple off-site properties, multiple CSMs may have to be developed.

Throughout the ARBCA Evaluation process, the CSM should be evaluated and revised to reflect accurate site conditions. Figure 6-1 is a graphical representation that may be used as a worksheet to develop a CSM. Figure 6-1 is a template for the tabular representation of a CSM and should be developed for each receptor for current and most likely future land uses.

The ARBCA Evaluator should clearly document all the source-pathway receptor-route combinations and present clear justification for deciding if the pathway is complete or not complete. There may be multiple CSMs if there are multiple off-site, impacted properties.

## 6.6 POINT OF EXPOSURE (POE)

The POE is the location where a receptor comes in contact with COPCs under current and most likely future use conditions. A separate POE is associated with each complete exposure pathway identified in the CSM (refer to Section 6.5). For direct-exposure pathways, the POE is located at the source of the COPCs. For example, for the ingestion of surface soil, the POE is at the same location as the source. For indirect-exposure pathways, the POE and the source of COPCs are physically separate. For example, for the case of indoor inhalation of vapors from subsurface soil, the POE is inside the building (the breathing space) whereas the source is the soil below the building. Thus, for each complete exposure pathway, the ARBCA Evaluator must identify the source and the POE.

For the Groundwater Resource Protection Evaluation, the groundwater ingestion POE is assumed to be located directly below the source for a RSL Evaluation. For RM-1 and RM-2 Evaluations, the groundwater ingestion POE will be established at the nearest point where a water well currently exists, or is most likely to exist, in the future. If no such wells exist or are unlikely to be installed, then the POE will be at the down-gradient property boundary. With prior Department approval, the POE may be located at an alternate distance from the property boundary if justified based on-site-specific conditions and the appropriate land-use controls are in place. The selected POE should not be a hypothetical or modeled well, but should be an actual well. Groundwater samples should be collected to verify the well concentrations as needed throughout the life of monitoring requirements. In certain case-by-case scenarios, a hypothetical well may be allowed, but Departmental approval would be necessary.

A Sentry Well (SW) is a monitoring well or multiple wells that must be located between the COPC source area and the POE along the flow direction. The SW(s) should also be an actual well and not a hypothetical or modeled well. The SW(s) serves to protect the POE. For RM-1 and RM-2 Evaluations, SW target levels will be developed and compared to the groundwater representative concentrations for that location. For most sites, multiple SWs should be selected for the Groundwater Resource Protection Evaluation. For sites with variable or radial flow, multiple POEs and SWs located along different flow directions may have to be evaluated. Therefore, at most sites, nearly all wells that are not named as source-area wells should be named as SWs.

The distance from the soil source, that is an input to the equations provided in Appendix E to back-calculate allowable soil and groundwater concentrations at the source and at SWs, is the distance from the soil source to the location where the actual groundwater monitoring POE well(s) exists. In most cases, the POE well(s) is located near the property boundary.

## 6.7 CALCULATION OF RISKS AND RISK-BASED TARGET LEVELS (RBTLs)

### 6.7.1 Overview of the Sequence: RSL Evaluation, RM-1 Evaluation, RM-2 Evaluation

Risk-based target levels (RBTLs) should be calculated if site maxima exceed the Regional Screening Levels (RSLs) or the Vapor Intrusion Screening Levels (VISLs) and the RM-1 or the RM-2 cumulative risks are exceeded. Before discussing how the RBTLs are calculated, a brief summary of the risk-assessment process is provided below:

The first step should be to compare site concentrations of all the chemicals of potential concern (COPCs) for the type of product released to the RSLs and VISLs. Any COPCs that exceed RSLs or VISLs go forward into an RM-1 Evaluation as "chemicals of concern" (COCs). If the site exceeds the RM-1 risks, all the RM-1 COCs should move forward into the RM-2 Evaluation. As a point of clarification, once the screening step has been completed and the COCs determined, that list of contaminants should remain without having additional contaminants dropped from the list.

The first step in both an RM-1 Evaluation and an RM-2 Evaluation is to compute the cumulative risk and the hazard index for each receptor. Evaluating one receptor at a time, one adds up the risks from all the carcinogenic COCs for every one of that receptor's complete pathways. This yields one cumulative risk for that receptor. Similarly, for all the non-carcinogenic COCs, one adds up the hazard quotients for each of that receptor's complete pathways. When added up, hazard quotients (HQs) become the hazard index (HI), which is the sum of the HQs. Following the completion of this exercise there should be a cumulative risk and an HI for each receptor. The cumulative risk should not exceed $1\times10^{-5}$, and the hazard index should not exceed 1.0. In an RM-1 Evaluation, if any receptor's cumulative risk exceeds $1\times10^{-5}$, or their hazard index exceeds 1.0, one can either develop RBTLs and clean up the site to those levels, or proceed to an RM-2 Evaluation.

In an RM-2 Evaluation, the cumulative risks and HIs need to be recomputed using site-specific, fate and transport properties. This yields a different calculation from those obtained in the RM-1 Evaluation. In the RM-2 Evaluation, if any receptor's cumulative risk or HI exceeds the limits of $1\times10^{-5}$ for the cumulative risk and 1.0 for the HI, then one must develop RBTLs using site-specific fate-and-transport properties. These RBTLs will be different from the RBTLs obtained in the RM-1 Evaluation.

### 6.7.2 Calculation of Risk-Based Target Levels (RBTLs)

RBTLs are the allowable concentrations calculated using the back-calculation mode. Cumulative risks are calculated utilizing the forward-calculation mode. Appendix E presents the equations and models used in the ARBCA evaluations in backward mode which is used to calculate risk-based target concentrations. The same models and equations are shown in forward mode in Appendix F which is used to calculate risks. These procedures require quantitative values of (i) target-risk levels, (ii) chemical-specific toxicity values, (iii) physical properties of the COCs, (iv) receptor-specific exposure factors, (v) fate and transport parameters, (vi) building parameters, and (vii) uptake equations/fate-and-transport models. Each of these factors is discussed below.

For an RSL Evaluation, RSLs and VISLs have been compiled by the USEPA for each of the COPCs for the commonly encountered, complete, exposure pathways. The RSLs are typically updated on a semi-annual basis.

The ARBCA Evaluator will calculate the target levels using site-specific data and pathway-specific models. RM-1 target levels should be developed utilizing the equations/models provided in Appendix E, the RSL toxicity parameters, the RSL chemical-specific parameters, the RSL User's Guide Table 1 default exposure factors and fate and transport parameters, and appropriate site-specific data. For an RM-2 Evaluation, the equations/models provided in Appendix E, the RSL chemical-specific and toxicity parameters, the standard default exposure factors and the fate and transport parameters factors listed in Table 1 of the RSL User's Guide, and appropriate site-specific data should be used unless alternate models are approved by the Department.

If the calculated, cumulative risks exceed the target risks for a receptor, the ARBCA Evaluator must calculate cleanup levels or risk-based target levels (RBTLs). There are many different combinations of cleanup levels that can ensure that the cumulative risk for a receptor does not exceed $1x10^{-5}$ for carcinogenic health effects and 1.0 for non-carcinogenic health effects. Three methods are discussed for carcinogenic health effects next.

Method 1 - Reduce each risk from each COC by the same amount

One way to calculate RBTLs is to simply take the representative concentration (for each COC, for each complete pathway, for each receptor) and divide it by an across-the-board factor that will result in a cumulative risk for the receptor being reduced down to $1x10^{-5}$. One may easily see the factor that will make the cumulative risk for the receptor be $1x10^{-5}$ by looking at the cumulative risk for the receptor. For example, if the cumulative risk for the receptor is $3.36x10^{-5}$, the factor by which to divide each representative concentration is 3.36. This is because, if the cumulative risk exceeds the target risk of $1x10^{-5}$ by a factor of 3.36, dividing each representative concentration by 3.36 will reduce the cumulative risk down to $1x10^{-5}$. Tip: Write the cumulative risk as a multiple of $10^{-5}$ in order to see the divider.

### Method 2 - Divide the target risk for each COC into as many COC-pathway combinations as there are for the receptor

Another way of computing RBTLs is to take the $1x10^{-5}$ total allowable risk per receptor and divide it up equally into the number COC and complete pathway combinations for the receptor. When counting the number of COC and complete pathway combinations, only count the COCs that have the relevant toxicological parameters available to compute their risk. For example, if the COCs are BTEX, MtBE, and naphthalene, and the four complete pathways are indoor and outdoor inhalation from soil and from groundwater, then, for carcinogenic risk, the number of COC and complete pathway combinations is 16, because only benzene, ethylbenzene, MtBE, and naphthalene have an inhalation unit risk. Therefore, the target risk for each COC and complete pathway combination is $0.0625 \times 10^{-5}$. The ARBCA Evaluator should use this target risk in the appropriate equations to compute RBTLs.

### Method 3 - Ratio method

Another way of computing RBTLs is to look at some proportions and set up an equation that can be solved for the RBTL (Alaska DEC, 2008). For computing the risk and RBTLs from the representative concentration for *one* COC and complete pathway combination, there are two equivalent ratios that can be solved for the RBTL for the COC:

$$\frac{\text{RBTL}_{\mathbf{coc}}}{\text{Target risk}} = \frac{\text{Representative concentration}_{\mathbf{coc}}}{\text{Calculated risk}_{\mathbf{coc}}}$$

$$\text{RBTL}_{\mathbf{coc}} = \frac{\text{Representative concentration}_{\mathbf{coc}} \times \text{Target risk}}{\text{Calculated risk}_{\mathbf{coc}}}$$

Since the cumulative risk of all COC and complete pathway combinations needs to be kept to less than $1x10^{-5}$, each individual target risk is going to be $1x10^{-5}$ divided by the number of COC and complete pathway combinations. Call the latter the "number of risks" and adjust the previous equation to show the reduced target risk.

$$\text{RBTL}_{\mathbf{coc}} = \frac{\text{Representative concentration}_{\mathbf{coc}} \times \text{Target risk}}{\text{Calculated risk}_{\mathbf{coc}} \times \text{Number of risks}}$$

This equation can be used to compute RBTLs that will satisfy the criterion that the cumulative risk will equal $1 \times 10^{-5}$.

The above methods can also be applied for non-carcinogenic health effects.

#### 6.7.2.1 Target Risk Level

A risk-based decision making process requires the specification of a target or acceptable risk level for both carcinogenic and non-carcinogenic, adverse, health effects.

For carcinogenic effects, risk is quantified using the Individual Excess Lifetime Cancer Risk (IELCR, RAGS, vol. 1, Part B, page 21) that represents an increase in the probability of an individual developing cancer due to exposure to a COC through a complete exposure pathway. Since a receptor may be exposed to multiple COCs and exposure pathways, the acceptable risk level should account for the effect of simultaneous exposure to multiple COCs and exposure pathways. The IELCR level used to calculate RSLs is $1\times10^{-6}$, while the IELCR level used in the calculation of the RM-1 and RM-2 target levels is $1\times10^{-5}$.

For non-carcinogenic effects, risk is quantified using a Hazard Quotient (HQ) that represents the ratio of the estimated dose for a chemical and an exposure pathway to the reference dose. When a receptor is exposed to multiple COCs and multiple exposure pathways, individual HQs may be added together to estimate the Hazard Index (HI). The HI is the sum of individual HQs. An HQ of 0.1 should be selected when viewing the RSL table while an HI of 1.0 should be used in the calculation of RM-1 and RM-2 target levels.

The target risk levels (IELCR and HQ and/or HI) may be used in one of two ways. First, the representative concentrations may be used to calculate the site-specific cumulative risks that are then compared with the target risk levels. If the cumulative risks (sum of risks for each COC and each complete exposure pathway for an individual receptor) exceed the target risk levels, risk management may be necessary. Risk management may include active remediation, remediation by monitored natural attenuation (MNA), institutional controls, or a combination. Groundwater COCs must be included within the cumulative risk calculation even if the established MCL is not exceeded. Ingestion of groundwater must be considered, and, when groundwater ingestion is a complete pathway, all COCs must be included in the cumulative risk evaluation. (Note: Not all MCLs are based on the same target risk level. Sites will not have to be remediated below the MCLs, but the target, cumulative-risk levels must be met when there are contaminants that do not have an established MCL). Following a cumulative risk evaluation where it is determined that the acceptable risks have been exceeded, target risk levels may be used to back calculate the target cleanup concentrations (RBTLs) for each chemical, each complete exposure pathway, each medium, and each receptor. The target concentrations are then used as a guide during risk management and/or remediation activities and compared with the representative concentration(s) (see Appendix B). Once it appears that the target concentrations have been met, the cumulative risks at the site should be re-evaluated to ensure that the target risk levels have been met.

For non-carcinogenic effects for the RSLs, a HQ of 0.1 should be used (Note: There is an option to select an HQ = 1.0. This option is not allowed for use in the State of Alabama). Since the additive effects of multiple chemicals and multiple exposure pathways must be considered for RM-1 and RM-2 Evaluations, an HI of less than or equal to 1.0 must be used in RM-1 and RM-2. When determining the additive effects of multiple chemicals and multiple exposure pathways, ingestion of groundwater must be considered, and all COCs must be included within the cumulative risk evaluation.

For the RM-1 and the RM-2 Evaluations, the cumulative IELCR at a site (the sum of the IELCR for each COC and each complete exposure pathway, for a receptor) less than or equal to $1\times10^{-5}$, and the cumulative HI at a site (the sum of HQs for each COC and each exposure pathway, for a receptor) less than or equal to 1.0 are required. A cumulative risk evaluation should be calculated using representative concentrations for each COC as described in Appendix B. To calculate the cumulative risk for an area of contamination, the forward calculation method must be used. The forward calculation method calculates risk from representative concentrations and receptor specific input parameters.

For evaluating whether or not a water supply well or spring poses an unacceptable risk, the foregoing target risk and hazard quotient values are not required. Instead, the chemical specific concentrations at the water supply well or spring should not exceed the MCLs, health advisories or the calculated target levels for direct ingestion of groundwater in accordance with the equations located in Appendix E or other appropriate models. The COC concentrations in the water supply well or spring can be determined either by site-specific sampling or by using a fate and transport model. Appendix E contains equations needed for the Domenico Model, which is based on laminar flow in a homogeneous geologic environment. For sites in unique geological environments not suited for the Domenico Model (such as karst or fractured flow regimes), another more appropriate model or modeling pack should be applied. It may be necessary to validate a model through the use of historical concentrations and potentiometric data to demonstrate that the model can approximate down gradient concentrations at a site. Modeled concentrations at the POE, Sentry Well (SW), and source area locations may need to be verified using actual data. Additional monitoring or corrective action may be required if the concentrations exceed the groundwater-ingestion target levels at the POE or values protective of the POE at the SW.

Similarly, for impacts to surface water bodies the above target risks do not apply. The target surface water concentrations should utilize the target-risk levels determined and developed by the ADEM Water Division in accordance with the Water Quality Criteria established in ADEM Admin. Code ch. 335-6-10. The appropriate use classification should be used (*i.e.*, Public Water Supply streams (consumption of water and fish) or Fish and Wildlife streams (consumption of fish only)).

### 6.7.2.2 Quantitative Toxicity Factors

The toxicity of chemicals is quantified using an oral slope factor ($SF_o$), an inhalation unit risk (IUR), and a dermal slope factor ($SF_{ABS}$) for chemicals with carcinogenic adverse health effects. For chemicals that cause non-carcinogenic adverse health effects, toxicity is typically quantified by oral reference dose ($RfD_o$), reference concentration (RfC), and a dermal reference dose ($RfD_{ABS}$). The most current toxicity values recommended by EPA must be used for ARBCA Evaluations. For COCs that may not have a value in the sources listed below, please contact the Department. Alternative values must be approved by the Department. The RSL Generic Tables list toxicity values. In absence of a toxicity value in the RSLs, the following hierarchy of sources should be used.

- Integrated Risk Information System (IRIS)
- National Center for Environmental Assessment (NCEA)
- EPA Region 4 Recommendations and various Memorandums

- Health Effects Assessment Summary Tables (HEAST)
- Agency for Toxic Substance and Disease Registry (ATSDR)
- California EPA
- Center for Environmental and Human Toxicology (CEHT), University of Florida
- Review of literature by qualified professionals to develop toxicity factors

Dermal slope factor and reference dose ($SF_{ABS}$ and $RfD_{ABS}$) may be converted from oral slope factor and oral reference dose using the following formula:

$$SF_{ABS} = SF_o / ABS_{GI}$$

$$RfD_{ABS} = RfD_o \times ABS_{GI}$$

where $ABS_{GI}$ is the gastrointestinal absorption factor and represents the bioavailability of the chemical following exposure through the oral route (U.S. EPA, 2004, RAGS E, equations 4.2 and 4.3).

### 6.7.2.3 Physical Properties of the COPCs

To calculate the risks and develop the target levels, the ARBCA Evaluation requires selected physical properties of the COCs. The values of these parameters are listed in the Chemical Specific Parameters Table located in the RSL Generic Tables. Since several of these values are experimentally determined, their values may differ from some references. The Department requires the use of physical values tabulated in the RSL Generic Tables and User's Guide for all ARBCA Evaluations. If the use of alternate values is necessary, the site owner/operator must provide sufficient justification to the Department to utilize a different value. The use of different values would be allowed only under an RM-2 Evaluation. The proposal to use the different values should be submitted in the RM-2 work plan prior to the use of the values in the evaluation.

### 6.7.2.4 Exposure Factors

Exposure factors describe the physiological and behavioral characteristics of the receptor. These factors include the following:

- Water ingestion rate
- Body weight
- Exposure duration
- Exposure frequency
- Soil ingestion rate
- Exposure times for indoor/outdoor inhalation
- Skin-surface area for dermal contact with soil

- Soil-skin adherence factor

A list of the exposure factors that should be used to calculate the RM-1 and RM-2 levels is presented in *Table 1 of the RSL User's Guide* and the *USEPA Exposure Factors Handbook: 2011 Edition*. The exposure factors are typically estimated based on literature, and site-specific measurements are not obtained. With prior approval of the Department, for an RM-2 Evaluation, site-specific values of the exposure factors may be used provided they can be adequately justified.

### 6.7.2.5 Fate and Transport Parameters

Fate and transport parameters are necessary to estimate the risks and target concentrations for the indirect-exposure pathways. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For an RM-1 Evaluation, the Department has selected typical and conservative values for all of the parameters that are presented in *Table 1 of the RSL User's Guide*. For an RM-2 Evaluation, a combination of site-specific and RM-1 values for these parameters may be used. However, the value of each parameter used, whether site- pecific or not, must be justified based on-site-specific conditions. Where site-specific conditions are significantly different from the RM-1 assumptions, an RM-2 Evaluation should be performed.

#### 6.7.2.5.1 Soil Parameters

A brief discussion of the soil parameters is presented below:

- $W_a$ - Length of Soil Source Area Parallel to Wind (cm)

  RM-1 assumes a length of 1500 cm, 4498 cm, or 6362 cm (small, medium, or large source, respectively) (the default value of $W_a$). The typical UST site will utilize the 1500-cm length in an RM-1 Evaluation.

  RM-2 allows for direct measurement of the $W_a$. This is rarely directly measured because wind direction is variable and the exact dimensions of the soil source may not be known. Therefore, $W_a$ is usually set equal to length of groundwater source parallel to groundwater flow direction (W), see section 6.7.2.5.2.

- $L_s$ - Depth to Subsurface Soil Sources (cm)

  RM-1 assumes 30.48 cm, which by definition is the shallowest possible $L_s$.

  RM-2 allows for the actual measured depth of contaminated soils. This may be the shallowest-detected contamination or an average depth of the shallowest-detected contamination from several borings.

- d - Lower Depth of Surficial Soil Zone (cm)

  RM-1 assumes 30.48 cm, which is the lower bound of the surficial soil zone.

RM-2 must also use 30.48 cm due to the definition of the surficial soil zone.

- $d_{\mathbf{sv}}$ – Depth to Soil-Vapor Measurement (cm)

  RM-1 assumes 30.48 cm, which is the depth to the soil-vapor sample.

  RM-2 allows for the actual depth of the soil-vapor sample measured.

- $h_{\mathbf{cap}}$ - Thickness of Capillary Fringe (cm)

  RM-1 assumes a thickness of 100 cm.

  RM-2 $h_{\mathbf{cap}}$ should be a thickness representative of the site soils/sediments and is based on soil grain size. Typically, $h_{\mathbf{cap}}$ should be based on literature values since direct measurement is not practical. Note that $h_{\mathbf{cap}}$ and thickness of the vadose zone ($h_{\mathbf{v}}$), when added together, should equal depth to groundwater, $h_{\mathbf{cap}} + h_{\mathbf{v}} = L_{\mathbf{gw}}$.

- $h_{\mathbf{v}}$ -Thickness of Vadose Zone (cm)

  RM-1 assumes the $h_{\mathbf{v}}$ is 200 cm.

  RM-2 $h_{\mathbf{v}}$ is calculated by subtracting the $h_{\mathbf{cap}}$ from the $L_{\mathbf{gw}}$. $h_{\mathbf{cap}} + h_{\mathbf{v}} = L_{\mathbf{gw}}$.

- $\rho_{\mathbf{s}}$ – Vadose Zone Dry Soil Bulk Density (g/cm$^3$)

  RM-1 assumes 1.5 g/cm$^3$ dry soil bulk density for the vadose zone.

  RM-2 allows for a direct measurement of $\rho_{\mathbf{s}}$. See Section 5.10 for a discussion related to the determination of soil bulk density. If multiple measurements from the vadose zone are available, use the average value.

- $f_{\mathbf{ocv}}$ - Fractional Organic Carbon Content in the Vadose Zone (g-c/g-soil)

  RM-1 assumes $f_{\mathbf{ocv}}$ is 0.002 g-C/g-soil.

  RM-2 allows for direct measurement of $f_{\mathbf{ocv}}$. See Section 5.10 for a discussion of proper determinative methods. If measurements of fractional organic matter (not the same as fractional organic carbon) are available, the value should be corrected as discussed in Section 5.10. If multiple values are available, the average values may be used.

- $\theta_{\mathbf{T}}$ - Total Porosity in the Vadose Zone (cm$^3$/cm$^3$ – soil)

  RM-1 assumes a $\theta_{\mathbf{T}}$ of 0.43 cm$^3$/cm$^3$.

RM-2 allows for determination of $\theta_{\mathbf{T}}$. In RM-1, the assumption is made that the total porosity is the same in the vadose zone, capillary fringe, and the soil that fills the foundation or wall cracks. In RM-2, there is now a provision to vary the porosity in the capillary fringe and in the soil that fills foundation or wall cracks. See $\theta_{\mathrm{T\ CAP}}$ and $\theta_{\mathrm{T\ CRACK}}$ below. See Section 5.10 for a discussion of proper determinative methods.

- $\theta_{\mathbf{ws}}$ - Volumetric Water Content in Vadose Zone ($cm^3/cm^3$)

RM-1 assumes $\theta_{\mathbf{ws}}$ is 0.143 $cm^3/cm^3$.

RM-2 $\theta_{\mathbf{ws}}$ values are typically measured as noted in Section 5.10. When using a site-specific value, the value is measured on a weight basis (gravimetric, grams of water/grams of dry soil) and must be converted to a volumetric value ($cm^3$ of water/$cm^3$ of soil) as discussed in Section 5.10. Note that $\theta_{\mathbf{as}} + \theta_{\mathbf{ws}} = \theta_{\mathbf{T}}$.

- $\theta_{\mathbf{as}}$ - Volumetric Air Content in Vadose Zone ($cm^3/cm^3$)

RM-1 assumes $\theta_{\mathbf{as}}$ value is 0.287 $cm^3/cm^3$.

RM-2 allows for a calculated $\theta_{\mathbf{as}}$ to be utilized. The Evaluator must determine what the total soil porosity in the vadose zone is, subtract the volumetric water content, and the remainder is the volumetric air content. Therefore, $\theta_{\mathbf{as}} = \theta_{\mathbf{T}} - \theta_{\mathbf{ws}}$

- $\theta_{\mathbf{Tcap}}$ - Total Porosity in the Capillary Fringe ($cm^3/cm^3$ soil)

RM-1 assumes a $\theta_{\mathbf{Tcap}}$ of 0.43 $cm^3/cm^3$.

RM-2 allows for determination of $\theta_{\mathbf{Tcap}}$. In RM-1, the assumption is made that the $\theta_{\mathbf{Tcap}}$ is the same in the vadose zone, capillary fringe, and the soil that fills the foundation or wall cracks. In RM-2, the porosity in the capillary fringe can be site-specific. Total soil porosity in the capillary fringe is typically assumed to be equal to the total vadose zone porosity unless site-specific data is available.

- $\theta_{\mathbf{wcap}}$ - Volumetric Water Content in Capillary Fringe ($cm^3/cm^3$)

RM-1 assumes $\theta_{\mathbf{wcap}}$ is 90% of total porosity in the capillary fringe, *i.e.*, 0.387 $cm^3/cm^3$ from multiplying 0.43 times 0.9. The sum of the air content and the water content in the capillary fringe would equal the total porosity in the capillary fringe, $\theta_{\mathbf{wcap}} + \theta_{\mathbf{acap}} = \theta_{\mathbf{Tcap}}$.

RM-2 allows for a site-specific $\theta_{\mathbf{wcap}}$ value. The value is typically derived by taking 90% of the total site-specific soil porosity in the capillary fringe. Total soil porosity in the capillary fringe is typically assumed to be equal to the total vadose zone porosity unless site-specific data is available.

- $\theta_{\mathbf{acap}}$ **-** Volumetric Air Content in Capillary Fringe ($cm^3/cm^3$)

  RM-1 assumes that the $\theta_{\mathbf{acap}}$ is 10% of the total porosity in the vadose zone. Since the assumed $\theta_{\mathbf{T}}$ is 0.43 $cm^3/cm^3$, the volumetric air content is 0.043 $cm^3/cm^3$.

  RM-2 assumes that the $\theta_{\mathbf{acap}}$ is 10% of the total porosity in the vadose zone. Therefore, $\theta_{\mathbf{acap}} + \theta_{\mathbf{wcap}} = \theta_{\mathbf{T}}$.

- $\theta_{\mathbf{Tcrack}}$ – Total Porosity in The Soil in The Foundation or Wall Cracks ($cm^3/cm^3$ soil)

  $\theta_{\mathbf{Tcrack}}$ is the total porosity in the soil in the foundation or wall cracks. Typically, it would be set equal to the vadose zone soil porosity in both RM-1 and RM-2 Evaluations; however, if site-specific data is available, it can be used in RM-2.

- $\theta_{\mathbf{wcrack}}$ - Volumetric Water Content in the Foundation or Wall Cracks ($cm^3/cm^3$)

  RM-1 assumes $\theta_{\mathbf{wcrack}}$ is equal to the volumetric water content in the soil in the vadose zone. The RM-1 value is 0.143 $cm^3/cm^3$. The sum of the air content in the foundation or wall cracks ($\theta_{\mathbf{acrack}}$) and the $\theta_{\mathbf{wcrack}}$ should equal total crack-soil porosity ($\theta_{\mathbf{Tcrack}}$), $\theta_{\mathbf{wcrack}} + \theta_{\mathbf{acrack}} = \theta_{\mathbf{Tcrack}}$.

  RM-2 also typically assumes that the $\theta_{\mathbf{wcrack}}$ is the same as the volumetric water content in the soil in the vadose zone. A site-specific value can, however, be used.

- $\theta_{\mathbf{acrack}}$ - Volumetric air content in foundation wall/cracks ($cm^3/cm^3$)

  RM-1 assumes that the volumetric air content in the soil that fills the foundation wall or cracks is the same as in the soil in the vadose zone. The value is 0.287 $cm^3/cm^3$.

  RM-2 allows for a site-specific $\theta_{\mathbf{acrack}}$ to be derived. However, the value is typically the same as the volumetric air content in the soil in the vadose zone. $\theta_{\mathbf{acrack}} + \theta_{\mathbf{wcrack}} = \theta_{\mathbf{Tcrack}}$.

#### 6.7.2.5.2 Groundwater Parameters

A brief discussion of the groundwater parameters is presented below:

- $L_{\mathbf{gw}}$ - Depth to Groundwater (cm)

  RM-1 assumes $L_{\mathbf{gw}}$ is 300 cm, or approximately 10 feet.

  When the $L_{\mathbf{gw}}$ is significantly less than 10 feet, an RM-2 Evaluation should be performed using site-specific $L_{\mathbf{gw}}$ and other fate-and-transport parameters even if RM-1 risks and target concentrations are not exceeded. Where the $L_{gw}$ as measured in monitoring wells fluctuates, the recent- average depth to groundwater should be used in the ARBCA Evaluations. This recent average depth should be calculated from the last 1 – 2 years of data. For consistency, static water levels should be utilized unless appropriate support for use of the "first water encountered while drilling" can be provided. The site-specific average depth to groundwater should be calculated by determining the average depth to groundwater in each well and then averaging the single well averages. Where significant differences in static water levels occur across the site, the shallowest average depth to groundwater should be utilized. The shallowest average depth to groundwater should be calculated by determining the average depth to groundwater in a few wells with the shallowest static water levels and then averaging the single well averages.

- Y - Width of Groundwater Source Area Perpendicular to Groundwater Flow Direction (cm)

  RM-1 assumes that Y is 1500 cm, 4498 cm, or 6362 cm (small, medium, and large sources, respectively). The typical UST site will utilize the 1500-cm width in an RM-1 Evaluation. Other sites in other programs may meet or exceed that value – the value used should have a basis.

  RM-2 allows for the site-specific Y to be measured. In both RM-1 and RM-2, it is assumed that Y is identical to the soil source area and is located directly below the soil source area. The soil source area is determined by evaluating the available soil data located in the source area which is located in close proximity to the origin of the release (tanks, dispensers, piping). This requires the ARBCA Evaluator to reconcile the soil boring data with the point of origin of the release. Be sure to include a site map, which shows Y, W, and $W_a$.

  For example, the ARBCA Evaluator may draw a boundary that encloses the area around the tanks, piping, and/or dispensers from where the release originated. Then, the ARBCA Evaluator should validate this selected source area by comparing the available soil-boring data to the selected source area. The Evaluator should then adjust the size of the source area if appropriate.

  The ARBCA Report should include the location of the tanks, piping, dispensers, wells, and borings to justify the selection of the source area.

- W - Length of Groundwater Source Area Parallel to Groundwater Flow Direction (cm)

  RM-1 assumes that W is 1500 cm or 6362 cm (small or large sources, respectively).
  The typical UST site will utilize the 1500-cm length in an RM-1 Evaluation.

  RM-2 allows for the site-specific W to be measured. In both RM-1 and RM-2, it is assumed that the groundwater source area is identical to the soil-source area and is located directly below the soil source area. The soil source area is determined in the same manner as discussed for parameter "Y".

  The ARBCA Report should include a map with the source area delineated, as well as the location of the tanks, piping, dispensers, wells, and borings to justify the selection of the source area. The lengths W, Y, and $W_a$ should be drawn on the map in the report.

- $\theta_{\mathbf{TS}}$ - Total Porosity in the Saturated Zone

  RM-1 assumes that $\theta_{\mathbf{TS}}$ is 0.43 $cm^3/cm^3$. This is the same value assumed for $\theta_{\mathbf{T}}$.

  RM-2 allows for a site-specific $\theta_{\mathbf{TS}}$ value to be utilized. In most cases, this value will be the same as the $\theta_{\mathbf{T}}$. Both a $\theta_{\mathbf{T}}$ and a $\theta_{\mathbf{TS}}$ should be collected when it appears that the properties of the two zones may substantially differ at a site. An estimate of the $\theta_{\mathbf{TS}}$ is needed when biodecay is used in the Groundwater Resource Protection Evaluation or the Surface Water Protection Evaluation.

- $\rho_{\mathbf{ss}}$ – Saturated Zone Dry Soil Bulk Density ($g/cm^3$)

  RM-1 assumes 1.5 $g/cm^3$.

  RM-2 allows for a direct measurement of $\rho_{\mathbf{ss}}$. In most cases, this value will be the same as the vadose-zone dry soil bulk density. Both a $\rho_{\mathbf{s}}$ and a $\rho_{\mathbf{ss}}$ should be collected when it appears that these two zones may differ at a site.

- $f_{\mathbf{ocs}}$ - Fractional Organic Carbon Content in the Saturated Zone (g-C/g-soil)

  RM-1 assumes $foc_s$ is 0.002 g-C/g-soil

  RM-2 allows for direct measurement of $foc_s$ in the saturated zone. In the absence of a measured value, use the value in the unsaturated zone. Both a $f_{\mathbf{ocv}}$ and a $f_{\mathbf{ocs}}$ should be collected when it appears that these two zones may differ at a site. See Section 5.10 for a discussion of proper determinative methods. If fractional organic matter is measured, it should be corrected to estimate $foc_s$ as discussed in Section 5.10.

- $\delta_{\mathbf{gw}}$ - Groundwater Mixing-Zone Thickness (cm)

  RM-1 assumes a thickness of 200 cm, which is derived from the saturated length of a 10-foot well screen.

  RM-2 allows for a site-specific value to be utilized. The 200-cm value should be considered a minimum. An equation to calculate $\delta_{\mathbf{gw}}$ is located in the EPA Soil Screening Guidance (1996, page 45, equation 45). Other procedures for determining $\delta_{\mathbf{gw}}$ may be utilized if approved by the Department.

- K - Hydraulic Conductivity in the Saturated Zone (cm/year)

  RM-2 allows for a site-specific value to be used. Literature values may be used if the reference is acceptable to the Department. Site-specific measurements may also be used as discussed in Section 5.10. Typically, an average of the measured values may be used.

- i - Hydraulic Gradient in the Saturated Zone

  RM-2 allows for a site-specific value to be used. Site-specific measurements must be obtained. An average gradient over the last 1 – 2 years should be determined for use in the ARBCA Evaluation. Tables and calculations documenting the site-representative gradient should be included in the ARBCA report. This can be included with Attachment 9. At sites where the groundwater flow direction shows marked variations, the hydraulic gradient and hence $U_{gw}$ (see below) may have to be estimated in more than one direction.

- $U_{gw}$ - Groundwater Darcy Velocity (cm/yr)

  RM-1 assumes a $U_{gw}$ of 157.68 cm/yr

  In RM-1, $U_{gw}$ is used to estimate the mean-field mixing dilution attenuation factor using the Summer's model. The RM-1 default value is 157.68 cm/yr.

  In RM-2, a site-specific value of $U_{gw}$ has to be used. This value is calculated as the product of saturated-zone hydraulic conductivity and hydraulic gradient.

- I - Infiltration Rate (cm/year)

  RM-1 assumes 14.46 cm/yr

  RM-2 allows a site-specific or regional-specific value. The value is obtained from regional data. I is obtained by taking 10% of the annual rainfall. Average annual rainfall values are based on a 30-year average. These normal values are updated every 10 years. Sources of rainfall/climatic data include the Alabama State Climatology Office, the Southeast Regional Climate Center, and the National Climatic Data Center. An ARBCA Evaluator may also use another rainfall reference provided it is approved by the Department.

#### 6.7.2.5.3 Other Fate and Transport Parameters

Additional parameters are needed to estimate the risks and target levels for the indirect exposure pathways. Of these parameters, distance to the POE and distance to a Sentry Well (SW) have been discussed in other sections of this guidance document. A brief discussion of other fate and transport parameters is presented below:

- $\delta_a$ – Breathing-Zone Height (cm)

  RM-1 assumes 200 cm.

  RM-2 must also use 200 cm.

- $U_a$ – Wind Speed within the Breathing Zone (m/s)

  RM-1 assumes 4.69 m/s.

  RM-2 allows a site-specific or regional-specific value.

- $K_f$ – Andelman Volatilization Factor for Domestic Water Use (L/$m^3$)

  RM-1 assumes 0.5 L/$m^3$.

  RM-2 must also use 0.5 L/$m^3$.

- Q/C – Inverse of Mean Concentration at Center of Square Source (g/$m^2$-s)/(kg/$m^3$)

  RM-1 assumes 81.05 (g/$m^2$-s)/(kg/$m^3$). The basis for this value comes from using the Atlanta, GA Meteorological Station where A Constant = 14.8349, B Constant = 17.9259, C Constant = 204.1516 and $A_{site}$ = 0.5 acres.

  RM-2 allows a site-specific value. This value can be calculated based on site area using the equation and inputs shown in Equation D-1 of the *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites* U. S. EPA (2002).

- V – Fraction of Vegetative Cover ($m^2$/$m^2$)

  RM-1 assumes 0.5 ($m^2$/$m^2$).

  RM-2 allows a site-specific value.

- $U_t$ – Equivalent Threshold Value of Wind Speed at 7 meters (m/s)

  RM-1 assumes 11.32 m/s.

  RM-2 must also use 11.32 m/s.

- F(x) – Wind-Speed Distribution Function from Cowherd and Others, (1985)

  RM-1 assumes 0.194.

  RM-2 must also use 0.194.

### 6.7.2.6 Equations and Models

Two types of equations or models, namely (i) the uptake equations and (ii) the fate and transport models, are required to calculate the risks and the target levels. For RM-1 and RM-2 Evaluations, the Department has selected the equations and models presented in Appendix E in backward mode and in Appendix F in forward mode. These equations and models can be used to calculate the risks and develop the RM-1 and RM-2 target levels. Please contact the Department for known vendors of privately available computational software that utilizes the ARBCA models and produces the output needed to complete an ARBCA risk assessment. Other software may be used, but must be accepted by the Department before the ARBCA Evaluation is conducted. Ultimately, it is the facility's responsibility to ensure that an accurate assessment is conducted and that there should not be full reliance on any software used. Alternate models may be used for an RM-2 Evaluation with the prior approval of the Department through the submittal of an RM-2 work plan. The ARBCA Evaluator should contact the Department to establish if a work plan is required. In some cases, the models (e.g., Domenico Model) presented in Appendix E may not be suitable for use at a site. The ARBCA Evaluator should exercise caution to ensure that the models being applied are appropriate for existing site conditions.

## 6.8 PROTECTION OF DEEPER GROUNDWATER

While performing ARBCA Evaluations the potential impacts to deeper aquifers must be evaluated. In some cases, a qualitative evaluation based on the vertical flow gradients may be sufficient. However, in other cases a quantitative evaluation of potential vertical migration of COCs may be necessary. Monitoring wells nested and set at different depths may need to be installed into the deeper aquifer. Several deeper wells may need to be installed, and may need to be installed as Type III double or multiple cased monitoring wells constructed in accordance with Section B.3.3 of the AEIRG. Due to the site-specific nature of the hydrogeology it may be necessary to submit a work plan indicating how the evaluation of the deeper aquifer will be conducted.

## 6.9 GROUNDWATER RESOURCE PROTECTION

The use of groundwater as a current and a potential future drinking water supply is the basis of the groundwater resource protection component of the ARBCA Evaluation. At sites where there are currently water supply wells located off-site, a determination of allowable soil and groundwater COC levels must be made to protect the water supply well. At sites where there are no water supply wells present, the remedial measures for soil and groundwater are required to be protective of the groundwater resource for likely future use. The Department is requires that releases be evaluated to protect the groundwater resource for future use. These two scenarios are described below:

- For situations where there is a water supply well(s) (active or inactive) within 500 feet of the site, the Groundwater Resource Protection Evaluation allows for the determination of allowable soil concentrations that will protect the groundwater at the POE which should be located on the facility's property in the direction of groundwater flow. An evaluation of the groundwater concentrations at the source of the release and at Sentry Wells (SWs) to determine what groundwater COC concentrations are acceptable for protection of the water supply well is also required. Upgradient water supply wells should also be evaluated and named in the case that groundwater flow direction changes in the future.

- For sites where there are no current water supply wells (active or inactive), a POE must be established at the downgradient property boundary. The POE must not be a hypothetical well.

This evaluation requires the selection of a well(s) in the source area for comparison to the target levels. The equations for computing the allowable amount of a chemical in a source well and for computing the dilution-attenuation factor are located in Appendix E. In addition to a source sentry well, additional SWs located between the source area and the POE must be selected. In most cases, there will be multiple source-area wells and nearly all other wells will be designated as SWs. The COC concentrations in these selected SWs are compared to the calculated allowable groundwater concentrations at a SW. The equation for computing the allowable amount of a chemical in a SW appears in Appendix E. Additionally, the Department will require that concentrations in the SW show a definite decreasing trend. These conditions will ensure that, in time, the contaminated groundwater would be restored to its appropriate state.

An allowable soil concentration in the source area must be calculated which will not allow groundwater at the POE to exceed the MCL or other acceptable target level. The equation for computing the allowable amount of a chemical in source soil appears in Appendix E.

For RM-1 calculations, the distances to the SWs and POE are site-specific input values. Fate-and-transport parameters utilize the RM-1 values in located in the RSL User's Guide. The use of biodegradation is not allowed under RM-1.

For RM-2 calculations, the appropriate distances to the SWs and POE are input as site-specific values. Site-specific fate and transport parameters also should be utilized. The use of biodegradation is allowed under RM-2, but must be clearly justified. Refer to Appendix G for calculating the site-specific biodegradation rate for petroleum contaminants.

See Appendix B for a detailed discussion of the proper selection of representative concentrations. Alternatively, instead of using the Domenico model in Appendix E to back calculate the soil concentrations at the source that are protective of the point of exposure via leaching to groundwater, the ARBCA Evaluator can utilize the Synthetic Precipitate Leaching Procedure (SPLP) EPA Method 1312, or the Toxicity Characteristic Leaching Procedure (TCLP) EPA Method 1311. In these procedures, the resulting "leached" material should be compared with a level protective of the ingestion of groundwater.

## 6.10 SURFACE WATER PROTECTION

Potential impacts to streams and other surface water bodies from a release are to be determined utilizing the process described in this section and Appendix C. Sampling for COCs in surface water may need to occur when COC migration is known or suspected to affect surface water. This is discussed further in Section 5.7.

The target levels for surface water protection are calculated using the equations located in [ADEM Admin Code ch. 335-6-10](). These target levels represent surface water quality criteria for Public Water Supply streams (consumption of fish and water) and for Fish and Wildlife streams (consumption of fish only). For an RM-1 Evaluation, these target levels must be met at the discharge point.

At sites where concentrations in the groundwater discharging/seeping into the surface water or stream cannot be measured, the concept of dilution attenuation factors (DAFs) may be used to back calculate the following:

(i) $C_{soil}$ = Allowable soil-source concentrations
(ii) $C_{gws}$ = Allowable groundwater-source concentrations
(iii) $C_{sw}$ = Allowable concentrations in groundwater in Sentry Wells (SWs) at different distances between the surface water and the source

Items (ii) and (iii) above are considered SW concentrations protective of the surface water. Details of this procedure are discussed in Appendix C. The equations to compute the allowable concentrations of chemicals of concern in source soil, in source groundwater, and in stream SWs appear in Appendix E. If the RM-1 fate and- transport assumptions are not representative of the site, and if the measured soil source or SW concentration(s) exceed the corresponding target levels, an RM-2 Surface Water Protection Evaluation is necessary.

For an RM-2 Evaluation, the surface water target levels as calculated following the equations located in [ADEM Admin Code ch. 335-6-10]() are applicable at the downstream edge of the mixing zone formed by the mixing of the discharge of the contaminated groundwater into the stream. See Appendix C to calculate allowable concentrations in the Surface Water Protection Evaluation. Biodegradation, for petroleum compounds in groundwater, may be utilized in an RM-2 Evaluation if adequate justification is provided.

If representative COC concentrations at the soil source, groundwater source, or Sentry Wells (SWs) exceed the RM-1 target levels for the stream, then remediation may be required at the site or an RM-2 Evaluation may be performed. Under an RM-2 Evaluation, alternate fate-and-transport models may be used. Also, alternate low-flow estimates used for the determination of target levels for the stream may be used, provided the procedure used is acceptable to the Department. Prior approval of alternate procedures must be obtained from the Department.

## 6.11 ESTIMATING SENTRY WELL (SW) TARGET CONCENTRATIONS FOR GROUNDWATER RESOURCE PROTECTION AND SURFACE WATER PROTECTION

In the ARBCA Evaluation, it is necessary to designate Sentry Wells (SWs) either on-site and/or off-site to confirm that the concentrations at the POE do not exceed the target levels in the groundwater or in a surface water body, if applicable. Monitoring of SWs should occur, and the data obtained from the monitoring of those wells should be utilized as representative concentrations to compare with calculated RM-1 or RM-2 target levels. Monitoring of SWs will be continued until the concentrations in the SWs stabilize below the calculated SW target levels.

The SW target levels can be estimated using the following relationship:

$$C_{target}^{SW} = C_{target}^{EW} \times \frac{DAF_{POE}}{DAF_{SW}} \tag{6-1}$$

where,

$C_{target}^{SW}$ = Target level in the Sentry Well (SW) [mg/L]

$C_{target}^{EW}$ = Target level in the exposure well or in the water discharging to the stream [mg/L]

$DAF_{POE}$ = Dilution-attenuation factor for the distance from the source to the exposure well or the point where the plume discharges into the stream

$DAF_{SW}$ = Dilution-attenuation factor for the distance from the source to the Sentry Well (SW)

In Equation 6-1, the DAFs represent the reduction in concentration as the COCs travel from the source to the POE or the SW. This reduction in concentration is due to the combined effect of several factors including advection, diffusion, dispersion, dilution, adsorption, and biochemical processes. In general, there are two ways to estimate the DAFs. The first way is to use a fate-and-transport model that can predict the concentration at the POE or SW relative to the concentration at the source, as done on page E-14. The second way is to calculate the ratio of the measured concentrations at the source well and at the POE or SW. The second method can be used only at sites where the plume is stable and sufficient groundwater-monitoring data are available.

For an RM-1 Evaluation, the ARBCA Evaluator must compute distance-dependent DAFs that are used to estimate the SW target levels. RM-1 DAFs are estimated using the Domenico’s Model (Appendix E) implemented with fate-and-transport parameters. For an RM-2 Evaluation, site-specific DAFs may be calculated using site-specific data or a different fate-and-transport model may be implemented using site-specific data. Please consult the Department before using an alternate model.

An example calculation is presented below:

The target levels in the SWs for a site with a POE at 500 feet from the source and a SW located at 300 feet from the source, *i.e.*, 200 feet upgradient from the POE, is estimated as follows:

$$C_{target}^{SW} = C_{target}^{EW} \times \frac{DAF_{500}}{DAF_{300}} \tag{6-2}$$

where,

$C_{\mathrm{target}}^{\mathrm{SW}}$ = Target level in the SW [mg/L]

$C_{target}^{EW}$ = Target level in the exposure well (groundwater standard) [mg/L]

$DAF_{500}$ = Dilution attenuation factor for the distance from the source to the exposure well located at 500 feet from the source (See Appendix E)

$DAF_{300}$ = Dilution attenuation factor for the distance from the source to the SW located at 300 feet from the source (See Appendix E)

In this example for benzene, using DAFs computed with RM-1 fate-and-transport parameters, the equation becomes as follows

$$C_{target}^{SW} = 0.005 \times \frac{63.36}{23.17} = 0.0137 mg / L \tag{6-3}$$

In this example, the soil source width perpendicular to groundwater flow, Y, is 1500 cm. The mixing-zone thickness, $\delta_{\mathrm{gw}}$ , is 200 cm. The equation for the dilution attenuation factor can be found on page E-14. Pages E-15 and E-17 provide the formulas for calculating allowable concentrations in sentry wells for the Groundwater Resource Protection and Surface Water Protection Evaluations. The calculated SW target level of 0.0137 mg/L will be used to establish SW monitoring requirements.

An identical procedure can be used to develop SW target levels for the protection of surface water. At sites where the SW concentrations are exceeded, the Department may require continued monitoring or remediation until the concentrations stabilize below the calculated target levels.

## 6.12 MANAGEMENT AND CONTROL OF NUISANCE CONDITIONS OR CONDITIONS REQUIRING INITIAL-ABATEMENT MEASURES

While the ARBCA process determines the target levels appropriate for a site, the process primarily addresses protection of human health due to chronic exposure. These calculations do not take into account nuisance conditions such as aesthetic conditions, odor, or visible staining of soils; therefore, the owner or operator will be required to mitigate all nuisance conditions that are significant at a site. The significance of the nuisance will be determined through an investigation conducted by the owner/operator and the Department.

The presence of vapors in a subsurface structure to include basements, buildings, sewers, and other utility conduits must also be mitigated to the satisfaction of the Department.

## 6.13 ECOLOGICAL EXPOSURE

Exposures to ecological receptors and habitats such as wetlands, sensitive environments, or threatened and/or endangered species should be thoroughly evaluated. A basic screening should be performed for those sites that may pose a threat to ecological receptors and habitats. Where an ecological threat may exist due to a release, a separate ecological evaluation should be performed. Note, within the ARBCA framework, protection of surface waters is considered independent of the ecological risk evaluation, and the ARBCA Evaluator should refer to ADEM Admin. Code ch. 335-6-10. Ecological risk assessment guidance may be found in *Ecological Risk Assessment Guidance for Superfund - Process for Designing and Conducting Ecological Risk Assessment.* (U. S. EPA, 1997). The following is a medium-specific list of ecological screening levels.

### 6.13.1 Surface Water

Surface water data collected during the assessment phase should be evaluated using the criteria located in ADEM Admin. Code ch. 335-6-10, using the aquatic life criteria in Table 1 of that chapter.

In the absence of an ADEM Water Quality Criteria Value, surface water concentrations should be compared to the appropriate EPA Region 4 Ecological Screening Value. If a value is not located in either of the above references, an EPA Region 3 Biological Technical Assistance Group (BTAG) screening value should be utilized.

In the absence of an ecological screening value for surface water in any of the above referenced locations, risk assessors should utilize the scientific literature and identify an applicable value. The selected value should be provided to the Department for review with a justification, including all references that were used in the determination.

### 6.13.2 Sediments

Sediment data collected during the assessment phase should be compared to the EPA Region 4 Ecological Screening Values for sediment. These are located in the *Region 4 Ecological Risk Assessment Supplemental Guidance Interim Draft*.

In the absence of an EPA Region 4 Ecological Screening Value for sediment, an EPA Region 3 Biological Technical Assistance Group (BTAG) sediment screening value should be utilized.

In the absence of an EPA Region 3 BTAG sediment screening value, the sediment concentrations should be compared to the *Florida Guidance Manual To Support The Assessment of Contaminated Sediments in Freshwater Ecosystems*. These guidelines contain values for marine, estuarine, and freshwater sediments. In the absence of an ecological screening value for sediment in one of the above-referenced locations, risk assessors should utilize the scientific literature to identify an applicable value. The selected value should be provided to the Department for review with a justification, including all references that were used in the determination.

Sediment that is not saturated year round should be evaluated as soil and sediment.

### 6.13.3 Soils

Soil data collected during the assessment phase should be compared to the EPA Ecological Soil Screening Levels (EcoSSLs).

In the absence of an ecological screening value for soils in one of the referenced locations, risk assessors should utilize the scientific literature and identify an applicable value. The selected value should be provided to the Department for review with a justification, including all references that were used in the determination.

Note that the benchmarks listed are subject to change, and the most current data should be used. If questions arise as to which set of benchmarks should be used, please contact the Department for additional guidance.

## 6.14 LEAD

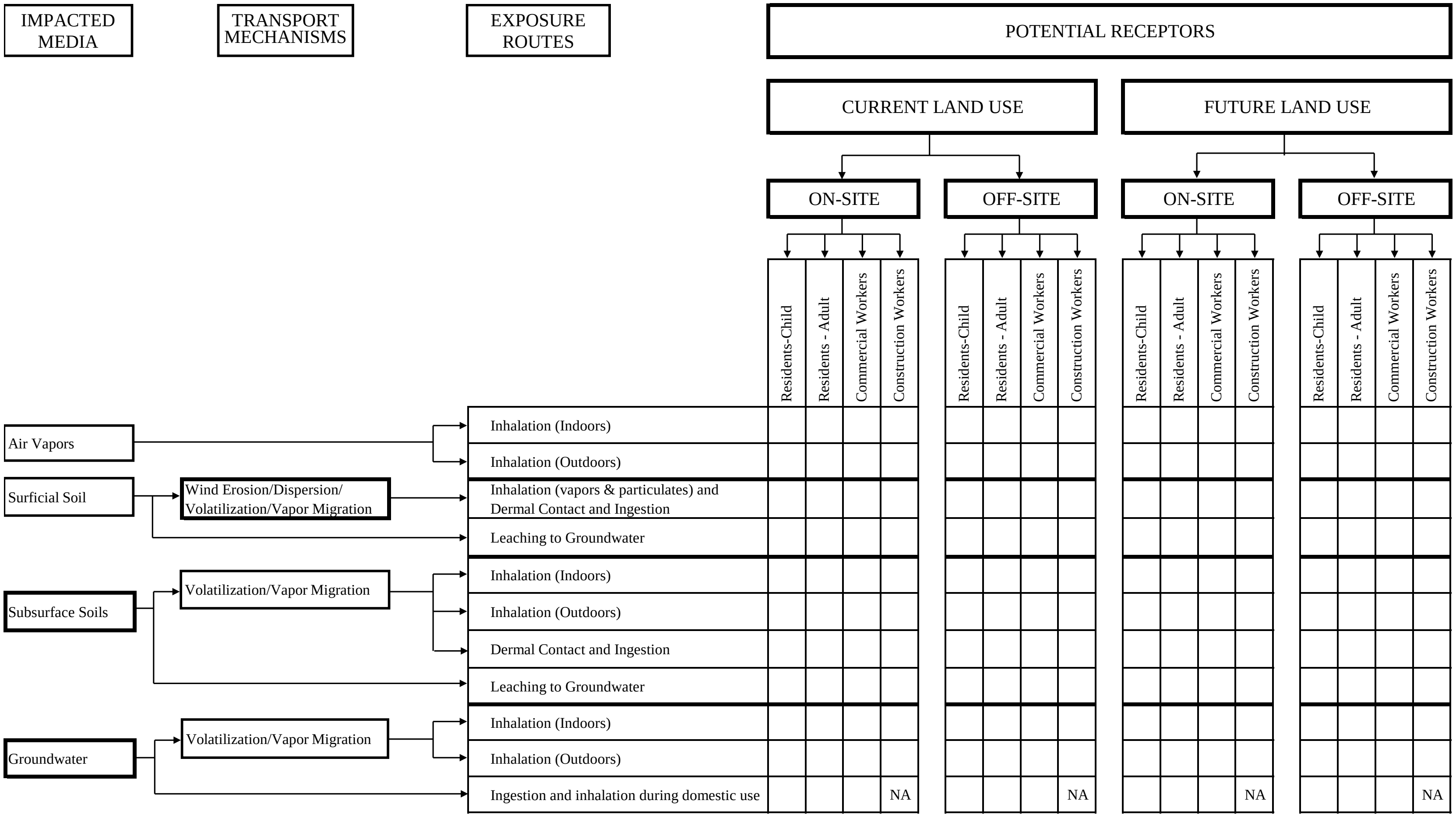
For the evaluation of lead-contaminated surficial soil, it is not appropriate to use the models located in Appendix E and Appendix J for the direct contact exposure pathways. The final cleanup values used for lead for the direct contact exposure pathways should be those values presented in the RSL Table for "Lead and Compounds," or the values should be developed using one of the following models dependent upon the exposure scenario. Models in Appendix E may be used to generate source soil cleanup values for lead in the Groundwater Resource Protection Evaluation and in the Surface Water Protection Evaluation.

The Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK) may be used to assess risk at sites due to lead contaminated soil for the unrestricted use scenario. The IEUBK attempts to predict blood-lead concentrations for children exposed to lead in their environment. The model allows the user to input relevant absorption parameters as well as intake and exposure rates.

The Adult Lead Model may be used to assess risk at sites due to lead contaminated soil where land use controls (LUCs) are required, and a commercial scenario will be used. This model uses methodology for assessing risks associated with non-residential (*i.e.*, commercial) adult exposures to lead in soil. The methodology focuses on estimating fetal blood-lead concentration in women exposed to lead-contaminated soils. This approach also provides tools that can be used for evaluating risks of elevated blood-lead concentrations among exposed adults.

Both of these models are part of EPA's Risk Assessment *Databases and Tools*.

## FIGURE 6-1 GRAPHICAL DISPLAY OF A CONCEPTUAL SITE MODEL



| IMPACTED MEDIA | TRANSPORT MECHANISMS | EXPOSURE ROUTES | POTENTIAL RECEPTORS | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | CURRENT LAND USE | | | | | | | | FUTURE LAND USE | | | | | | | |
| | | | ON-SITE | | | | OFF-SITE | | | | ON-SITE | | | | OFF-SITE | | | |
| | | | Residents-Child | Residents - Adult | Commercial Workers | Construction Workers | Residents-Child | Residents - Adult | Commercial Workers | Construction Workers | Residents-Child | Residents - Adult | Commercial Workers | Construction Workers | Residents-Child | Residents - Adult | Commercial Workers | Construction Workers |
| Air Vapors | | Inhalation (Indoors) | | | | | | | | | | | | | | | | |
| | | Inhalation (Outdoors) | | | | | | | | | | | | | | | | |
| Surficial Soil | Wind Erosion/Dispersion/ Volatilization/Vapor Migration | Inhalation (vapors & particulates) and Dermal Contact and Ingestion | | | | | | | | | | | | | | | | |
| | | Leaching to Groundwater | | | | | | | | | | | | | | | | |
| Subsurface Soils | Volatilization/Vapor Migration | Inhalation (Indoors) | | | | | | | | | | | | | | | | |
| | | Inhalation (Outdoors) | | | | | | | | | | | | | | | | |
| | | Dermal Contact and Ingestion | | | | | | | | | | | | | | | | |
| | | Leaching to Groundwater | | | | | | | | | | | | | | | | |
| Groundwater | Volatilization/Vapor Migration | Inhalation (Indoors) | | | | | | | | | | | | | | | | |
| | | Inhalation (Outdoors) | | | | | | | | | | | | | | | | |
| | | Ingestion and inhalation during domestic use | | | | NA | | | | NA | | | | NA | | | | NA |

| | YES | NO |
|---|---|---|
| Free Product? | ☐ | ☐ |
| Utilities Threatened (See Section 5.6)? | ☐ | ☐ |
| Surface Waters within a 500 foot radius? | ☐ | ☐ |
| Ecological Receptors? | ☐ | ☐ |

■ Indicates potentially completed pathways

NA Not applicable as per the ADEM policy

FIGURE 6-1 GRAPHICAL DISPLAY OF A SITE CONCEPTUAL-EXPOSURE MODEL

# 7.0
# REGIONAL SCREENING LEVEL EVALUATION

The objective of the Regional Screening Level (RSL) Evaluation is to perform a preliminary risk evaluation to identify concentrations of Chemicals of Potential Concern (COPCs) from all source areas and areas of interest within the site that may need further evaluation. The RSL Evaluation should not be confused with the Preliminary Investigation which is a physical site assessment.

The RSL Evaluation may be performed at sites using data collected during closures, environmental audits, and preliminary investigations and as the first stage in every ARBCA Evaluation. The RSL Evaluation requires the comparison of the maximum concentration (a calculated representative concentration for soils or sediments may be used if there is enough data to support the use of a calculated value such as the 95th Upper Confidence Limit (UCL) about the mean) of COPCs detected within each ED/DU with the RSLs and the Vapor Intrusion Screening Levels (VISLs). The RSLs are updated biannually.

## 7.1 WHEN TO PERFORM A REGIONAL SCREENING LEVEL EVALUATION

An RSL Evaluation requires the comparison of the maximum site concentrations to the RSLs and the VISLs. The RSL Evaluation may be performed at two stages in the ARBCA process: (i) as a screening tool on closure data, preliminary investigations, and environmental audits, and (ii) after site assessment is complete, as the first step in every risk assessment. Refer to the current *Alabama Environmental Investigation and Remediation Guidance (AEIRG)* for the requirements of site characterization.

If it is determined that the indoor vapor inhalation pathway is complete and that sub-slab or other appropriate soil-vapor samples need to be collected and analyzed, then a plan to collect and analyze soil vapor data should be submitted to the Department. Refer to the current AEIRG and to the June 2015 *USEPA Technical Guide for Assessing & Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* or the June 2015 *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* for additional details for the collection of such data.

## 7.2 COMPARISON OF DATA WITH REGIONAL SCREENING LEVELS

The data collected during the initial site assessment and investigation should be evaluated to ensure the following:

- A representative data set of current soil and groundwater concentrations are available.
- Site characteristics are comparable to assumptions used to develop the RSLs and VISLs.
- Analytical methods used are consistent with the COPCs for the site based on site history.
- All QA/QC requirements are met.
- Detection limits do not exceed the RSLs or VISLs.
- Appropriate background data has been collected.

If the data satisfies these requirements, the maximum soil and groundwater concentrations should be compared with the RSLs. A calculated representative concentration for soils or sediments may be used if there is enough data to support the use of a calculated value such as the 95th Upper Confidence Limit (UCL) about the mean.

The RSLs are risk-based concentrations developed with DOE's Oak Ridge National Laboratory under an Interagency Agreement. RSLs represent an update and merger of the EPA Region 3 Risk Based Concentration Table, EPA Region 6 Human Health Medium Specific Screening Level Table, and the EPA Region 9 Preliminary Remediation Goals Table. The RSLs are used for screening evaluations as described in Section 6.7.1. The RSL website is now the source of screening levels for all the EPA regions. The RSLs are calculated using generic input values derived without site-specific data and provide comparison values for residential (*i.e.*, unrestricted use) and commercial/industrial exposures to air, soil, and tapwater (drinking water).

The VISLs list chemicals considered to be volatile and sufficiently toxic through the soil gas intrusion pathway. These levels also provide generally recommended, media-specific, risk-based screening level concentrations for groundwater, near-source soil gas, sub-slab soil gas, and indoor air. The results of risk-based screening can help the data review team identify areas, buildings, and/or chemicals that can be eliminated from further assessment. Exceeding a subsurface screening level generally suggests, however, that further evaluation of the vapor intrusion pathway is appropriate.

If an acceptable level of site investigation has been performed as determined by the Department, and the maximum (or, if appropriate, a calculated representative concentration), media-specific concentrations do not exceed the RSLs or VISLs, then additional site evaluation may not be necessary. If any of the concentrations for the chemicals of potential concern (COPCs) exceed any of the RSLs or VISLs, then either remediation should commence or an RM-1 or an RM-2 Evaluation should be conducted for those constituents which exceed their respective RSLs. These constituents are referred to as the chemicals of concern (COCs) and are used to assess the cumulative risk within each ED/DU in the RM-1 and/or RM-2 Evaluation.

Sites with adequate site-specific information as described in Section 6.0 may move directly into the RM-2 Evaluation following an RSL Evaluation. It is permissible in most cases to adopt RSLs and VISLs as cleanup goals, but this requires the prior approval of the Department. Since a site may be granted a no-further-action or corrective action complete status under an RSL Evaluation, it is important that the site evaluation identify the maximum or representative, media-specific concentrations. If there is a potentially complete pathway that does not appear to be adequately addressed by the RSLs, an RM-1 and/or an RM-2 Evaluation should be undertaken to include it and all other complete pathways.

# 8.0
# RISK MANAGEMENT-1 EVALUATION

The RM-1 Evaluation requires the calculation of the risk for each COC, each complete exposure pathway, and the cumulative risks for each receptor. If the cumulative risks do not exceed the Department-specified target risk levels, there are no groundwater resource protection related exceedances, and no surface water protection related exceedances, a No Further Action at this time (NFA) or Corrective Action Process Terminated determination may be granted by the Department. Consistent with the assumptions made in the Conceptual Site Model (CSM), certain land use controls (LUCs) may be needed. If the cumulative risks at the site exceed the target risk levels, the responsible party may either compute RM-1 target clean-up concentrations for each COC, each complete pathway, and each receptor as identified in the CSM, or the responsible party may conduct an RM-2 evaluation.

The RM-1 and RM-2 Evaluations should be documented. All computations must be completed using the equations and models included in Appendix E.

An RM-1 Evaluation requires the following steps:

## 8.1 CHARACTERIZATION AND CLASSIFICATION OF THE SITE

This process has been previously described in Sections 4.0 and 5.0.

## 8.2 DEVELOPMENT OF THE CONCEPTUAL SITE MODEL

The development of an CSM has been described in Section 6.5. This step includes the location of the POE and Sentry Wells (SW) as per Section 6.6. If an ecological risk assessment is needed for the site, please refer to the guidance in Section 6.13, and discuss the situation with the Department.

## 8.3 CALCULATION OF RISKS AND DEVELOPMENT OF RM-1 TARGET LEVELS

For each complete exposure pathway identified in the CSM, the risk should be calculated using the RM-1 values in the most current RSL User's Guide and appropriate site-specific data. If the cumulative risks exceed the target risk levels, RM-1 target concentrations may be developed, or the ARBCA Evaluator may proceed to an RM-2 Evaluation. If the ARBCA Evaluator chooses to compute RM-1 target concentrations, the equations/models in Appendix E must be used. The user should compare the RM-1 fate and transport parameters to the known site characteristics. If the parameters are not representative of the site conditions, then an RM-2 Evaluation will be required. In some cases, models other than those located in Appendix E may be more suitable due to site-specific conditions. The most current toxicity values recommended by the Department must be used for ARBCA Evaluations. For COCs that may not have a quantitative toxicity value, please contact the Department. Additional information regarding toxicity values can be found in Section 6.7.2.2.

The RM-1 target soil concentrations protective of the groundwater resource depend on the distance to the POE from the source. These target soil concentrations should be developed assuming no attenuation in the unsaturated zone and no biodegradation in the saturated zone.

For indirect exposure pathways (where the exposure occurs at a location or medium different than the source medium, for example, ingestion of water from a downgradient well impacted by leaching of chemicals from the soil), an RM-1 Evaluation requires the use of fate and transport models. The Department has selected conservative fate and transport models that have to be implemented with conservative and typical input parameters. Details of the procedures utilized to back calculate the RBTLs are shown in Appendices D and E.

## 8.4 COMPARISON OF RM-1 TARGET LEVELS WITH REPRESENTATIVE CONCENTRATIONS

If the calculated risk for any receptor exceeds the target risk levels, it is necessary to either develop RM-1 target concentrations and remediate the site to these levels, with the approval of the Department, or perform an RM-2 Evaluation. If the ARBCA Evaluator decides to develop RM-1 target levels, they should be compared with the representative concentrations for each exposure pathway within each ED/DU after the remediation activities have been completed. Presence of product should be noted and considered as discussed in Appendix B. Depending on the site conditions, multiple representative concentrations may have to be developed for a site. For example, at a site where a groundwater plume exists below an on-site commercial building and has migrated off-site under a residential building, representative groundwater concentrations for on-site and off-site receptors would be different. Representative concentrations should be developed for each ED/DU. Appendix B provides detailed procedures for determining exposure domains and for calculating representative concentrations.

Following remediation activities at a site, representative concentrations should be updated within each ED/DU. Before remediation may be considered complete, the target cumulative risk must be met for each receptor in the CSM. In some cases, this may require the ARBCA Evaluator to re-compute the cumulative risks and hazard indices using the current representative concentrations. The representative concentrations should be evaluated as follows:

### 8.4.1 Soils

For both surficial and subsurface soils, the selection of the representative concentration assumes the site has been adequately assessed. Representative soil source concentrations required for the evaluation of the protection of groundwater pathway should be calculated based on the soil data collected within the source area. The dimensions for the source area used to calculate the representative concentrations should be identical to the dimensions used to develop the concentrations protective of the groundwater resource pathway. Recent average and recent maximum concentrations should be determined as necessary to calculate the risks and compare them with the target risk levels. See Appendix B for details on computing representative concentrations.

The soil data from the most recent comprehensive investigation should be used. If recent (< 4 years old) soil data has not been obtained, it may be appropriate to collect soil data and use the current soil data to estimate the representative concentration. These data should be obtained through the implementation of data acquisition or investigation utilizing the procedures outlined in the most current AEIRG. Where new data are available, an average within a ED/DU may be used. Where only older (> 4 years old) data are available, the maximum value may be utilized if there have been no additional releases since the data was collected and the Department concurs that the data set is complete. If a new release has occurred, soil assessment activities should adequately characterize the extent of the new release.

#### 8.4.1.1 Surficial Soil

The representative surficial soil concentrations should be determined based on recent (<4 years old) surficial soil concentration data. Appendix B discusses the calculation of representative concentrations. The representative surficial soil concentrations should be used to calculate the risks and compare with the RM-1 target concentrations as a guide to determine when it is probable that the exposure domain/decision unit will have to be remediated to a level that does not exceed the acceptable risk level.

For the Department to consider an NFA or make a Corrective Action Process Terminated determination, the current ED/DU specific, representative concentrations should not exceed the relevant RM-1 target, cleanup levels.

#### 8.4.1.2 Subsurface Soil

The representative subsurface soil concentration should be calculated based on recent (<4 years old) subsurface soil concentration data. Appendix B discusses the calculation of representative concentrations. The representative subsurface soil concentrations should be used to calculate the risks and compare with the RM-1 target concentrations as a guide to determine when it is probable that the ED/DU will have to be remediated to a level that does not exceed the acceptable risk levels.

For the Department to consider an NFA or make a Corrective Action Process Terminated determination at a site, the current ED/DU specific, representative concentrations should not exceed the relevant RM-1 target, cleanup levels.

### 8.4.2 Groundwater

Based on the CSM, several representative groundwater concentrations may have to be estimated at a site. These could include (i) representative concentrations in the source area, (ii) representative concentrations in the SWs, (iii) on-site representative concentrations to evaluate the protection of indoor inhalation, (iv) on-site representative concentrations to evaluate the protection of outdoor inhalation, (v) off-site representative concentrations to evaluate the protection of indoor inhalation, and (vi) off-site representative concentrations to evaluate the protection of outdoor inhalation. The procedure to select and properly calculate these values is discussed in Appendix B.

As discussed in Appendix B, the appropriate representative concentrations should be selected for each groundwater exposure for the inhalation and ingestion pathways. An RM-1 Evaluation should be performed with a minimum of four (4) consecutive groundwater monitoring events using data collected quarterly or semi-annually. If semi-annual data are utilized, the sampling events should be conducted during the wet and dry seasons (for example, March and September) to account for seasonal variations. In certain situations and with the Department's approval, an ARBCA Evaluation can also be performed when only minimal groundwater data (one or two sampling events) are available. In such cases, and subsequent to the evaluation, the Department may require additional confirmatory data before the final decision.

Current groundwater data may have to be collected if the groundwater data are not current (data should be no older than 2 years). If recent groundwater data have not been obtained, it may be appropriate to obtain these data and utilize current groundwater data. These data can be obtained through the implementation of a groundwater monitoring plan approved by the Department.

For complete human exposure pathways, the representative groundwater concentrations should be used to calculate the risks and compare with the RM-1 target concentrations as a guide to determine when the ED/DU has been remediated to a level that does not exceed the target risk.

For the Groundwater Resource Protection Evaluation, the relevant RM-1 target levels for the groundwater source and a sufficient number of SWs should be compared with site-specific average and maximum groundwater concentrations. For sites with soil and/or groundwater COC concentrations that exceed the RM-1 target levels for the Groundwater Resource Protection Evaluation, the site should be remediated to the RM-1 target levels or an RM-2 Evaluation may be conducted to further evaluate these exceedances.

For a site to receive an NFA or a Corrective Action Process Terminated determination, the current, ED/DU specific, representative concentrations should be less than the RM-1 target concentrations. Furthermore, none of the wells should have increasing concentrations or concentrations consistently above the RM-1 target concentrations. The plume must also be stable or decreasing.

### 8.4.3 Surface Water

Appropriate surface water samples should be collected when COC migration is known or suspected to affect a surface water body. Water samples should be collected upstream of, downstream of, and at a groundwater discharge point for COC analyses and compared to concentrations as calculated using the equations located in ADEM Admin. Code ch. 335-6-10. Refer to Section 6.10 and Appendix C.

## 8.5 SELECTION OF THE NEXT COURSE OF ACTION

The Department may issue an NFA or make a Corrective Action Process Terminated determination letter if the following conditions are met:

- An acceptable site investigation has been performed as determined by the Department.
- Target cumulative risks are not exceeded.
- There are no Groundwater Resource Protection Evaluation exceedances as determined by the Department.
- There are no Surface Water Protection Evaluation exceedances as determined by the Department.
- Representative concentrations calculated per Appendix B meet the criteria in Section 8.4.
- No nuisance conditions exist at the site.
- Free product has been properly addressed at the site as determined by the Department.
- The site-specific fate and transport parameters are not significantly different than the RM-1 values.
- The plume must be stable or decreasing.
- The Department agrees with the overall RM-1 Evaluation.
- Any necessary LUCs (*e.g.*, an environmental covenant per ADEM Admin. Code div. 335-5) have been implemented and a monitoring plan, if necessary, has been developed, approved, and implemented.

An NFA or Corrective Action Process Termination granted with restrictions (*e.g.*, with LUCs, long-term monitoring, *etc.*) is valid only so long as the restrictions are maintained.

If the site concentrations exceed the acceptable cumulative risk levels, the Groundwater Resource Protection standards or the Surface Water Protection criteria, the following three risk-management alternatives are available:

**Alternative 1**: **Localized Exceedances**. Site concentrations exceed the RM-1 target concentrations in a small portion of the site. The site owner/operator, with the Department's approval, may choose to conduct interim remediation to meet acceptable cumulative risk levels.

**Alternative 2**: **Selection of RM-2 Evaluation**. The responsible party conducts an RM-2 Evaluation, which may require the acquisition of additional site data. An RM-2 Evaluation may also be necessary when the fate and transport assumptions used in the RM-1 Evaluation are significantly different from the known or suspected site-specific conditions.

**Alternative 3**: **Remediation to RM-1 Target Levels**. With the Department's approval, the responsible party may elect to develop a Remediation Plan to clean up the site to RM-1 target levels. The Plan would have to be approved by the Department and meet the appropriate programmatic and regulatory requirements.

The owner/operator should carefully review the site conditions and recommend one of the three alternatives listed above.

# 9.0
# RISK MANAGEMENT-2 EVALUATION

An RM-2 Evaluation may be conducted when (i) RM-1 target levels are exceeded and it is not appropriate to remediate the site to RM-1 target levels; (ii) RM-1 assumptions are significantly different from site-specific conditions, so that the estimated RM-1 cumulative risks may not be representative of site-specific conditions; (iii) the COCs are not listed in the RSL table or VISL calculator; (iv) the site has a significant ecological risk that must be evaluated on a site-specific basis; or (v) as directed by the Department.

The RM-2 Evaluation allows site-specific decision making for the selection of alternative fate and transport models and input parameters that will result in a cumulative target cancer risk of 1.0E-05 and/or hazard index of 1.0. Since the RM-2 Evaluation provides considerable site specific decision making, it may be necessary for the responsible party to develop an overall work plan clearly outlining the methodology as well as the input parameters to be used to develop RM-2 target levels. If the proposed RM-2 Evaluation will use all default models and parameters except site-specific soil geotechnical parameters, the ARBCA Evaluator should move directly to an RM-2 Evaluation without the submittal of a plan. However, if the proposed RM-2 Evaluation includes the use of alternative models or complex measurement of any site specific parameters, a very detailed work plan may be necessary. The responsible party should receive the Department's approval prior to proceeding with the development of the RM-2 work plan.

## 9.1 CONTENTS OF AN RM-2 WORK PLAN

When the proposed RM-2 Evaluation requires the use of alternate models or complex measurements, a detailed work plan may be required to be submitted prior to the RM-2 Evaluation. The plan should include details regarding the collection and use of any site-specific parameters. If alternate models are proposed, they should be described in detail and must be approved by the Department prior to their use. A copy of the model may be required to be submitted to the Department.

## 9.2 IMPLEMENTATION OF THE WORK PLAN

Upon receipt of approval of the work plan, the responsible party should implement the work plan as per the schedule in the work plan. In case there are any delays, it is the responsible party’s obligation to inform the Department of the delay and revised schedule.

Upon completion of the work, the responsible party should document the results and submit them to the Department. The report must include recommendations and the future risk management decisions.

## 9.3 PERFORMANCE OF AN RM-2 EVALUATION

### 9.3.1 Conceptual Site Model

The site owner/operator should develop the CSM if it has not already been developed and identify the complete exposure routes and pathways. Refer to Section 6.5 for details regarding content and development of the CSM. All COCs and all complete exposure pathways should be evaluated under the RM-2 Evaluation (even those that satisfy RM-1 target levels). Thus, the CSM for the RM-2 Evaluation will be exactly the same as the CSM for the RM-1 Evaluation unless additional information warrants a change. In most cases where an RM-1 Evaluation has been completed, this step will involve reference to the previously developed CSM if no revisions are necessary.

### 9.3.2 Target Risk

The acceptable, cumulative carcinogenic risk for an RM-2 Evaluation is 1.0E-05. For non-carcinogenic risk, the hazard index must be less than or equal to 1.0. See Section 6.7.2.1 for a more detailed discussion of the target risk.

### 9.3.3 Exposure Factors

In most cases, the ARBCA Evaluator may choose to utilize the exposure factors provided in the Regional Screening Table User's Guide and the most current Exposure Factors Handbook. In exceptional circumstances, the evaluator may propose alternate exposure factors, but a work plan is required. These factors must be justified and acceptable to the Department.

### 9.3.4 Physical Properties

The ARBCA Evaluator should utilize the physical properties of the COCs as provided in the RSL Table. If a COC is not listed, the evaluator must propose and justify the use of physical properties as previously discussed in this guidance. Alternate physical properties must be approved by the Department prior to use.

### 9.3.5 Toxicological Properties

The current toxicity values accepted by the Department must be used. The RSL Table provides the current, acceptable values as of the date of this guidance. If toxicity values for a COC are not listed, the evaluator may propose and justify the use of toxicological properties as previously discussed in Section 6.7.2.2. Alternate toxicological properties must be justified and approved by the Department prior to use.

### 9.3.6 Fate and Transport Parameters and Building Parameters

The ARBCA Evaluator may choose to utilize the default fate and transport parameters and building-specific parameters provided in the RSL User's Guide. The Department also allows representative site-specific fate and transport parameters to be used for an RM-2 Evaluation.

Sections 5-7 and 5-10 describe the methods appropriate for determining site specific values. At a minimum, site measured values of soil source dimensions, depth to subsurface soil sources, thickness of the vadose zone, depth to groundwater, hydraulic gradient, hydraulic conductivity, and the distances to the point of exposure and sentry wells must be used. Where site specific values are not available for parameters, professional judgment has to be used to determine whether to perform additional assessment or to use appropriate literature values. If additional data are necessary, a data acquisition work plan should be developed and approved by the Department prior to performing the RM-2 Evaluation.

The Department will allow the use of site-specific, chemical-specific, bio-decay rates in the fate and transport model in the Groundwater Resource Protection Evaluation and the Surface Water Protection Evaluation based on site-specific evaluation of historic monitoring-well data, or alternatively, from justifiable literature values. Note that the use of bio-decay rates in RM-2 Evaluations must be justified based on site specific information, including but not limited to:

- Consistent decreasing COC trends in the monitoring wells; and
- Measurement of intrinsic parameters that provide evidence of natural attenuation.

The work plan should describe the method to be used to estimate intrinsic parameters.

### 9.3.7 Fate and Transport Models

The same models and algorithms that were used to develop RM-1 target levels should be used for an RM-2 Evaluation. Alternate models may be used to calculate the RM-2 target levels with the Department's approval. These models must be approved by the Department prior to their implementation and acceptance of the calculated cumulative-risk level and RM-2 target levels.

### 9.3.8 Calculation of Representative Concentrations

The representative soil and groundwater concentrations are calculated the same as for an RM-1 Evaluation (Section 8.4) and as discussed in Appendix B and may be used to estimate the site risk. If the site risk in RM-2 exceeds the acceptable risk level, the ARBCA evaluator must develop RM-2 target concentrations.

### 9.3.9 RM-2 Groundwater Resource Protection Evaluation

The use of groundwater as a current and a future drinking water supply is the basis of the Groundwater Resource Protection Evaluation within the ARBCA Evaluation. A determination of allowable soil and groundwater contaminant levels must be made when there are water supply wells on-site or off-site. At sites where there are no water supply wells present, the cleanup levels for soil and groundwater are required to be protective of the groundwater resource for likely future use. If the likely future use of a site is determined to be a use other than unrestricted use, LUCs may be installed in perpetuity or until the Department has determined that unrestricted use conditions have been attained at the site.

For the RM-2 Evaluation, the groundwater ingestion POE will be established at the nearest point where a water well currently exists, or may exist, in the future (this is generally an actual monitoring well located at the property boundary). If no such wells exist and are unlikely to be installed, then the POE will be at the closest down-gradient monitoring well located within the boundaries of the property (the UST program has provisions in place allowing the well to be located at the closest down-gradient residential property boundary where a water supply well may be installed). Determination of likely installation of a well and resulting POE may depend on considerations such as availability of a public water supply, potability of shallow water (yield and quality), history of aquifer use, existence of municipal restrictions to install wells, and the most-likely future land use.

A sentry well (SW) is a monitoring well(s) that must be located between the COC source area and the POE. The SW serves as a sentry or guard well(s) for the protection of the POE. For RM-2 Evaluations, SW target levels will be developed that will be compared to the groundwater representative concentrations in each SW. For most sites, several SWs should be selected for the Groundwater Resource Protection Evaluation. For sites with variable or radial flow, multiple POEs and corresponding SWs may have to be evaluated.

### 9.3.10 Vapor Inhalation Pathway Evaluation

If it is determined by the Department and/or the ARBCA Evaluator that the inhalation pathway is potentially complete, the representative soil, groundwater concentrations, soil gas or air concentrations for indoor and outdoor inhalation pathways should be determined and the risk determined. The type of samples collected should be discussed with the Department and a plan of action determined prior to collection of the data. The appropriate USEPA 2015 guidance document should be followed and a plan addressing the pathway should be submitted to the Department: *Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* or *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. Additional guidance to assist with assessing this pathway and for plan development can also be found in the ITRC Technical & Regulatory Guidance Document, *Vapor Intrusion Pathway: A Practical Guideline*.

### 9.3.11 Source Water Assessment Areas

Source Water Assessment Areas (SWAAs) I or II should be identified and evaluated as necessary. A definition and a table describing SWAAs I and II are located in the ADEM Admin. Code ch. 335-7-15. SWAAs should be thoroughly evaluated under an RM-2 Evaluation on a case-by-case basis.

### 9.3.12 RM-2 Surface Water Protection Evaluation

Potential impacts to streams and other surface water bodies from a release must be determined. Sampling for COCs in surface water bodies may need to occur when COC migration is known or suspected to affect a surface water body. Surface water target level calculations are located in ADEM Admin. Code ch. 335-6-10. These equations represent the surface water quality criteria for Public Water Supply streams (consumption of fish and water) and for Fish and Wildlife streams (consumption of fish only), respectively.

For an RM-2 Evaluation, the surface water target levels are applicable at the downstream edge of the mixing zone formed by the mixing of the discharge of the contaminated groundwater into the stream. Biodegradation of chemicals as they migrate from the source to the stream may be utilized in an RM-2 Evaluation if adequate justification is provided. Under an RM-2 Evaluation, alternate fate and transport models may be used. Prior approval of alternate models must be obtained through approval of an RM-2 work plan by the Department. See Appendix C and Sections 6.10 and 6.11 for the method of computing acceptable concentrations in the source area and in stream sentry wells, in order to achieve the calculated allowable stream concentrations.

If the chemical is not listed in ADEM Admin. Code ch. 335-6-10, the current version of the *National Recommended Water Quality Criteria* should be used. For constituents not addressed in either of the above references, the Department should be contacted for guidance on the matter.

### 9.3.13 Ecological Evaluation

For a detailed, site-specific determination of risks posed to ecological receptors at a site, see Section 6.13. The values determined should not be exceeded in the groundwater discharging/seeping into a stream.

### 9.3.14 Evaluation of Other Pathways

Other complete exposure pathways such as ingestion of food crops for human consumption grown in impacted media, ingestion of fish and shellfish, or use of groundwater for irrigation purposes should be evaluated under the RM-2 Evaluation. Refer to the *Risk Assessment Guidance for Superfund Volume I Human Health Evaluation Manual Part A* (U. S, EPA, 1989) for detailed guidance on evaluation of risk due to food intake.

## 9.4 RISK MANAGEMENT RECOMMENDATIONS

If representative site concentrations within an ED/DU exceed the acceptable cumulative risk levels, a Remediation Plan will be required to address the exceedances and RM-2 target levels should be developed to guide the remediation activities. The following risk management alternatives are available:

1. Remediation to RM-2 target levels. The site owner/operator develops a Remediation Plan to remediate the site to RM-2 target levels. The Plan must be approved by the Department. Following the completion of the remediation activities, confirmatory sampling should be conducted to ensure that the cumulative risk levels within each ED/DU meet acceptable levels.

2. Conduct a Post-ARBCA monitoring program. When representative site concentrations minimally exceed acceptable cumulative risk levels, the owner/operator may conduct compliance monitoring to confirm site concentrations are not increasing and/or natural attenuation is occurring. Furthermore, it may be necessary for the site to install engineering controls in addition to any other LUCs to limit the exposure time below the

period of time used in the RM-2 Evaluation. These additional controls should be maintained until such time that the cumulative risk level within each exposure domain/decision unit is reduced to an acceptable level.

After the completion of an RM-2 Evaluation, the Department may issue an NFA or Corrective Action Process Terminated letter if the following conditions are met:

- An acceptable site investigation has been performed as determined by the Department.
- Target cumulative risk levels are not exceeded.
- There are no substantial Groundwater Resource Protection related exceedances as determined by the Department.
- There are no substantial Surface Water Protection related exceedances as determined by the Department.
- Representative concentrations meet the criteria in Appendix B.
- No nuisance conditions exist at the site.
- Free product has been properly addressed at the site as determined by the Department.
- The site-specific fate and transport parameters are adequately justified.
- The plume must be stable or decreasing.
- The Department agrees with the RM-2 Evaluation and determines that additional confirmatory or groundwater monitoring is not necessary.
- Any necessary LUCs such as an environmental covenant per ADEM Admin Code div. 335-5 have been implemented.

An NFA or Corrective Action Process Termination granted with conditions (*e.g.*, with LUCs such as an environmental covenant per ADEM Admin. Code div. 335-5) is valid only so long as the restrictions are maintained.

# 10.0
# RISK-MANAGEMENT ISSUES

The target levels used in the ARBCA process are based on assumptions related to site characteristics, land use, exposure, and fate and transport parameters. The risk management step must be performed to either (i) remediate the site to the calculated risk-based target levels (RBTLs), or (ii) to ensure that the site conditions do not significantly change in the future which may result in an unacceptable level of risk to human health and the environment.

Upon completion of the appropriate RSL, RM-1, or RM-2 Evaluation, groundwater monitoring for confirmation of assumptions, sentry well monitoring, or evaluation of the effectiveness of the remediation method may be necessary. If additional groundwater monitoring is not required, and the site concentrations are acceptable, an NFA or a Corrective Action Process Terminated letter may be issued.

The following subsections provide information regarding risk-management issues.

## 10.1 GROUNDWATER MONITORING

Within the ARBCA process, there are two objectives of groundwater monitoring, namely (i) confirmatory monitoring and (ii) post-ARBCA groundwater monitoring. The specific amount of data required will vary from site to site and will require the Department's concurrence.

The objective of confirmatory monitoring is to adequately understand the nature and extent of groundwater impacts and to confirm plume stability. Confirmatory monitoring may also be required by the Department even when the concentrations do not exceed the site-specific target levels.

The objective of post-ARBCA groundwater monitoring is to confirm that concentrations in an exposure well or Sentry Well (SW) will not exceed the target levels established using the ARBCA process. Thus, post-ARBCA groundwater monitoring is performed only after the site-specific target levels have been established.

Typically one or more wells may be selected as the SWs. Monitoring of SWs should continue until the concentrations in these wells do not exceed the SW target levels as discussed in Section 6.11, and the concentrations are stable or decreasing. The SW target levels are established so that the concentrations at the POE do not exceed the RSLs.

## 10.2 CORRECTIVE ACTION PLANS

Where the acceptable, cumulative risk levels for the site are exceeded, a site owner/operator may be required to prepare a Remediation Plan for the site. Further guidance on the development of Remediation Plan is located in the current *Alabama Environmental Investigation & Remediation Guidance* and within the *Remediation Checklist*. A Remediation Plan may consist of a combination of remedial technologies. The calculated RM-1 or RM-2 target levels for a site serve as the RBTLs.  Remedial technologies that will adequately reduce the site concentrations below the RBTLs should be used.

## 10.3 LAND-USE CONTROLS

The ARBCA process will recognize the presence of existing controls in the development of the CSM.  Existing implicit or explicit LUCs help determine the future land use.  For example, existing right-of-ways and highways will be considered in developing the CSM prior to the selection of RM-1 or RM-2 target levels.

After the completion of the tiered risk evaluation, the Department may accept owner-imposed LUCs as a way to eliminate certain exposure pathways.  LUCs will be site-specific and will be the site owner/operator's responsibility to demonstrate to the Department the need to impose the control, its long-term implications, and the methods to be used to ensure their permanence.  An environmental covenant may be appropriate, in accordance with ADEM Admin. Code div. 335-5.

Careful consideration should be exercised when addressing exposure pathways through the use of LUCs.  If remedial decisions are based on LUCs, those controls must be maintained in perpetuity, and the long-term costs and implications of monitoring and maintaining the controls should be thoroughly and carefully considered.

## 10.4 NO FURTHER ACTION / CORRECTIVE ACTION PROCESS TERMINATED PROCEDURE

When the ARBCA Evaluation has been performed and the site has been remediated to the acceptable cumulative risk levels and site conditions are otherwise acceptable to the Department, a letter of “No Further Action,” a letter of “No Further Action with Conditions,” or a “Corrective Action Process Terminated” letter may be issued.  The letter indicates that, based on the information submitted to the Department, the concentrations of COCs on or adjacent to the site do not pose an unacceptable level of risk.

The “NFA with Conditions” letter will specify some of the assumptions and site characteristics utilized in the ARBCA Evaluation.  For example, the letter may indicate that the site was evaluated under the commercial land-use scenarios and that future site activities were expected to be compatible with this land use.  An environmental covenant may be appropriate.  A “Corrective Action Performance Standards Attained” letter may also be utilized for this purpose and contain such conditions.

# 11.0
# REFERENCES

ADEM, 2001a, *Alabama Risk-Based Corrective Action for Underground Storage Tanks – Guidance Manual (Revision 1.0),* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2008, *Alabama Risk-Based Corrective Action for Underground Storage Tanks – Guidance Manual (Revision 2.0),* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2005, *Alabama Environmental Investigation and Remediation Guidance (AEIRG),* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2013 (or latest version), ADEM Land Division – *Uniform Environmental Covenant Program, Division 335-5,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2015 (or latest version), *ADEM Water Division – Water Quality Program, Volume 1, Division 335-6-10,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2015 (or latest version), *ADEM Water Division – Water Quality Program, Volume 1, Division 335-6-11,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2015 (or latest version), *ADEM Water Division – Water Supply Program, Division 335-7-15,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, 2016 (or latest version), *ADEM Land Division – Hazardous Waste Program, Division 335-14-2,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, *Remediation Checklist,* http://www.adem.alabama.gov/programs/land/guidanceReports.cnt

ASTM D2216-10, *Standard Test Methods for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass*, ASTM International, West Conshohocken, PA, 2010, www.astm.org

ASTM D2937-10, *Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method,* ASTM International, West Conshohocken, PA, 2010, www.astm.org

ASTM D2974-07a, *Standard Test Methods for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils, ASTM International*, West Conshohocken, PA, 2007, www.astm.org

ASTM E1739-95(2015), *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites,* ASTM International, West Conshohocken, PA, 2015, www.astm.org

ASTM E1943-98(2015), *Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites*, ASTM International, West Conshohocken, PA, 2015, www.astm.org

ATSDR, *Agency for Toxic Substances and Disease Registry*, http://www.atsdr.cdc.gov/
Environmental Quality Management, Inc., 2004, *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*, Durham, NC, prepared for USEPA, Office of Emergency and Remedial Response, Washington, D.C.

*Florida Department of Environmental Protection*, http://www.dep.state.fl.us/waste/categories/wc/pages/LinksToGuidanceDocuments.htm
March 25, 2016

Geological Survey of Alabama, http://www.gsa.state.al.us/
*Mid-Atlantic Risk Assessment User's Guide*, http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm, May 2013

OEHHA, *Science for a Healthy California*, http://oehha.ca.gov/chemicals

Prism Climate Group, Northwest Alliance for Computational Science and Engineering, *Average Annual Precipitation map for Alabama*, http://www.prism.oregonstate.edu/gallery/view.php?state=AL

United States Department of Labor, *Occupational Safety and Health Administration* https://www.osha.gov

U.S. EPA, *About the National Center for Environmental Assessment (NCEA)*, https://www.epa.gov/aboutepa/about-national-center-environmental-assessment-ncea
August 15, 2016

U.S. EPA, *Water Resources*, https://www.epa.gov/learn-issues/water-resources#what-you-can-do August 11, 2016

U.S. EPA, *Hazardous Waste Test Methods / SW-846:* https://www.epa.gov/hw-sw846 August 2, 2016

U.S. EPA, *Ecological Soil Screening Level (Eco-SSL) Guidance and Documents*, https://www.epa.gov/risk/ecological-soil-screening-level-eco-ssl-guidance-and-documents September 30, 2015

U.S. EPA, *Exposure Factors Handbook 2011 Edition (Final).* U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-09/052F, 2011. https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252

U.S. EPA, *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments - Interim Final (PDF)* (EPA 540-R-97-006, OSWER 9285.7-25, PB97-9632 11, June 1997

U.S. EPA, *Biological Technical Assistance Group (BTAG) Screening Values*, https://www.epa.gov/risk/biological-technical-assistance-group-btag-screening-values February 1, 2016

U.S. EPA, *Regional Screening Levels (RSLs) - User's Guide (May 2016)*, https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide-may-2016 June 15, 2016

U.S. EPA, *Regional Screening Levels (RSLs) - Generic Tables (May 2016)* https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016

US EPA, *Regional Screening Levels (RSLs)*, May 27, 2016 https://www.epa.gov/risk/regional-screening-levels-rsls

U.S. EPA, 1989. *Risk Assessment Guidance for Superfund. Volume I: Human health evaluation manual (Part A)(PDF). Interim Final.* Office of Emergency and Remedial Response. EPA/540/1-89/002

U.S. EPA, *Integrated Risk Information System*, https://www.epa.gov/iris July 18, 2016

U.S. EPA, *About the National Center for Environmental Assessment (NCEA)*, https://www.epa.gov/aboutepa/about-national-center-environmental-assessment-ncea August 15, 2016

U.S. EPA, *Health Effects Assessment Summary Tables (HEAST)*, https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877&CFID=57931993&CFTOKEN=46826783 August 15, 2016

US EPA, *OSWER Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air (PDF)(268 pp, 3 MB)*, June 2015, OSWER Publication 9200.2-154

US EPA, *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites (PDF)*(129 pp, 3 MB, June 2015, EPA 510-R-15-001)

US EPA, Water Quality Criteria, *National Recommended Water Quality Criteria - Aquatic Life Criteria Table* https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table

U.S. EPA, *ProUCL Software* https://www.epa.gov/land-research/proucl-software

U.S. EPA, *Risk Assessment - Region 4 Ecological Risk Assessment Supplemental Guidance*, https://www.epa.gov/risk/region-4-ecological-risk-assessment-supplemental-guidance

U.S. EPA *Risk Assessment - Risk Tools and Databases*, https://www.epa.gov/risk/risk-tools-and-databases October 27, 2015

U.S. EPA 1991a. *Human health evaluation manual, supplemental guidance: "Standard default exposure factors (PDF)"*. OSWER Directive 9285.6-03

U.S. EPA 1991b. *Risk Assessment Guidance for Superfund, Volume I: Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals).* Office of Emergency and Remedial Response. EPA/540/R-92/003. December 1991

U.S. EPA. 1996a*: User's Guide*. Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-23

U.S. EPA. 1996b. *Soil Screening Guidance: Technical Background Document*. Office of Emergency and Remedial Response. Washington, DC. OSWER No. 9355.4-17A

U.S. EPA 2000. *Exposure and Human Health Reassessment of 2,3,7,8-Tetrachlorodibenzo-p-Dioxin (TCDD) and Related Compounds. Part I: Estimating Exposure to Dioxin-Like Compounds. Volume 3--Properties, Environmental Levels, and Background Exposures. Draft Final Report.* EPA/600/P- 00/001. Office of Research and Development, Washington, DC. September

U.S. EPA, 2000b. *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (PDF)*

U.S. EPA, 2001 (PDF). WATER9. Version 1.0.0. Office of Air Quality Planning and Standards, Research Triangle Park, NC. Web site

U.S. EPA 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites. OSWER 9355.4-24. December 2002

U.S. EPA 2004. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment) Final. OSWER 9285.7-02EP.July 2004. Document (PDF) and website

U.S. EPA 2009. Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part F, Supplemental Guidance for Inhalation Risk Assessment) Final. OSWER 9285.7-82. January 2009. Document (PDF), memo (PDF) and website

The US Geological Survey Water-Resources Investigations Reports entitled *Geohydrology and Susceptibility of Major Aquifers to Surface Contamination in Alabama; Areas 1 -13* (U. S. Geological Survey, 1989)

National Centers for Environmental Information, *National Oceanic and Atmospheric Administration (NOAA), Climate Data Online*, http://www.ncdc.noaa.gov/cdo-web/

Atkins, J. B., and Pearman, J. L., 1994, *Low-Flow and Flow-Duration Characteristics of Alabama Streams*, U.S. Geological Survey, Water-Resources Investigations Report, 93-4186

Bingham, R. H., 1982, *Low-Flow Characteristics of Alabama Streams*, U. S. Geological Survey Water-Supply Paper 2083, U.S. Government Printing Office, Washington D.C.

Buscheck, T. E., and C. M. Alcantar, 1995. Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation, in Hinchee, R. E., J. T. Wilson, and D. C. Downey, editors, 1995, *Intrinsic Bioremediation*, Battelle Press, Columbus, Ohio, pages 109 - 116.

Domenico, P. A., and Palciauskas, V. V., 1982, Alternative Boundaries in Solid Waste Management, *Groundwater*, vol. 20, no. 3, pp. 303-311.

# APPENDIX A

# LIST OF ACRONYMS USED IN THIS GUIDANCE MANUAL

# APPENDIX A
# LIST OF ACRONYMS USED IN THIS GUIDANCE MANUAL

| ACRONYM | DEFINITION |
|---|---|
| $ABS_{GI}$ | Fraction of Contaminant Absorbed in Gastrointestinal Tract |
| $ABS_{d}$ | Fraction of Contaminant Absorbed Through The Skin |
| ADAP | ARBCA Data Acquisition Plan |
| ADEM | Alabama Department of Environmental Management (referred to as the "Department") |
| ARBCA | Alabama Risk-Based Corrective Action |
| AST | Aboveground Storage Tank |
| ASTM | American Society for Testing and Materials |
| ATSDR | Agency for Toxic Substances and Disease Registry |
| bgs | Below Ground Surface |
| BTAG | Biological Technical Assistance Group |
| BTEX | Benzene, Toluene, Ethylbenzene and Xylenes |
| CALs | Corrective Action Limits |
| CAP | Corrective Action Plan |
| CEHT | Center for Environmental And Human Toxicology |
| COC(s) | Chemicals of Concern |
| COPC(s) | Chemicals of Potential Concern |
| CRF | Concentration Reduction Factor |
| CSA | Closure Site Assessment |
| CW | Compliance Well |
| DAF | Dilution Attenuation Factor |
| DIGC | Direct Ingestion of Groundwater Concentration |
| DOE | Department of Energy |
| DU | Decision Unit |
| ECOSSL | Ecological Soil Screening Level |
| EPA | Environmental Protection Agency |
| EA | Environmental Assessment |
| FID | Flame-Ionization Detector |

| | |
|---|---|
| FP | Free Product |
| GIS | Global Information System |
| GRP | Groundwater Resource Protection |
| GSA | Geological Survey of Alabama |
| HEAST | Health Effects Assessment Summary Table |
| HQ | Hazard Quotient |
| HI | Hazard Index |
| IELCR | Individual Excess Lifetime Cancer Risk |
| IRIS | Integrated Risk Information System |
| IUR | Inhalation Unit Risk |
| LEL | Lower Explosive Limit |
| LUC | Land-Use Control |
| MCL(s) | Maximum Contaminant Level(s) |
| MTBE | Methyl Tertiary Butyl Ether |
| NAF | Natural Attenuation Factor |
| NFA | No Further Action |
| NOR | Notification of Requirements to Conduct Investigative and Corrective Action |
| OSHA | Occupational Safety and Health Administration |
| PAH(s) | Polynuclear/Polycyclic Aromatic Hydrocarbons |
| PEL(s) | Permissible Exposure Limits |
| PI | Preliminary Investigation |
| PID | Photo-Ionization Detector |
| POE | Point of Exposure |
| PPM | Parts per Million |
| RBCA | Risk-Based Corrective Action |
| RBTL | Risk-Based Target Level |
| RfC | Reference Concentration |
| RfD | Reference Dose |
| $RfD_{ABS}$ | Absorbed Reference Dose ($RfD_O$ * ABS $_{GI}$) |
| RM-1 | Risk Management Level-1(evaluation) |
| RM-2 | Risk Management Level-2 (evaluation) |

| | |
|---|---|
| RNA | Remediation by Natural Attenuation |
| RSL | Regional Screening Level |
| CSM | Conceptual Site Model |
| $SF_O$ | Oral Slope Factor |
| $SF_{ABS}$ | Absorbed Slope Factor ($SF_O$ / $ABS_{GI}$) |
| SG | Specific Gravity |
| SI | Secondary Investigation |
| SQAGs | Sediment Quality Assessment Guidelines |
| SW | Sentry Well (formerly, Point-of-Compliance Well) |
| SWAA | Source Water Assessment Area |
| TPH | Total Petroleum Hydrocarbons |
| TT | Treatment Technique |
| USEPA | United States Environmental Protection Agency |
| USGS | United States Geological Survey |
| VISL | Vapor Intrusion Screening Level |
| WHPA | Well Head Protection Area |
| 7Q10 | 7Q10 is the lowest flow in a stream averaged over a seven day period that has a recurrence frequency of once in ten years in other words, *i.e.*, on an average, the low flow occurs once every ten years. |

# APPENDIX B - TABLE OF CONTENTS

# APPENDIX B

# ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

# APPENDIX B
# ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

---

## B.1 BACKGROUND

When the ARBCA process is performed in the forward mode, representative concentrations are necessary to estimate the risk (individual excess lifetime cancer risk for carcinogenic effects or the hazard quotient for non-carcinogenic adverse health effects) for each receptor, for each complete route of exposure (identified in the CSM), and each COC. In the forward mode, site-specific, risk management decisions are based on a comparison of the cumulative, estimated risk with the regulatory specified target risk levels. Thus, the outcome of an ARBCA Evaluation critically depends on the representative concentrations. If target risk levels are exceeded, target concentrations - risk-based target levels (RBTLs) - are computed for a site using the backward mode. The calculation of representative concentrations is complicated by several factors. These include (i) spatial variability in the concentrations, (ii) temporal variability in the concentrations, and (iii) lack of sufficient site-specific concentration data. To account for these factors, several methodologies have been used in risk assessments to estimate the representative concentrations. These include the use of (i) a maximum concentration, (ii) a statistically estimated concentration such as the upper bound of the 95th percentile confidence interval about the mean that depends on the underlying statistical distribution of the data, (iii) an arithmetic average, (iv) a volumetric average (very rarely used), and/or (v) an area-weighted average. Each of these methodologies has pros and cons and there is no uniformly accepted methodology to estimate the representative concentration. Therefore, the application of a particular methodology to estimate a representative concentration is ultimately a policy choice. To be consistent with the models used and assumptions made in the exposure assessment, either maximum concentrations or 95th Upper Confidence Limit about the mean should be used in the ARBCA evaluations. Free, publicly available software (ProUCL) to compute the upper bound on the mean is available.

Additional complications in the calculation of the representative concentrations arise because the concept of a representative concentration is often mistakenly associated with a site as opposed to an exposure pathway. Since there may be several complete pathways at a site, several representative concentrations, one for each complete pathway (*i.e.* subsurface soil – indoor inhalation, subsurface soil – outdoor inhalation, groundwater – indoor inhalation, groundwater – outdoor inhalation, *etc.*), have to be estimated. The following sections describe the concept and the methodology that should be used to estimate the representative concentrations within the ARBCA process.

***In an effort to reduce evaluation time, if the historical maximum concentrations do not cause an exceedance of the target risk levels, it would not be necessary to compute an additional representative concentration. If an exceedance occurs, the representative concentrations using the appropriate statistical method or the last 1-2 years of maximum values may be used to compute the cumulative risk levels for each pathway.***

## B.2 ARBCA GENERAL CONSIDERATIONS FOR ESTIMATING REPRESENTATIVE CONCENTRATIONS

A representative concentration is defined as a site constituent concentration for a specific chemical of concern (*i.e.*, benzene, toluene, lead, *etc.*) for a particular medium (surficial soil, subsurface soil, groundwater, surface water, *etc.*) that represents the site concentration for a particular exposure pathway. It is first used to compute the cumulative risks and hazard indices for individual receptors to determine if an unacceptable risk is present for any receptor. If target risks are exceeded, the representative concentrations are later compared to RM-1 or RM-2 risk-based target levels (RBTLs).

The estimation of the representative concentrations requires considerable professional judgement. The selection of the appropriate site values to be utilized in the ARBCA Evaluation requires proper identification of complete pathways, selection of the appropriate ED/DU for a particular pathway, and the choice of the appropriate representative concentration. Prior to performing the ARBCA evaluation, the appropriate representative concentration should be selected for the EDs/DUs for the mediums and pathways of concern.

### B.2.1 Maximum Representative Concentrations

The appropriate type of representative concentration must be selected based on the amount of data available and the spatial arrangement of the data. There are several types of representative concentrations to select from. The selection must be based on the availability of site data.

<u>Maximum Values</u> –When utilizing a maximum value, the ARBCA Evaluator needs to determine what type of maximum value is appropriate for the evaluation. Depending on the pathway and the receptor, the ARBCA procedure allows the use of a historical maximum (using entire historical data set) or a recent maximum value for a particular period of record (last 1-2 years of data). The decision to utilize the appropriate type of maximum value should be based on the stage at which the site data is being evaluated. <u>Limited amounts of site data will need to use historical maximums in many cases. When more site data, such as</u>

groundwater monitoring data, is available, the use of a recent maximum value would be appropriate.

The historical maximum is the highest detection ever recorded for each COC. The historical maximum should be used for the RSL Evaluation. The historical maximum is not necessarily utilized for the final determination of the representative concentration, unless the historical maximum happens to fall within the appropriate period of record. While the inhalation pathways allow for various types of representative concentrations to be used, the on-site and off-site groundwater ingestion pathway in RM-1 and RM-2 requires that the maximum historical value from a water use well be utilized.

The appropriate period of record will vary for soil and groundwater. Various time periods can be evaluated which include the historical maximums or the recent maximum for a particular period of record (usually 1 – 2 years of data). In the ARBCA Evaluation, it is important to use the appropriate maximum value for the appropriate pathway. Maximum values should be determined separately for both the on-site scenario and the off-site scenario.

For soil, the maximum concentration for each COC is the maximum value detected during the soil sampling program. A separate maximum value is obtained for surficial soil versus subsurface soil. Where two separate soil sampling programs occurred during different time frames and both sets of data represent the site adequately, the most recent soil data may be utilized and the maximum from that recent data set used as the representative concentration. Since most of the soil source data is obtained during the Preliminary Investigation, and the soil data determining the extent of contamination is often obtained during the Secondary Investigation, it will be necessary to look at both these of data sets to choose the appropriate representative data.

For groundwater, the recent maximum value should be considered the highest detection for each COC during the past one to two years of data, or the past four to eight sampling events, whichever yields an adequate data set. Recent maximum concentrations are determined for the on-site scenario and the off-site scenarios.

### B.2.2 Determination of the Exposure Domain/Decision Unit

The first and most critical step in the selection of an appropriate representative concentration is to identify the size and location of the area over which the representative concentration will be calculated. The exposure domain (ED), or more commonly known as the decision unit (DU), is the area over which the receptor may be exposed to the contaminated medium

### Considerations When Establishing EDs/DUs

The current and expected future use(s) of the site/property must be considered, among other factors, when establishing reasonable EDs/DUs for a property.

If the owner wishes to achieve "unrestricted use" at a site and no land-use controls are placed on the parcel (e.g., Environmental Covenant), then the ED/DU size selected should be that of a residential lot size or smaller (e.g., 1/3 ac – 1 ac.)

If the desired end state of a property is "commercial" or "industrial" use, then the ED/DU should consider the typical commercial lot size (e.g., ½ ac – 10 ac) or the typical industrial lot size (e.g., 5 ac – 100 ac or sometimes larger) while also considering the various uses of the property and locations of structures, green spaces, recreational areas, etc. Separate EDs/DUs would be likely appropriate for each of the different property uses. Many times separate EDs/DUs should be established for human exposures verses ecological exposures as generally the ecological receptors do not have well-defined boundaries. If there are multiple target species, there may need to be EDs/DUs defined for each species due to the wide variation in their roaming and feeding ranges which define their home range. In addition, the exposure pathways may vary from one ED/DU to another based on the variation in the receptors and their uses of the property.

Many times there is not enough information at a particular site to determine a specific layout or the configuration of a facility. In those cases, an alternative means of addressing the various types of property utilization would be to divide the overall property into an appropriate number of smaller EDs/DUs such that the cleanup will be protective regardless of the final development configuration.

ED/DUs should also be defined vertically, thus creating 3-dimensional (3-D) units. A surficial ED/DU would typically be defined as the surface area down to 1-ft bgs. Subsurface ED/DUs extend to the water table or bedrock and should be defined as 3-D intervals not to exceed 5ft in thickness.

A possible example is that of a 10-acre, unrestricted use scenario site with groundwater at a depth of 10 ft bgs. Such a site could yield as many or more than 30 EDs/DUs. In this example, there could be ten 1-ac surficial portions from 0-1 ft bgs, ten 1-ac portions from 1-6 ft bgs, and ten 1-ac portions from 6-10 ft bgs. If this site also contained sensitive ecological receptors, there could be even more EDs/DUs based upon the receptors home range and typical behavior patterns.

(surficial soil, subsurface soil, groundwater, or soil vapor). The ED/DU must be established for the on-site scenario as well as any off-site affected or potentially affected properties. Separate domains or units may also exist for current scenarios versus future scenarios.

For example, at a site where a groundwater plume exists below an on-site, commercial building and has also migrated off site under a residential building, separate representative concentrations must be established for the commercial scenario and the residential scenario. A representative concentration for the on-site, commercial property would be developed, and a representative concentration for the off-site residence would be established. These would be two different data sets. For this example, there would be separate RBTLs used in the ARBCA Evaluation due to differing land uses, and there would be different representative concentrations established for the on-site and off-site scenarios.

In the case where there is an off-site, commercial property as well as an on-site commercial property, the EDs/DUs would be different due to the on-site/off-site situation, but there would likely be the same RBTLs calculated if there are the same types of human receptors and activities, such as a commercial worker present on both properties working similar hours in a similar environment. Separate representative concentrations would be established – one for the on-site, commercial worker and one for the off-site, commercial worker. However, if the activities were different at the two sites or one had established an Environmental Covenant in accordance with ADEM Admin. Code div. 335-5 and the other had not, the RBTLs may be different. Different RBTLs may also be different within a site that may be diverse in nature with a variety of activities occurring at the site – this would be typical of larger, more complex sites.

In addition to the on-site/off-site situation, an evaluation for current and future exposures should be conducted. This evaluation requires significant professional judgement to determine the ED/DU for the current and future exposure scenarios. The determination of the ED/DU for a future scenario depends on the existing knowledge of the future construction/development plans. The following decision making process should be used for determining the future ED/DU for indoor and outdoor inhalation:

A. If actual plans exist for location of a new building (enclosed space), the footprint of the building should be used to define the exposure domain for the future indoor inhalation evaluation.

B. If actual construction/development plans do not currently exist for a new building (enclosed space), then (1) estimate the potential dimensions of the building (may be the size of a current, on-site building), (2) place this estimated building footprint over the area that yields the highest representative concentration. Remember, the defined area yielding the highest representative concentration is likely to be different for surficial soil, subsurface soil, and groundwater.

Maps showing the defined areas for current and future, indoor and outdoor exposure scenarios for the various media should be supplied within the ARBCA Report.

Because a site may have varying EDs/DUs for a current scenario versus a future scenario, separate representative concentrations should be calculated which represent these two scenarios. Due to the uncertainty regarding the future use of property, it is expected that an Environmental Covenant will be placed on all properties or areas of property where the future use of the property is not considered to be an “unrestricted scenario.”

### B.2.3 Documentation of the Selection of the Representative Concentrations

Detailed documentation of the calculation of the representative concentration should be included in the ARBCA Report. Information should include:

- Maps indicating the EDs/DUs selected for the various media, complete exposure pathways for both on-site and off-site scenarios, and current and future scenarios.
- Tables listing the soil boring and monitoring well data used in determining the representative concentration for each boring or well. All data should be listed and the data utilized in the determination of the representative concentrations clearly noted.
- Tables including the calculated representative concentration for each pathway and medium.

## B.3 CALCULATION OF REPRESENTATIVE CONCENTRATIONS

As mentioned above, a representative concentration is necessary for each complete exposure pathway at a site. Based on the pathways considered in the ARBCA process, the following representative concentrations are necessary for each medium:

### B.3.1 Surficial Soil

The ARBCA process requires the evaluation of two routes of exposure associated with the surficial soil. These are (i) the ingestion of chemicals in groundwater due to leaching of residual chemicals in the surficial soil, and (ii) accidental ingestion of, dermal contact with, and outdoor inhalation of vapors and particulates from surficial soil. Thus, at least, two different surficial soil representative concentrations are required; however, it is possible that the representative concentrations may be the same. Where multiple surficial spills or leaks have been delineated at a site, separate evaluations may need to be performed for the various contaminated surficial soil areas.

#### B.3.1.1 Representative Surficial Soil Concentration for the Groundwater Resource Protection Evaluation and the Surface Water Protection Evaluation

Surficial soil and subsurface soil concentrations protective of groundwater or surface water resources are estimated based on the Domenico (1990) model. Figure B-1 shows the schematic of Domenico's model illustrating soil leaching to groundwater. This model assumes that the leachate from the surficial or subsurface soil source travels vertically downward to the water table without any lateral or transverse spreading. Thus, the horizontal dimensions of the soil source and the groundwater source are assumed to be identical. For this pathway, the target soil source concentration protective of groundwater has to be compared with the representative soil source concentration that can be calculated as discussed below.

The representative soil source concentration should be estimated using the soil data within the source area. Thus, prior to estimating the representative concentration, it is necessary, to (i) clearly locate the horizontal dimensions of the source, and (ii) identify the surficial and/or subsurface soil data available within the source area. The representative concentration can then be estimated within this source area.

#### B.3.1.2 Representative Soil Concentrations for Dermal Contact, Ingestion, and Inhalation of Vapors and Particulates

For this pathway, the representative surficial soil concentration should be based on the receptor's ED/DU, *i.e.*, the area over which the receptor may be exposed to the surficial soil. The exact ED/DU of the receptor is very difficult to estimate especially since the exposure area should be representative of a period of time equal to the receptor's exposure duration.

To estimate the representative concentration for this pathway, it would be necessary to (i) estimate the receptor's EDs/DUs, and (ii) determine the number of surficial soil samples available within the ED/DU. This information should be used to estimate the representative concentration. The maximum value for each chemical within the ED/DU may also be utilized, if appropriate. The appropriate value should be determined and reported within the ARBCA Report.

### B.3.2 Subsurface Soil

The ARBCA process includes three routes of exposure associated with subsurface soil. These three routes are all considered indirect exposure pathways. These are (i) the ingestion of chemicals in groundwater due to the leaching of residual concentrations from subsurface soil, (ii) indoor inhalation of vapor emissions, and (iii) outdoor inhalation of vapor emissions. Therefore, three different subsurface soil representative concentrations may be required.

### B.3.2.1 Representative Subsurface Soil Concentration for the Groundwater Resource Protection and Surface Water Protection Evaluations

Referring to Figure B-1, the leachate from the subsurface soil is assumed to travel vertically downward without any lateral or horizontal spreading. Therefore, the representative concentration for this pathway should be based on the concentrations measured within the source area.

As in the case of surficial soil concentrations protective of groundwater, discussed in Section B.3.1.1, the representative subsurface soil source concentration should be determined using the most appropriate statistical method. The maximum value in the source area may also be utilized, if appropriate.

The subsurface soil source representative concentrations should be compared with the surficial soil source representative concentrations. The higher value should be used in the Groundwater Resource Protection and Surface Water Protection Evaluations.

### B.3.2.2 Representative Subsurface Soil Concentrations for the Protection of Indoor Inhalation

Subsurface soil concentrations protective of indoor inhalation are estimated following the EPA guidance documents, *Addressing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. The appropriate guidance should be followed when estimating the risk due to the vapor intrusion pathway. The Department retains the discretion to adopt or approve approaches on a case-by-case basis that differ from the cited guidance documents, where appropriate.

### B.3.2.3 Representative Subsurface Soil Concentrations for Protection of Outdoor Inhalation

Subsurface soil concentrations protective of outdoor inhalation are estimated based on the Johnson and Ettinger model that assumes no lateral or transverse spreading of the vapors as they travel upward through the unsaturated zone. Thus, the representative concentration should be estimated based on subsurface soil measurements within the receptor's ED/DU. The ED/DU is the area that the receptor is likely to be able to access on the property and perform outdoor activities. In the absence of site-specific information about the receptor's activity patterns, the delineation of this domain remains subjective.

To estimate the representative subsurface soil concentration for this pathway, it is necessary to (i) identify the ED/DU of the outdoor breathing zone for the current receptor, (ii) identify the ED/DU of the outdoor breathing zone for the potential future receptor, and (iii) identify the soil concentration data available within each of these two domains/units. The representative concentration would be the arithmetic average concentration within each domain. The maximum value for each chemical within the domain/unit may also be utilized, if appropriate. If data are not available within the area, data adjacent to the ED/DU may be used. If the ED/DU of the current and future outdoor breathing zones are different, two different representative concentrations, one for current conditions for each COC and one for future conditions for each COC, may be necessary.

Where subsurface soil concentrations are located on-site and off-site, separate representative concentrations must be established to compute risks and to compare to receptor specific target levels. Where off-site data is not readily available, the nearest on-site data could be used as “mirror” data and assumed to be representative of adjacent, off-site conditions.

### B.3.3 Groundwater

The ARBCA process requires the evaluation of five routes of exposure associated with groundwater. These are the (i) current onsite ingestion of groundwater, (ii) protection of the groundwater resource for off-site and/or future groundwater ingestion, (iii) indoor inhalation of vapor emissions from groundwater, (iv) outdoor inhalation of vapor emissions from groundwater and (v) protection of surface water. Thus, five or more different groundwater representative concentrations may be required.

#### B.3.3.1 Representative Groundwater Concentration for Current, On-site and Off-site Ingestion of Groundwater

For the current, on-site and off-site ingestion of groundwater pathway, MCLs or equivalent concentrations have to be met at the current point of exposure (POE) well. This would include any inactive or active drinking water well or other well which can supply water for ingestion. Two sets of data need to be evaluated for this pathway. Data from the actual water supply (water use) well(s) allow for evaluating the current exposure. Data from monitoring wells (which can be “source wells” and sentry wells) can provide for an evaluation of a potential future impact to existing well(s).

Data from the actual water supply well or POE well is compared against the established MCLs or groundwater target levels. Historical maximum data is used as the representative concentration.

After identifying the available groundwater monitoring data from the site, source area well(s) at the source area and several sentry wells (SWs) located between the source area and the water supply well would need to be determined. Representative concentrations in those wells should be determined looking at the last 1-2 years of well data. The ARBCA Evaluator should use the appropriate equations located in Appendix E to determine allowable chemical concentrations for SWs based on the proximity of these wells to the water supply well.

Since this is a direct exposure pathway, care should be taken in ensuring protection of the water supply well. The Groundwater Resource Protection Evaluation must be performed to evaluate potential future impacts.

#### B.3.3.2 Representative Groundwater Concentration for Groundwater Resource Protection.

This pathway is required for each ARBCA Evaluation, in the RSL Evaluation, in the RM-1 Evaluation, and in the RM-2 Evaluation. This evaluation is performed to determine acceptable soil and groundwater concentrations protective of a current or future off-site, drinking water well. For this pathway, MCLs or equivalent drinking water concentrations must be met at the POE well. See Section 6.9 of the ARBCA guidance manual for further discussion of the proper location of the POE.

An important aspect of the Groundwater Resource Protection Evaluation is the selection of several existing monitoring wells as SWs. In addition to determining the POE for the Groundwater Resource Protection Evaluation, several SWs have to be located and target SW concentrations have to be calculated at these wells. This includes "source area" monitoring wells located at or very near the soil source. For most sites, several SWs should be identified that are located between the source and the POE to allow for fluctuating or unresolved groundwater flow directions. Therefore, representative concentrations for several SWs need to be established.

For the evaluation of this pathway, the representative concentration should be calculated based on the measured SW concentrations. The Groundwater Resource Protection Evaluation is a “well to well” comparison, and therefore, area-weighted averaging is not used for groundwater. The following discussion applies to both the groundwater source well and the sentry wells located between the source and the POE:

- For sentry wells with fluctuating concentrations, the representative concentration is estimated as the arithmetic average of the recent two years or recent eight measurements, whichever represents the longer time duration. Consecutive quarterly monitoring is considered optimum.
- For sentry wells with a clear decreasing trend, the representative concentration is estimated as the arithmetic average of the recent one year of data or recent four measurements, whichever represents the longer time duration.
- For sentry wells with a clear increasing trend, the representative concentration is estimated as the arithmetic average of the recent one year of data or recent four measurements, whichever represents the shorter duration. Note that for wells with increasing concentration trends, continued monitoring, at a minimum, will be required until the trend stabilizes.

Documentation of the well data utilized in determining the representative concentrations should be included in the ARBCA Report. This is usually a table of the historical concentrations of the chemicals of concern in each well, for every monitoring event. Where significant data gaps exist or available data does not appear to be adequate, additional sampling and therefore, recalculation of the representative concentrations may be required upon the Department's review of the report. It may be necessary in situations where there is a high degree of uncertainty to use maximum concentrations.

#### B.3.3.3 Representative Groundwater Concentrations for Protection of Indoor Inhalation

Groundwater concentrations protective of indoor inhalation are estimated using the Johnson and Ettinger (1991) model as the basis. In June 2015, the USEPA published two documents that focus on the assessment of vapor intrusion at sites, the *Technical Guide for Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and the *Technical Guide for Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. In addition, the ITRC has published two helpful guidance documents, *Vapor Intrusion Pathway: A Practical Guideline* and *Petroleum Vapor Intrusion*. These documents should be utilized to determine the most appropriate method to determine the representative concentrations for groundwater that will be protective of groundwater at a site. When evaluating the vapor intrusion pathway, the Department's project manager should be contacted and the method planned for use should be discussed and agreed upon prior to mobilization of sample collection activities.

### B.3.3.4 Representative Groundwater Concentration for Protection of Outdoor Inhalation

The method used to estimate the groundwater representative concentrations for this pathway is very similar to the method used for the indoor inhalation pathway, discussed in B.3.3.3. The representative concentration should be based on the data collected within the domain of the breathing zone of the receptors. Both current and future receptor domains should be considered. Therefore, several different representative concentrations may have to be estimated.

Since the arithmetic or area-weighted average for a current scenario may be different from a future scenario, the higher of the two values should be selected as the representative concentration for the outdoor inhalation pathway for groundwater.

### B.3.3.5 Representative Groundwater Concentration for Protection of Surface Water

The development of representative groundwater concentrations for protection of surface water is very similar to the procedure for determining representative concentrations for the Groundwater Resource Protection Evaluation. The surface water body is the "point of exposure." Target levels for the stream are calculated using the appropriate equation and water body designation per ADEM Admin. Code ch. 335-6-10. Target levels for stream sentry wells must be calculated. Both source area monitoring wells and stream sentry monitoring wells must be established. The source wells are located in or near the soil source area. Several stream sentry wells are established which are located between the source area and the surface water body. Once these wells are established, then the representative concentrations are determined as discussed in Section B.3.3.2.

## B.4 GENERAL CONSIDERATIONS FOR SELECTION OF APPROPRIATE SITE DATA

The estimation of the representative concentrations requires considerable professional judgement. Prior to performing the computations, the following should be considered.

### B.4.1 Surficial and Subsurface Soil Concentrations

The following considerations are necessary to evaluate whether existing soil data is representative.

- Evaluate whether the spatial distribution of the data is sufficient to define the release. Whereas the exact number of samples cannot be specified, data should be available from the areas of known, or likely, sources. Also, both surficial and subsurface soil data may be necessary.
- If the data are "old" (> 4 years old) and the concentrations exceed the RSLs, it may be useful to collect new data. Old data may be disregarded if sufficient new data are collected. A new release will always require the collection of additional data.
- If there is a sufficient number of soil samples within the exposure domain/decision unit the 95% UCL about the mean may be used rather than using the maximum concentrations. US EPA's software, ProUCL may be used to generate the representative concentration. Please note that in order not to violate the Central Tendency Theorem, generally 30-50 or more samples must be available for the calculation.
- Non-detect soil samples located at the periphery of the selected ED/DU should not be used.
- Non-detect samples within the ED/DU may be replaced by half their detection limits if detection limits are less than the appropriate RSL. If detection limits are greater than RSL, the ARBCA Evaluator should use the detection limit as the sample concentration.
- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole, in some cases it may be appropriate for these to be averaged to estimate the concentrations representative of the area elements. Prior to averaging the concentrations, the Department should be contacted and the site should receive concurrence in the matter. Surficial and subsurface soil samples should not be averaged together.

### B.4.2 Groundwater Concentrations

The following steps are necessary to determine the representative groundwater concentrations:

- To account for the temporal variation in groundwater concentrations, the concentration in a single well may be estimated as:

A. For a well with fluctuating concentrations, the representative concentration is estimated as the maximum concentration over the recent two years or recent four measurements.

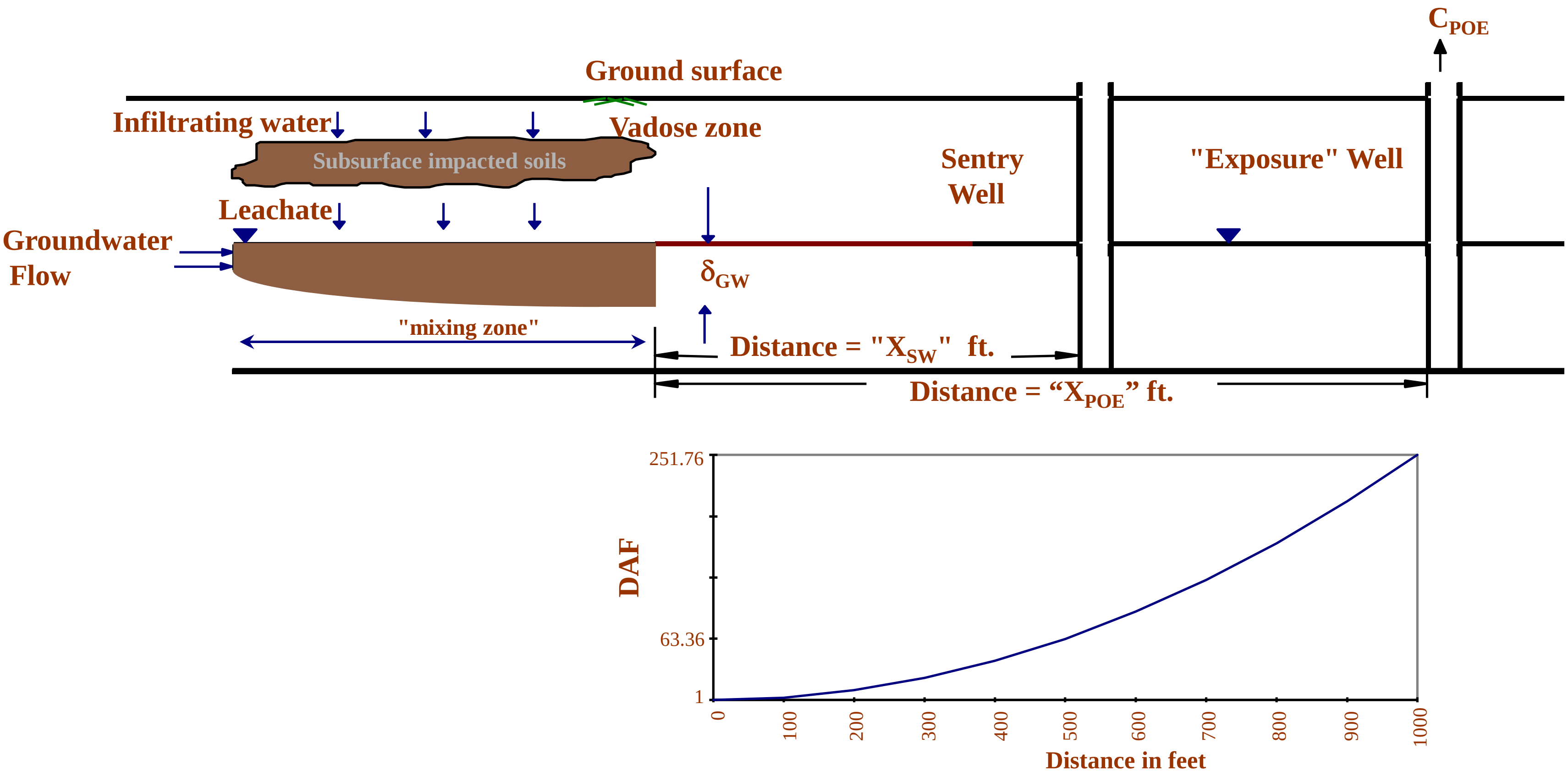
B. For a well with a clear decreasing trend, the representative concentration is estimated as the maximum concentration of the recent two years of data or recent four measurements, whichever represents the shorter time duration.

C. For a well with a clear increasing trend, the representative concentration is estimated as the maximum concentration of the recent two years of data or recent four measurements, whichever represents the shorter duration. Note that for wells with increasing concentration trends, continued monitoring, at a minimum, will be required until the trend stabilizes.

D. Non-detect samples may be replaced by half their detection limits if detection limits are less than the appropriate RSL. If detection limits are greater than the RSL, the ARBCA Evaluator should use the detection limit as the sample concentration.

E. Wells with concentrations consistently below detection limits in the periphery of the ED/DU should not be used.

- For a well that contained free product during a sampling event, the representative concentration of that sampling event would be the effective solubility of the chemical or the highest measured concentration at that site, whichever is higher. Note that wells currently containing free product will be required to undergo corrective actions to remove the product. See the “Chemical Specific Parameters” table located in in the RSL Generic Tables for effective solubility. More information describing the calculation of the effective solubility of a chemical and an effective solubility calculator may be found on *EPA’s On-Line Tools for Site Assessment Calculation* site.



Allowable groundwater concentration at the source protective of a POE located at a distance $X_{POE}$ from the source = $C_{POE}$ x $DAF_{POE}$

Allowable groundwater concentration at a sentry well, located at a distance $X_{SW}$ from the source,
protective of a POE located at a distance $X_{POE}$ from the source = $C_{POE}$ x $DAF_{POE}/DAF_{SW}$

Allowable soil concentration at the source protective of a POE located at a distance $X_{POE}$ from the source = $C_{POE}$ x $DAF_{POE}/LF_{SW}$

**FIGURE B-1. CALCULATION OF GROUNDWATER RESOURCE PROTECTION TARGET LEVELS**

# APPENDIX C
# CONCENTRATIONS PROTECTIVE OF A STREAM

# APPENDIX C
# CONCENTRATIONS PROTECTIVE OF A STREAM

## C.1 BACKGROUND

While performing an ARBCA Evaluation at a site, it is necessary to identify surface water bodies (lakes, perennial streams, drainage ways, intermittent streams, wetlands, *etc.*) located near the site. These streams may be affected by the discharge of a groundwater plume into the surface water body. Surface water bodies located within 500 feet from the downgradient edge of the groundwater plume should be identified. At sites where such surface water bodies have been identified, the ARBCA process requires the back calculation of allowable concentrations for the soil source, groundwater source, and stream sentry well(s) protective of the stream. The method used to develop these target levels is presented in the following sections.

## C.2 METHODOLOGY

A schematic of the potential migration of chemicals of concern (COCs) from the soil source to the stream is shown in Figure C-1. Residual COC concentrations at the soil source could potentially leach into groundwater below the source. This leachate would mix with the regional groundwater directly below the site and migrate in the downgradient direction towards the stream. Upon reaching the stream, the plume would discharge into the stream and mix with the water in the stream. At a certain distance downstream of the groundwater plume discharge point, the COCs discharged into the stream would completely mix with the water in the stream.

The method used to calculate RM-1 and RM-2 allowable soil and groundwater concentrations protective of streams is based on numerous conservative assumptions. These include (i) a steady-state groundwater plume, (ii) a steady-state flow in the stream, and (iii) no loss of COCs in the stream due to natural attenuation processes such as adsorption to the sediments, volatilization from the stream, *etc.* Further, in an RM-1 Evaluation, surface water standards and equations listed in ADEM Admin. Code ch. 335-6-10 must be met at the point of discharge, *i.e.*, mixing within the stream is not considered in the RM-1 calculation.

Estimation of allowable soil source concentrations protective of streams are computed using the following steps:

### Step 1: Identify streams potentially affected by COCs at the site

The objective of this step is to identify surface water bodies located near the site that may be affected by the COCs at the site. Surface water bodies include intermittent streams, drainage ditches, creeks, ponds, perennial streams, wetlands, and lakes. Surface water bodies located within 500 feet of the downgradient edge of the site should be identified, unless otherwise required by the Department. These surface water bodies should be located on a site map as well as a topographic map. The water use should also be identified per ADEM Admin. Code r. 335-6-10-.03. Surface water intakes for public water supply, located within 1 mile downstream of the site, should also be identified.

### Step 2: Identify concentration(s) upstream ($C_{su}$) of the groundwater discharge

The background concentration in a stream should be measured. Background concentration is defined as the concentration in the stream, upstream of the location where the impacted groundwater plume discharges into the stream. Measurement of this concentration may help identify any upstream sources of contamination. This measured concentration is represented as $C_{su}$.

### Step 3: Estimate the allowable concentration of each COC in the stream ($C_{str}$)

Target surface water concentrations should be calculated using the criteria presented in ADEM Admin. Code ch. 335-6-10 for the appropriate use classification. In Equation C-1, these concentrations are represented as $C_{str}$.

### Step 4: Estimate the allowable concentration in the groundwater at the point of discharge ($C_{gw}$)

For an RM-1 Evaluation, groundwater concentrations at the point of discharge, $C_{gw}$, are set equal to the allowable stream concentration, $C_{str}$. Thus, for an RM-1 Evaluation, mixing within the stream is neglected. For an RM-2 Evaluation, mixing within the stream is used, *i.e.*, the allowable stream concentrations, $C_{str}$, have to be met at the downstream edge of the mixing zone within the stream. The allowable groundwater concentrations at the point of discharge can be estimated using the following mass balance equation:

$$C_{gw} = \frac{C_{str}\left(Q_{gw} + Q_{sw}\right)}{Q_{gw}} - C_{su}\left(\frac{Q_{sw}}{Q_{gw}}\right) \quad \text{(C-1)}$$

Where:

$Q_{gw}$ = Impacted groundwater discharge into the stream ($ft^3$/day)

$C_{gw}$ = Allowable concentration in groundwater at the point of discharge into the stream (mg/L)

$Q_{sw}$ = Stream flow upstream of the point of groundwater discharge (stream flow rate) ($ft^3$/day)

$C_{str}$ = Allowable downstream concentration at the downstream edge of the stream's mixing zone (mg/L)

$C_{su}$ = The COC's concentration upstream of the groundwater plume discharge (mg/L)

The impacted groundwater discharge, $Q_{gw}$, in Equation C-1, is estimated as follows:

$$Q_{gw} = U_{gw} \times 8.99 \times 10^{-5} \times A_{gw} \quad \text{(C-2)}$$

$$U_{gw} = K \times i \quad \text{(C-3)}$$

Where:

$U_{gw}$ = Groundwater Darcy velocity (cm/year)

$K$ = Hydraulic conductivity of the saturated zone (cm/year)

$i$ = Hydraulic gradient (cm/cm)

$A_{gw}$ = Cross sectional area of impacted groundwater flow ($ft^2$)

$8.99\text{x}10^{-5}$ = Conversion factor (cm/year to ft/day)

In Equation C-2, $A_{gw}$ is estimated as:

$$A_{gw} = L_p \times D_p \quad \text{(C-4)}$$

Where:

$L_p$ = Width of the groundwater plume discharging to the stream (ft)

$D_p$ = Thickness of the groundwater plume discharging to the stream (ft)

For an RM-1 Evaluation, the dimensions of the plume discharging into the stream can be estimated as (Domenico and Palciauskas, 1982):

$$L_p = \frac{Y}{30.48} + 2\sqrt{\alpha_y X_s} \tag{C-5}$$

$$D_p = \frac{\delta_{gw}}{30.48} + \sqrt{\alpha_z X_s} \tag{C-6}$$

Where:

$Y$ = Width of the soil source perpendicular to the flow direction (cm)
$\delta_{gw}$ = Groundwater mixing-zone thickness (cm)
$X_s$ = Distance from the downgradient edge of the groundwater source to the stream (ft)
$\alpha_y$ = Lateral dispersivity (ft)
$\alpha_z$ = Vertical dispersivity (ft)
30.48 = Conversion factor (cm/ft)

In Equation C-5 and C-6, $\alpha_y$ and $\alpha_z$ can be estimated as:

$$\alpha_y = \frac{X_s}{30} \tag{C-7}$$

$$\alpha_z = \frac{X_s}{200} \tag{C-8}$$

For an RM-2 Evaluation, the width of the groundwater plume may be estimated using Equation C-5 or measured at the site. To measure the width of the plume that discharges into the stream, monitoring wells must be installed along the stream bank. Other measurement procedures may be utilized if accepted by the Department. The method proposed should be included in a written plan submitted to the Department.

For an RM-2 Evaluation, the Department requires that the $7Q10$ flow (Defined in Equation C-9) be used to estimate the upstream flow, $Q_{sw}$, in Equation C-1. When flow data is available, the Department prefers the use of the Ratio Method. The application of flow data from USGS gages makes the assumption that flow is proportional to drainage area. This is a fairly accurate assumption as long as flow characteristics at the gage and the location of interest are similar. Flow characteristics refer primarily to the recession indices present in the watershed above the location of interest and, to a lesser extent, the mean annual precipitation in the watershed above the location of interest. The longer the period of record for the gage, the more accurate the estimates tend to be (for the gage itself). For streams that are gauged, the 7$Q$10 can also be obtained directly from Atkins and Pearman (1994) or by calling a local U.S. Geological Survey Hydrological office. This is the less preferred method but is acceptable if the Ratio Method is not feasible. This flow rate is estimated using the method developed by Bingham (1982) and consists of a regression equation using a base-flow recession index, drainage area, and mean annual precipitation. This method can be used to estimate low flow in streams with drainage areas of 5 to 2,460 square miles. If there are questions regarding the determination of 7$Q$10 flow, the Chief of the Technical Support Section of the Water Quality Branch of the Water Division should be contacted for assistance.

The specific regression equation takes the form:

$$7Q10 = 0.15\times10^{-5}\times(G-30)^{1.35}(A)^{1.05}(P-30)^{1.64} \tag{C-9}$$

Where:

7$Q$10 = Estimated stream flow (ft$^3$/s)

$G$ = Stream flow recession index (unitless) (determined from gauge data using the Geological Survey of Alabama (GSA) maps and references, in absence of GSA gauge data as last resort, $G$ may be determined from Bingham, 1982)

$A$ = Contributing drainage area (square miles)

$P$ = Mean annual precipitation (inches)

The mean annual precipitation should be obtained from the NOAA website and the rain data that is closest to the area of interest should be utilized. In order to locate the annual precipitation data go to “browse datasets” – “annual summaries” – then use either the search tool to query by location or the GIS mapping tool to find a station. For a quick, less accurate reference, the Northwest Alliance for Computational Science and Engineering produces a useful Average Annual Precipitation map for Alabama. See Section 6.7.2.5.2 - Infiltration rate, "I", for additional sources of rainfall data.

For situations where the site is located in an area with more than one stream index, compute the 7$Q$10 for the entire drainage area using each index, then calculate the estimated 7$Q$10 based on a weighted average. For example, for a site with a drainage area of 75 square miles and 55 in. of annual precipitation, 70% of the drainage is in an area with an index of 50, and 30% is in an area with an index of 100, calculate the 7$Q$10 for both indices using the total drainage area as shown below:

Example: Drainage using first index

$$7Q10 = 0.15 \times 10^{-5} \times (50 - 30)^{1.35} (75)^{1.05} (55 - 30)^{1.64}$$

$7Q10 = 1.6$ cfs

Drainage using second index

$$7Q10 = 0.15 \times 10^{-5} \times (100 - 30)^{1.35} (75)^{1.05} (55 - 30)^{1.64}$$

$7Q10 = 8.5$ cfs

Determine the weighted average based on the 70 and 30 percent of the basin draining each area.

1.6 cfs (0.7) = 1.1 cfs
8.5 cfs (0.3) = 2.6 cfs
Weighted avg = 3.7 cfs, therefore the 7Q10 = 3.7 cfs

The $7Q10$ estimated from Equation C-9 can be converted to $Q_{sw}$ using the following equation:

$$Q_{sw} = 7Q10 \times 86{,}400 \qquad \text{(C-10)}$$

Where:

86400 = Conversion factor (seconds/day)

For streams with a drainage area less than 5 square miles, streams with intermittent flow, or wetlands, $7Q10$ is assumed to be zero

### **Step 5: Estimate the allowable concentration in groundwater at the source ($C_{gws}$) and the stream sentry wells ($C_{cw}$)**

The allowable groundwater concentration at the source protective of the stream can be estimated using the concept of the dilution attenuation factor. Thus, the allowable groundwater concentration at the source, $C_{gws}$, can be estimated as:

$$C_{gws} = C_{gw} \times DAF_{stream} \qquad \text{(C-11)}$$

Where:

$C_{gws}$ = Allowable concentration in groundwater below the source (mg/L)

$DAF_{stream}$ = Dilution attenuation factor in the saturated zone between the source and the stream [unitless]

$C_{gw}$ = Allowable groundwater concentration at the point of discharge to the stream, estimated using Equation C-1 in RM-2 (mg/L). In RM-1, $C_{gw} = C_{str}$

The target concentration in a stream sentry well located between the source and the stream, can be estimated as follows:

$$C_{sw} = \frac{DAF_{stream}}{DAF_{sw}} \times C_{gw} \qquad \text{(C-12)}$$

Where:

$C_{sw}$ = Allowable concentration at the stream-sentry well [mg/L]

$DAF_{stream}$ = Dilution attenuation factor in the saturated zone between the source and the stream (unitless)

$DAF_{sw}$ = Dilution attenuation factor in the saturated zone between the source and the stream-sentry well (unitless)

Note that the concept quantified by Equation C-12 is also used to develop the sentry-well concentrations for the protection of the groundwater resource (refer to Section 6.11).

For RM-1 and RM-2 Evaluations, the $DAF_{stream}$ and $DAF_{sw}$ can be calculated using the simplified version of Domenico's model, as discussed in Section 6.11. For the specific form of the Domenico's model, refer to Appendix E.

### Step 6: Estimate the allowable soil-source concentration ($C_{soil}$)

The allowable soil-source concentration can be conservatively estimated assuming no attenuation in the unsaturated zone, *i.e.*, the leachate concentration at the soil source is identical to the leachate concentration reaching the water table. The source soil concentration can be estimated as:

$$C_{soil} = \frac{C_{gw} \times DAF_{stream}}{LF_{sw}} \qquad \text{(C-13)}$$

Where:

$C_{soil}$ = Allowable source soil concentration (mg/kg)

$LF_{sw}$ = Leaching factor from soil to groundwater [(mg/L-$H_2O$)/(mg/kg-soil)]

See Appendix E of the ARBCA guidance document for the equation to calculate the leaching factor.

## C.3 IMPLEMENTATION OF THE ABOVE METHOD

To implement the above method in RM-1, the user must determine (i) the distance from the source to the downgradient stream, (ii) the location of the stream sentry wells, and (iii) distance from the source to the stream sentry wells.

The allowable soil source concentrations have to be compared with the representative soil source concentrations at a site to determine if the representative soil source concentrations are protective of the stream. In addition, the allowable groundwater source concentration has to be compared with the representative groundwater source concentrations.

The RM-1 target groundwater concentrations in the stream sentry wells can be calculated using Equation C-12.

The stream sentry well target concentrations have to be compared with the representative stream sentry well concentrations to determine whether the stream sentry well concentrations are protective of the stream. Refer to Appendix B for procedures to develop representative stream sentry well concentrations.

The equations in Appendix E can be used to calculate the allowable soil and groundwater source concentrations and the stream sentry well concentrations. The data required are listed below (parameters in *italics* are used only for the estimation of target levels protective of streams):

### Stream Data

| | |
|---|---|
| Distance from the downgradient edge of the groundwater source to the stream ($X_s$) | - to calculate $DAF_{stream}$, $L_p$, and $D_p$ |
| Mean Annual precipitation in the area (P) | - to calculate 7Q10 |
| Stream flow recession index (G) | - to calculate 7Q10 |
| Contributing drainage area (A) | - to calculate 7Q10 |
| Concentration upstream of the plume discharge ($C_{su}$) | - to calculate $C_{gw}$ |
| Allowable concentration in the stream ($C_{str}$) | - ADEM Admin. Code ch. 335-6-10 |

### Compliance Well Data

| | |
|---|---|
| Distance from the downgradient edge of the groundwater source to the Stream sentry well ($X_{s\ sw}$) | - to calculate $DAF_{sw}$ |

### Chemical Data

| | |
|---|---|
| Henry's Law constant (H) | - RSL Chemical Specific Parameters Table |
| Half-life (days), when using decay | - to calculate $DAF_{sw}$ and $DAF_{stream}$ |
| Organic carbon partition coefficient (Koc) | - RSL Chemical Specific Parameters Table |

### Aquifer Properties

| | |
|---|---|
| Hydraulic conductivity (K) | - to calculate Darcy velocity |
| Hydraulic gradient (i) | - to calculate Darcy velocity |
| Groundwater mixing zone thickness ($\delta_{gw}$) | - to calculate $LF_{sw}$, $DAF_{sw}$, and $DAF_{stream}$ |
| Infiltration rate (I) | - to calculate $LF_{sw}$ |
| Organic-carbon content in the saturated zone ($f_{ocs}$) | - to calculate retardation factor in the saturated zone |
| Saturated-zone porosity ($\theta_{TS}$) | - to calculate seepage velocity in the saturated zone |
| Saturated-zone dry bulk density ($\rho_{ss}$) | - to calculate retardation factor in the saturated zone |

### Vadose-Zone Soil Properties

| | |
|---|---|
| Total porosity ($\theta_T$) | - to calculate $LF_{sw}$ |
| Organic-carbon content (foc) | - to calculate $LF_{sw}$ |
| Water content ($\theta_{ws}$) | - to calculate $LF_{sw}$ |
| Dry bulk density ($\rho_s$) | - to calculate $LF_{sw}$ |

**Source Parameters**

| | |
|---|---|
| Length of groundwater source parallel to the groundwater flow (W) | - to calculate $LF_{sw}$ |
| Groundwater mixing-zone thickness ($\delta_{gw}$) | - to calculate thickness of plume at the point of discharge |
| Width of groundwater source perpendicular to the groundwater flow (Y) | - to calculate $DAF_{sw}$, $DAF_{stream}$, and width of plume at the point of discharge |

These values are utilized in the equations located in Appendix E to calculate the allowable concentrations protective of a stream in (i) soil at the soil source, (ii) groundwater at the groundwater source, and (iii) groundwater at the stream sentry well. Appropriate justification for using the selected values should be provided in the final report.

## Sources

Atkins, J. B., and Pearman, J. L., 1994, *Low-Flow and Flow-Duration Characteristics of Alabama Streams*, U.S. Geological Survey, Water-Resources Investigations Report, 93-4186.

Bingham, R. H., 1982, *Low-Flow Characteristics of Alabama Streams*, U. S. Geological Survey Water-Supply Paper 2083, U.S. Government Printing Office, Washington D.C.

Domenico, P. A., and Palciauskas, V. V., 1982, Alternative Boundaries in Solid Waste Management, *Groundwater*, vol. 20, no. 3, pp. 303-311.

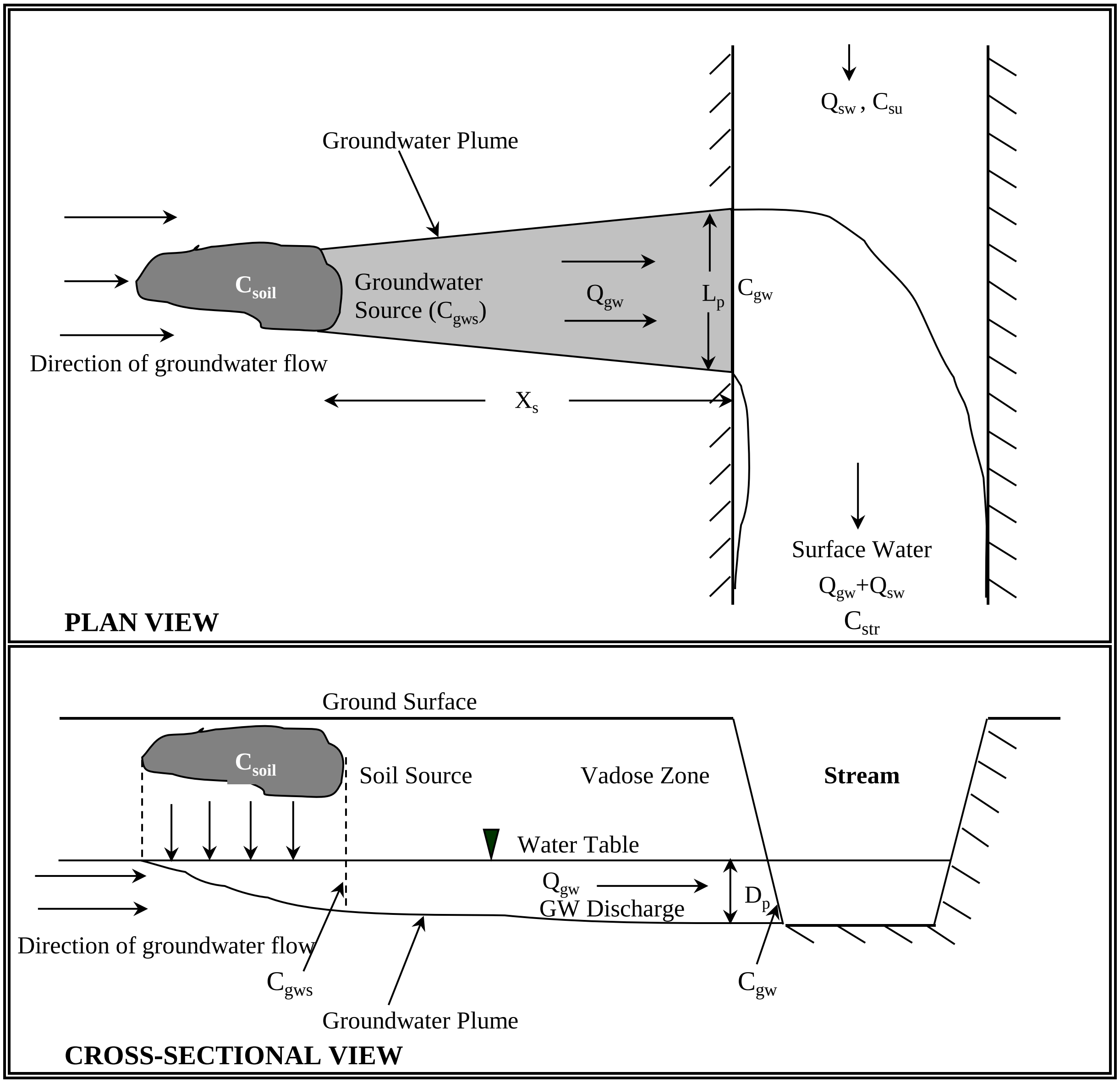


**Figure C-1: Schematic of Leachate Migration from the Soil Source to the Stream**

**Explanation of Symbols**

$Q_{sw}$ = Stream flow upstream of the point of groundwater discharge[$ft^3$/day]

$C_{su}$ = Concentration upstream of the groundwater discharge [mg/L]

$Q_{gw}$ = Impacted groundwater discharge into the stream [$ft^3$/day]

$C_{str}$ = Allowable downstream concentration after uniform mixing [mg/L]

$C_{gw}$ = Allowable concentration in the groundwater discharge to the stream [mg/L]

$C_{gws}$ = Allowable concentration in the groundwater at the edge of the soil source [mg/L]

$C_{soil}$ = Allowable soil concentration at the source [mg/kg]

$L_p$ = Width of groundwater plume discharging to the stream [ft]

$D_p$ = Thickness of groundwater plume discharging to the stream [ft]

$X_s$ = Distance from the downgradient edge of the groundwater source to the stream [ft]

# APPENDIX D

# BACK CALCULATION OF RISK-BASED TARGET LEVELS AND FORWARD CALCULATION OF RISKS AND HAZARD QUOTIENTS

# APPENDIX D
# BACK CALCULATION OF RISK-BASED TARGET LEVELS AND FORWARD CALCULATION OF RISK AND HAZARD QUOTIENT

---

## D.1 Introduction

The back calculation of risk-based target levels essentially provides the answer to the question, “To what level must I remediate my site?” Risk-based target levels (RBTLs) act as a guide to help a site determine goals for soil and/or groundwater concentration cleanup values prior to a remediation activity. The forward calculation process determines the cumulative risk at a site and is the primary factor used to determine if a site has met the appropriate cleanup goals. The back calculation and forward calculation when used together as a tool can be used to address the following situations:

- Determination of the residual concentrations which can be left in the soil such that concentrations in an existing or potential drinking water well or a stream will not exceed the target (MCL) values for the COCs.

- Determination of the residual concentrations that can be left in the soil such that the risk due to inhalation of volatile emissions from the soil to an on-site or off-site receptor does not exceed an acceptable level.

- Determination of residual concentrations which can be left in the surficial soils such that the risk due to accidental ingestion, direct contact, and inhalation of COCs does not exceed an acceptable level.

RBTLs can be site specific depending on the data used in the back calculation process. Calculation of these concentrations depends on a variety of factors including the acceptable level of risk, site receptor characteristics (industrial vs. residential or adult vs. child), transport mechanisms, properties of the chemical, and distance between the receptor and the source.

While performing these calculations, it is important to distinguish between direct and indirect exposure pathways. Direct exposure pathways are those in which the receptor comes in direct contact with the affected media. Examples of direct exposure include ingestion of soil and dermal contact with soil. Indirect pathways are those where the exposure occurs away from the source. For example, volatilization of chemicals from subsurface soil may result in exposure by inhalation inside a building, or leaching of chemicals in the soil to groundwater may result in exposure from the ingestion of groundwater at a nearby well. Evaluation of the indirect exposure pathways requires the use of chemical fate and transport models.

A step-by-step process to back calculate the RBTLs is described in the following sections.

## D.2 Step-by-Step Procedure

### STEP 1: IDENTIFY ACCEPTABLE RISK LEVEL AND HAZARD QUOTIENT

The acceptable individual excess lifetime cancer risk (IELCR) for carcinogenic effects and the acceptable hazard quotient (HQ) for non-carcinogenic effects is a policy decision. For the assessment and remediation of a contaminated site, in the RSL Evaluation, the Department currently uses a value of 1.0E-6 for lifetime cancer risks, and the acceptable HQ is 0.1. In the RM-1 and RM-2 Evaluations, the Department currently uses values of 1.0E-5 for lifetime cancer risks, and the acceptable hazard index (HI) is 1.0 ($HI = \Sigma HQ$). Please note that some MCLs may have been based upon different target risks and hazard quotients. MCLs are promulgated values and must be used before a calculated value is used. Additionally, screening levels for lead are developed using methodologies that do not involve risk or hazard quotient – see Section 6.14.

### STEP 2: ESTIMATE THE TOXICITY OF THE CHEMICALS OF CONCERN (COCs)

The toxicity of chemicals with carcinogenic effects is quantified using the potency values - oral slope factor ($SF_o$) and the inhalation unit risk (IUR). For non-carcinogenic effects, the toxicity is quantified using the oral reference dose ($RfD_o$) and the reference concentration (RfC). These toxicity values are provided in the RSL Summary Table for each of the chemicals of concern. These values should be utilized unless there is a valid reason to use alternative values. Any alternative value must be approved by the Department. The toxicity values in the RSL Table are updated semi-annually as new information on the toxicity of the COCs is made available.

### STEP 3: ESTIMATE THE ALLOWABLE EXPOSURE POINT CONCENTRATIONS

The allowable exposure point concentrations are estimated using the uptake equations for the relevant route of exposure and appropriate exposure factors.

The exposure factors the ARBCA Evaluator is expected to use to develop the RM-1 RBTLs are presented in the Regional Screening Table User's Guide. During an RM-2 Evaluation, the Department may consider and approve alternative exposure factors if justified by site-specific conditions. It is the responsibility of the evaluator conducting the analysis to provide justification for the use of these alternative values and to obtain the acceptance of these values from the Department.

For direct routes of exposure, the estimated concentration will be the risk-based target level. However, for indirect routes of exposures, the estimated target levels are applicable at the point of exposure. Additional analysis as presented in the following step is necessary to relate the exposure point concentrations to the source concentrations.

## STEP 4: ESTIMATE THE ALLOWABLE SOURCE CONCENTRATION

This step varies depending on the specific indirect route of exposure and the transport mechanism from the source to the receptor point. However, the objective in each case is to use the allowable exposure concentration estimated in Step 4 to estimate the source concentrations.

Example (1) - Estimation of subsurface soil concentrations protective of inhalation exposures.

For this exposure pathway, the concentrations estimated in Step 3 would be the concentration in the air that the receptor is breathing. A two-step procedure may be used to estimate allowable soil concentrations. Initially, if the receptor is located on site, a closed-box model may be used to estimate the allowable emission rate. Second, using an emission model, the estimated allowable emission rate is related to the allowable soil concentration.

Implementation of these two models, requires several input parameters. It is important that the responsible party clearly identify the data used and provide adequate justification for the specific values used for the RM-1 or RM-2 Evaluations.

Example (2) - Estimation of soil concentrations protective of ingestion of groundwater.

For this exposure pathway, the concentration estimated in Step 4 would be the concentration in the exposure well. The allowable leachate concentration at the source is calculated as the allowable concentration at the exposure point multiplied by the dilution-attenuation factor (DAF).

The DAF is the ratio of the concentration at the source to the concentration at the receptor [termed as the concentration reduction factor (CRF), dilution attenuation factor (DAF), or the natural attenuation factor (NAF)] and is estimated using a fate and transport model. The DAF (greater than or equal to one) depends on several factors, such as the distance to the well, groundwater velocity, chemical properties, size of the source, *etc.*, that are site-specific and are accounted for by the groundwater models. Several coupled models may be required to estimate the dilution-attenuation factor, *e.g.*, an unsaturated zone transport model, a saturated zone mixing model, and a saturated zone transport model. The allowable leachate concentration is finally converted to an allowable soil concentration either by using the results of a site-specific leachate test or by assuming equilibrium partitioning between the soil concentration and the leachate concentration.

Soil concentrations protective of a stream are calculated using the same process as the calculation of soil concentrations protective of the groundwater resource. The only difference is that the target concentrations at the POE will be different from the target concentration in the stream. Also refer to Appendix C.

## D.3 Implementation

The specific equations used to implement the above listed steps for the previously calculated RM-1 and RM-2 RBTLs are shown in Appendix E.

## D.4 Forward Mode

In forward mode, the ARBCA Evaluator calculates the IELCRs for carcinogenic effects and the HQs for non-carcinogenic effects, adds up all the IELCRs for a receptor, and adds up all the HQs for a receptor. In RM-1 and RM-2, the total IELCR for any receptor, should not exceed $1 \times 10^{-5}$. The total of all the HQs for a receptor, should not exceed the HI = 1.0. The equations for the IELCRs and the HQs appear in Appendix F.

# APPENDIX E

# MODELS/EQUATIONS FOR ESTIMATING RM-1 AND RM-2 TARGET LEVELS

# APPENDIX E
# MODELS/EQUATIONS FOR ESTIMATING RM-1 AND RM-2 TARGET LEVELS WITHIN THE ARBCA PROCESS

The symbols used in the equations presented in this appendix follow the following three sources:

1. ASTM, *Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites*, 1995, Designation: E-1739-95. ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428.

2. *Mid-Atlantic Risk Assessment User's Guide*, May 2013, http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm.

3. Environmental Quality Management, Inc., 2004, *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*, Durham, NC, prepared for USEPA, Office of Emergency and Remedial Response, Washington, D.C.

The two USEPA Vapor Intrusion Documents, *Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* should be utilized as the primary reference for the Indoor and Outdoor Vapor Intrusion pathway equations

To calculate target concentrations at sites due to the vapor intrusion pathway, it is often helpful to use the Vapor Intrusion Screening Level (VISL) Calculator. This calculator contains tables that provide target levels (RBTLs) that may be used to address a specific COC or group of COCs. In certain cases, it may be more appropriate to utilize the equations provided in one of the two USEPA Vapor Intrusion Documents, *Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites*. The Department recommends that target levels focus on soil gas target levels collected at an approximate depth of 3 ft below the area of concern (*i.e.*, basement, slab, or crawl space). The Department prefers the use of soil gas target levels but it may be appropriate in certain cases to allow the evaluation to occur using an alternate media. Prior to evaluating the vapor intrusion pathway, the facility should consult with the Department.

## DIRECT INGESTION OF GROUNDWATER

Carcinogenic Effects

$$RBTL_{ingw} = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times IR_w \times SF_o}$$

Non-carcinogenic Effects

$$RBTL_{ingw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{ED \times EF \times IR_w}$$

Source: USEPA, RAGS, Vol. I, 1989, p. 6-35

where:

$RBTL_{ingw}$ = Risk-based target level for ingestion of water [mg/L]
$TR$ = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$ = Target hazard quotient for a chemical [-]
$BW$ = Body weight [kg]
$AT_c$ = Averaging time for carcinogens [year]
$AT_{nc}$ = Averaging time for non-carcinogens [year]
$ED$ = Exposure duration [year]
$EF$ = Exposure frequency [day/year]
$IR_w$ = Water ingestion rate [L/day]
$SF_o$ = Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
$RfD_o$ = Chemical-specific oral reference dose [mg/kg-day]
$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

# INGESTION OF SOIL
# (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

Carcinogenic Effects

$$RBTL_{ings} = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times IR_{soil} \times ABS_{GI} \times SF_o \times 10^{-6}}$$

Non-carcinogenic Effects

$$RBTL_{ings} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{ED \times EF \times IR_{soil} \times ABS_{GI} \times 10^{-6}}$$

Source: USEPA, RAGS Vol. I Part A, 1989

where,

$RBTL_{ings}$ = Risk-based target level for ingestion of soil [mg/kg]

$TR$ = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]

$THQ$ = Target hazard quotient for a chemical [-]

$BW$ = Body weight [kg]

$AT_c$ = Averaging time for carcinogens [year]

$AT_{nc}$ = Averaging time for non-carcinogens [year]

$ED$ = Exposure duration [year]

$EF$ = Exposure frequency [day/year]

$IR_{soil}$ = Soil ingestion rate [mg/day]

$ABS_{GI}$ = Oral absorption fraction [-]

$SF_o$ = Chemical-specific oral cancer slope factor [(mg/kg-day)$^{-1}$]

$RfD_o$ = Chemical-specific oral reference dose [mg/kg-day]

$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

$10^{-6}$ = Converts mg to kg [mg/kg]

# DERMAL CONTACT WITH SOIL
## (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

### Carcinogenic Effects

$$RBTL_{ds}=\frac{TR\times BW\times AT_{c}\times 365}{ED\times EF\times SA_{soil}\times EV_{soil}\times AF\times ABS_{d}\times SF_{ABS}\times 10^{-6}}$$

### Non-carcinogenic Effects

$$RBTL_{ds}=\frac{THQ\times BW\times AT_{nc}\times 365\times RfD_{ABS}}{ED\times EF\times SA_{soil}\times EV_{soil}\times AF\times ABS_{d}\times 10^{-6}}$$

Source: USEPA, RAGS Vol. I Part E, 2004, Page 3-9

where,

$RBTL_{ds}$ = Risk-based target level for dermal contact with soil [mg/kg]
$TR$ = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$THQ$ = Target hazard quotient for a chemical [-]
$BW$ = Body weight [kg]
$AT_c$ = Averaging time for carcinogens [year]
$AT_{nc}$ = Averaging time for non-carcinogens [year]
$ED$ = Exposure duration [year]
$EF$ = Exposure frequency [day/year]
$SA_{soil}$ = Skin surface area available for contact with soil [$cm^2$]
$EV_{soil}$ = Event frequency [event/day]
$AF$ = Soil to skin adherence factor [$mg/cm^2$-event]
$ABS_d$ = Chemical-specific dermal absorption fraction [-]
$SF_{ABS}$ = Chemical-specific dermal cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
$RfD_{ABS}$ = Chemical-specific dermal reference dose [mg/kg-day]
$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]
$10^{-6}$ = Converts mg to kg [kg/mg]

## INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL AND CONSTRUCTION SOIL (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

Carcinogenic Effects

$$RBTL_{inhs}=\frac{TR\times AT_{c}\times 365\times 24}{ED\times EF\times ET_{out}\times IUR\times (VF_{s}+VF_{p})\times 1000}$$

Non-carcinogenic Effects

$$RBTL_{inhs}=\frac{THQ\times AT_{nc}\times 365\times 24\times RfC}{ED\times EF\times ET_{out}\times (VF_{s}+VF_{p})}$$

Source: USEPA Regional Screening Table – User's Guide, May 2013

where,

$RBTL_{inhs}$ = Risk-based target level of inhalation of vapors and particulates from soil [mg/kg]

$TR$ = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]

$THQ$ = Target hazard quotient for a chemical [-]

$AT_c$ = Averaging time for carcinogens [year]

$AT_{nc}$ = Averaging time for non-carcinogens [year]

$ED$ = Exposure duration [year]

$EF$ = Exposure frequency [day/year]

$ET_{out}$ = Outdoor exposure time [hr/day]

$IUR$ = Chemical-specific inhalation unit risk $[(ug/m^3)^{-1}]$

$RfC$ = Chemical-specific inhalation reference dose $[mg/m^3]$

$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

$24$ = Converts days to hours [hr/day]

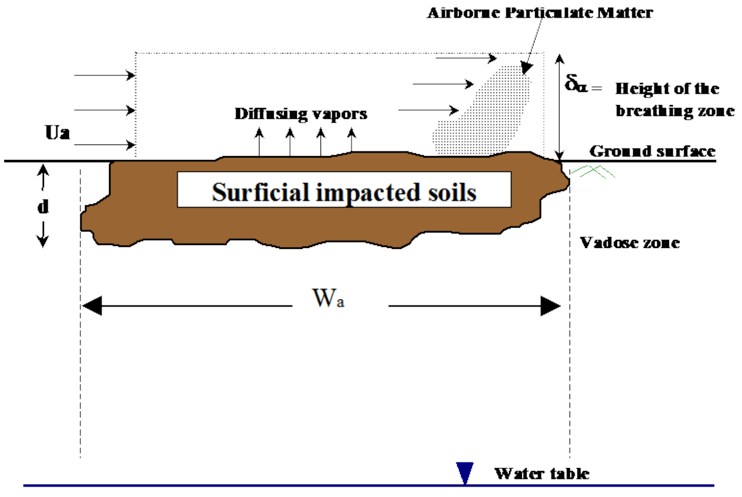
$1000$ = Converts mg to ug [ug/mg]

$VF_s$ = Volatilization factor for vapor emissions from soil $[(mg/m^3\text{-air})/(mg/kg\text{-soil})]$

$VF_p$ = Volatilization factor for particulate emissions from soil $[(mg/m^3\text{-air})/(mg/kg\text{-soil})]$

# INGESTION OF, DERMAL CONTACT WITH, AND INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL AND CONSTRUCTION SOIL
## (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

$$RBTL_s = \frac{1}{\frac{1}{RBTL_{ings}} + \frac{1}{RBTL_{ds}} + \frac{1}{RBTL_{inhs}}}$$



where,

$RBTL_s$ = Risk-based target level of soil [mg/kg]
$RBTL_{ings}$ = Risk-based target level for ingestion of soil [mg/kg]
$RBTL_{ds}$ = Risk-based target level for dermal contact with soil [mg/kg]
$RBTL_{inhs}$ = Risk-based target level of inhalation of vapors and particulates from soil [mg/kg]

Source: USEPA Regional Screening Table – User's Guide, May 2013

# SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER

$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

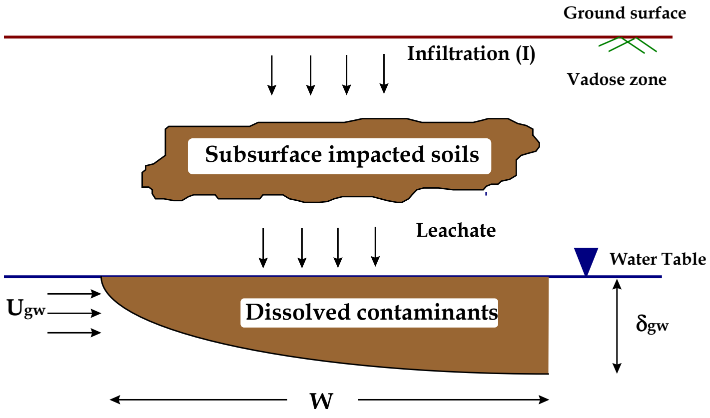
where:

$RBTL_{SL}$ = Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]

$RBTL_w$ = Risk-based target level for ingestion of groundwater [mg/L-$H_2O$]

$LF_{SW}$ = Leaching Factor (from subsurface soil to groundwater) [(mg/L-H2O)/(mg/kg-soil)]

Source: ASTM, 1995, E1739-95



## LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

$$LF_{SW}=\frac{\rho_s}{[\theta_{ws}+K_{sv}\rho_s+H\times\theta_{as}]\times\left(1+\frac{U_{gw}\times\delta_{gw}}{IW}\right)}$$

Source: ASTM, 1995, E1739-95

where:

$LF_{SW}$ = Leaching factor from subsurface soil to groundwater [(mg/L-$H_2O$)/(mg/kg-soil)]

$\rho_s$ = Dry soil bulk density [g-soil/$cm^3$-soil]

$\theta_{ws}$ = Volumetric water content in vadose zone soils [$cm^3$-$H_2O$/$cm^3$-soil]

$K_{sv}$ = $f_{ocv} \times K_{oc}$

= Chemical-specific soil-water sorption coefficient for the unsaturated zone [$cm^3$-$H_2O$/g-soil]

$f_{ocv}$ = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]

$H$ = Chemical-specific Henry's Law constant [(L-$H_2O$)/(L-air)]

$\theta_{as}$ = Volumetric air content in the vadose zone soils [$cm^3$-air/$cm^3$-soil]

$U_{gw}$ = Groundwater Darcy Velocity [cm/year]

$\delta_{gw}$ = Groundwater mixing zone thickness [cm]

$I$ = Infiltration rate of water through soil [cm/year]

$W$ = Length of source area parallel to groundwater flow [cm]

## SATURATION CONCENTRATION IN SOIL VAPOR AND SOIL

**$C_v^{SAT}$ :** Soil vapor concentration at which dissolved phase becomes saturated [mg/m$^3$-air]

Single Component

$$C_v^{SAT} = \frac{P^s \times MW}{R \times T} \times 10^6$$

Multiple Components

$$C_v^{SAT} = \frac{x_i \times P_i^s \times MW_i}{R \times T} \times 10^6$$

where,

$C_v^{SAT}$ = Soil vapor concentration at which vapor phase become saturated [mg/m$^3$-air]

$P^s$ = Saturated vapor pressure [atm]

$P_i^s$ = Effective vapor pressure of component *i* in water = $x_i \times P^s$ [atm]

$R$ = Ideal gas constant [0.08206 atm•L/mol•K]

$T$ = Temperature [K]

$S_{ei}$ = Effective solubility of component *i* in water = $x_i \times S$ [mg/L-water]

$x_i$ = Mole fraction of component *i* = $(w_i \times MW_{\text{avg}})/MW_i$ [-]

$w_i$ = Weight fraction of component *i* [-]

$MW_{\text{avg}}$ = Average molecular weight of mixture [g/mole]

$MW_i$ = Molecular weight of component *i* [g/mole]

$\rho_s$ = Vadose zone dry soil bulk density [g-soil/cm$^3$-soil]

$10^6$ = Conversion factor [(g/L)/(mg/m$^3$)]

Source: ASTM, 1995, E1739-95

**$C_s^{SAT}$ :** Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]

Single Component

$$C_s^{sat} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \rho_s]$$

Multiple Components

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

where:

$C_s^{SAT}$ = Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]

$S$ = Pure component solubility in water [mg/L-water]

$S_{ei}$ = Effective solubility of component *i* in water = $x_i \times S$ [mg/L-water]

$x_i$ = Mole fraction of component *i* = $(w_i \times MW_{\text{avg}})/MW_i$ [-]

$w_i$ = Weight fraction of component *i* [-]

$MW_{\text{avg}}$ = Average molecular weight of mixture [g/mole]

$MW_i$ = Molecular weight of component *i* [g/mole]

$\rho_s$ = Vadose zone dry soil bulk density [g-soil/cm$^3$-soil]

$H$ = Chemical-specific Henry's Law constant [L-water/L-air]

$\theta_{as}$ = Volumetric air content in the vadose zone soils [cm$^3$-air/cm$^3$-soil]

$\theta_{ws}$ = Volumetric water content in vadose zone soils [cm$^3$-water/cm$^3$- soil]

$K_{sv}$ = $f_{ocv} \times K_{ocv}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm$^3$-water/g-soil]

$f_{ocv}$ = Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM, 1995, E1739-95

# DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\,\alpha_x}\left[1 - \sqrt{1 + \frac{4\,\lambda\,\alpha_x}{v}}\right]\right] \times erfc\left[\frac{\left[(x - vt)\sqrt{1 + \frac{4\,\lambda\,\alpha_x}{v}}\right]}{2\sqrt{\alpha_x \times v \times t}}\right] \times$$

$$\left[erf\left[\frac{(y + Y/2)}{2\sqrt{\alpha_y\,x}}\right] - erf\left[\frac{(y - Y/2)}{2\sqrt{\alpha_y\,x}}\right]\right] \times \left[erf\left[\frac{(z + \delta_{gw})}{2\sqrt{\alpha_z\,x}}\right] - erf\left[\frac{(z - \delta_{gw})}{2\sqrt{\alpha_z\,x}}\right]\right]$$

where:

$C$ = Dissolved-phase concentration [mg/L]

$C_o$ = Dissolved-phase concentration at the source (at x=y, $0 \leq z \leq \delta_{gw}$) [mg/L]

$v$ = Retarded seepage velocity [cm/year]

$\lambda$ = First order decay rate [1/year]

$\alpha_x$ = Longitudinal dispersivity [cm]

$\alpha_y$ = Lateral dispersivity [cm]

$\alpha_z$ = Vertical dispersivity [cm]

$x, y, z$ = Spatial coordinates [cm]

$t$ = Time [year]

$x$ = Distance along the centerline from the downgradient edge of dissolved-plume source zone or source well [cm]

$Y$ = Width of soil source perpendicular to the groundwater flow direction [cm]

$\delta_{gw}$ = Groundwater mixing zone thickness [cm]

$DAF$ = $C_o/C(x)$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

At the centerline, for steady-state (after a long time) the DAF can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\,\alpha_x}\left[1 - \sqrt{1 + \frac{4\,\lambda\,\alpha_x}{v}}\right]\right] \times erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right] \times erf\left[\frac{\delta_{gw}}{2\sqrt{\alpha_z\,x}}\right] \qquad (1)$$

At the centerline, for steady-state, the DAF without decay can be obtained by setting y = 0, z = 0, x << vt, and $\lambda = 0$ as:

$$\frac{1}{DAF} = \frac{C(x)}{C_o} = erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right] \times erf\left[\frac{\delta_{gw}}{2\sqrt{\alpha_z\,x}}\right] \qquad (2)$$

Note: Comparing to ASTM E1739-95, p. 31, where $Y = S_w$, $\delta_{gw} = S_d$, $v = u$, and $C_o = C_{source}$

At the centerline, for steady-state, the DAF with decay can be calculated using Equation (1). In Equation (1), the retarded seepage velocity ($v$) is calculated as:

$$v = (K\ i)/(R_s\ \theta_{TS})$$

where:

$K$ = Hydraulic conductivity [cm/year]

$i$ = Hydraulic gradient [--]

$\theta_{TS}$ = Total porosity in the saturated zone [$cm^3/cm^3$-soil]

$R_s$ = Retardation factor in the saturated zone [--]

## ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Allowable soil concentration at the source} = \textit{Target groundwater concentration at the } POE \times \frac{DAF_{POE}}{LF_{SW}}$$

$$\text{Allowable groundwater concentration at the source} = \textit{Target groundwater concentration at the } POE \times DAF_{POE}$$

$$\text{Allowable groundwater concentration at the sentry well} = \textit{Target groundwater concentration at the } POE \times \frac{DAF_{POE}}{DAF_{SW}}$$

where:

$POE$ = Point of exposure
$SW$ = Sentry well
$DAF_{POE}$ = Dilution Attenuation Factor between the point of exposure and the source
$DAF_{SW}$ = Dilution Attenuation Factor between the sentry well and the source
$LF_{SW}$ = Dry soil leaching factor

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate} = \frac{0.693}{\textit{Half Life}}$$

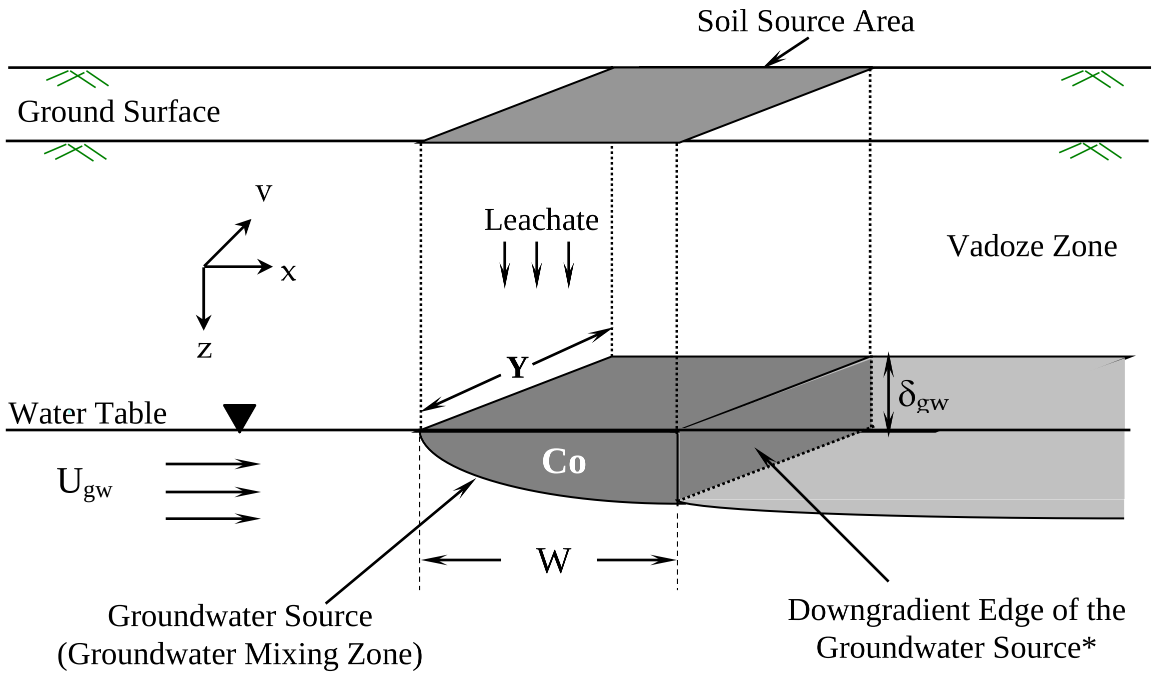
$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right) \qquad K_{ss} = f_{ocs} \times K_{oc}$$

$$\text{Retardation Factor for Metals in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_d}{\theta_{TS}}\right)$$

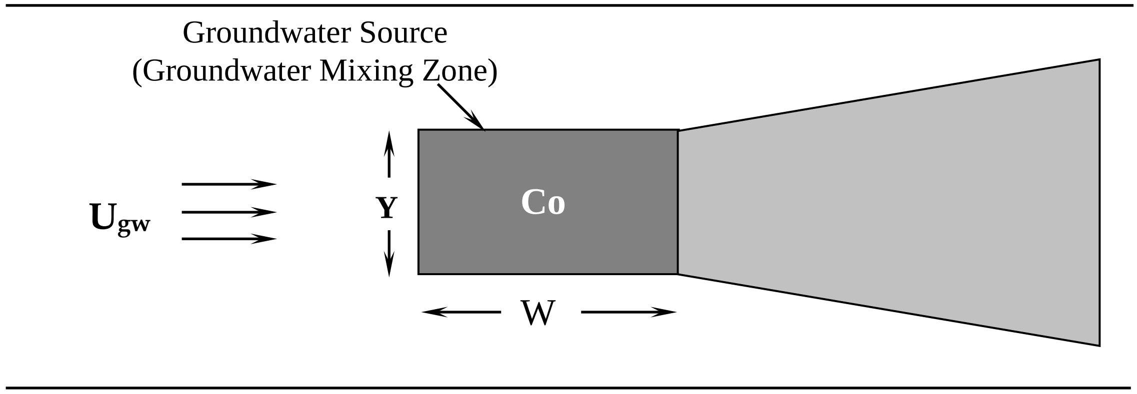
where:

$\rho_{ss}$ = Saturated zone soil bulk density [g-soil/cm$^3$-soil]
$K_{ss}$ = Chemical-specific soil-water sorption coefficient in the saturated zone [cm$^3$-H$_2$O/g-soil]
$K_d$ = Chemical-specific soil-water distribution coefficient for metals in the saturated zone [mL/g]
$\theta_{TS}$ = Total porosity in the saturated zone [cm$^3$/cm$^3$-soil]
$f_{ocs}$ = Fractional organic carbon content in the saturated zone [g-C/g-Soil]

## SCHEMATIC DESCRIPTION OF DOMENICO’S MODEL



**SECTION**



**PLAN**

**Note:**

(* Assumes only vertical leaching, i.e., there is no horizontal spreading in the unsaturated zone.)

## STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT POINT OF DISCHARGE

$$C_{gw} = \frac{C_{str}\left(Q_{gw} + Q_{sw}\right)}{Q_{gw}} - C_{su}\left(\frac{Q_{sw}}{Q_{gw}}\right)$$

$$Q_{gw} = \left(Z + \sqrt{\alpha_z X_s}\right) \times \left(Y + 2\sqrt{\alpha_y X_s}\right) \times U_{gw}$$

where,

$Q_{gw}$ = Impacted groundwater discharge into the stream [ft$^3$/day]

$C_{gw}$ = Allowable concentration in groundwater at the point of discharge into the stream [mg/L]

$Q_{sw}$ = Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft$^3$/day]

$C_{str}$ = Allowable concentration at the downstream edge of the stream's mixing zone, *i.e.*, the applicable stream water quality criteria [mg/L]

$C_{su}$ = COC concentration upstream of the groundwater plume discharge [mg/L]

$Y$ = GW source dimension perpendicular to GW flow direction [ft]

$Z$ = GW source (mixing zone) thickness [ft]

$\alpha_y$ = Lateral dispersivity [ft]

$\alpha_z$ = Vertical dispersivity [ft]

$X_s$ = Distance from the downgradient edge of the groundwater source to the stream [ft]

$U_{gw}$ = Darcy velocity [ft/day]

See also Appendix C, pages C-3 and C-4.

# APPENDIX F
# MODELS/EQUATIONS FOR ESTIMATING RISKS

# APPENDIX F
# MODELS/EQUATIONS FOR ESTIMATING RISKS

The symbols used in the equations presented in this appendix follow the following three sources:

1. ASTM, *Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites*, 1995, Designation: E-1739-95. ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428.

2. *Mid-Atlantic Risk Assessment User's Guide*, May 2013, http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm.

3. Environmental Quality Management, Inc., 2004, *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*, Durham, NC, prepared for USEPA, Office of Emergency and Remedial Response, Washington, D.C.

# Table of Content

# APPENDIX F
# MODELS/EQUATIONS FOR ESTIMATING RISKS

The symbols used in the equations presented in this appendix follow the following three sources:

1. ASTM, *Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites*, 1995, Designation: E-1739-95. ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428.

2. *Mid-Atlantic Risk Assessment User's Guide*, May 2013, http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm.

3. Environmental Quality Management, Inc., 2004, *User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings*, Durham, NC, prepared for USEPA, Office of Emergency and Remedial Response, Washington, D.C.

The two USEPA vapor intrusion documents, *Assessing and Mitigating the Vapor Intrusion Pathway from Subsurface Vapor Sources to Indoor Air* and *Addressing Petroleum Vapor Intrusion at Leaking Underground Storage Tank Sites* should be utilized as the primary reference for the Indoor and Outdoor Vapor Intrusion pathway equations

To calculate risk at sites due to the vapor intrusion pathway, it is often helpful to use the Vapor Intrusion Screening Level (VISL) Calculator to calculate the risk due to a specific COC.  In certain cases, it may be appropriate to sum the risk calculated for the individual constituents calculated using the VISL Calculator to determine the cumulative risk for the vapor intrusion pathway.  The Department recommends the use of soil gas collected at an approximate depth of 3 ft below the area of concern (*i.e.*, basement, slab, or crawl space) and use of the "SG_IA_calc" worksheet. The "SG_IA_calc" worksheet allows the user to enter the scenario, risk information, soil gas concentrations, and select chemicals to calculate indoor air concentration and indoor air risk associated with the contaminated media.  The "GW_IA_calc" may be used to calculate the risk from a groundwater concentration, but due to the many variables that typically exist between the groundwater surface and the basement, slab, or crawl space, the Department prefers the use of soil gas samples.  Prior to evaluating the vapor intrusion pathway using the VISL Calculator, the facility should consult with the Department.

## DIRECT INGESTION OF GROUNDWATER

Carcinogenic Effects

$$IELCR_{ingw} = \frac{C_w \times ED \times EF \times IR_w \times SF_o}{BW \times AT_c \times 365}$$

Non-carcinogenic Effects

$$HQ_{ingw} = \frac{C_w \times ED \times EF \times IR_w}{BW \times AT_{nc} \times 365 \times RfD_o}$$

Source:  U. S. EPA, RAGS, Vol. I, 1989, p. 6-35

where:

$IELCR_{ingw}$ = Individual's excess lifetime cancer risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in drinking water [-]
$HQ_{ingw}$ = Hazard quotient for a chemical in drinking water [-]
$C_w$ = Contaminant concentration in drinking water [mg/L]
$BW$ = Body weight [kg]
$AT_c$ = Averaging time for carcinogens [year]
$AT_{nc}$ = Averaging time for non-carcinogens [year]
$ED$ = Exposure duration [year]
$EF$ = Exposure frequency [day/year]
$IR_w$ = Water ingestion rate [L/day]
$SF_o$ = Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
$RfD_o$ = Chemical-specific oral reference dose [mg/kg-day]
$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

## INGESTION OF SOIL
## (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

Carcinogenic Effects

$$IELCR_{ings} = \frac{C_s \times ED \times EF \times IR_{soil} \times ABS_{GI} \times SF_o \times 10^{-6}}{BW \times AT_c \times 365}$$

Non-carcinogenic Effects

$$HQ_{ings} = \frac{C_s \times ED \times EF \times IR_{soil} \times ABS_{GI} \times 10^{-6}}{BW \times AT_{nc} \times 365 \times RfD_o}$$

Source: U. S. EPA, RAGS Vol. I Part A, 1989

where,

$IELCR_{ings}$ = Individual's excess lifetime cancer risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in soil through ingestion [-]
$HQ_{ings}$ = Hazard quotient for a chemical in soil [-]
$C_s$ = Contaminant concentration in soil [mg/kg]
$BW$ = Body weight [kg]
$AT_c$ = Averaging time for carcinogens [year]
$AT_{nc}$ = Averaging time for non-carcinogens [year]
$ED$ = Exposure duration [year]
$EF$ = Exposure frequency [day/year]
$IR_{soil}$ = Soil ingestion rate [mg/day]
$ABS_{GI}$ = Oral absorption fraction [-]
$SF_o$ = Chemical-specific oral cancer slope factor [(mg/kg-day)$^{-1}$]
$RfD_o$ = Chemical-specific oral reference dose [mg/kg-day]
$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]
$10^{-6}$ = Converts mg to kg [mg/kg]

## DERMAL CONTACT WITH SOIL
## (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

### Carcinogenic Effects

$$IELCR_{ds} = \frac{C_s \times ED \times EF \times SA_{soil} \times EV_{soil} \times AF \times ABS_d \times SF_{ABS} \times 10^{-6}}{BW \times AT_c \times 365}$$

### Non-carcinogenic Effects

$$HQ_{ds} = \frac{C_s \times ED \times EF \times SA_{soil} \times EV_{soil} \times AF \times ABS_d \times 10^{-6}}{BW \times AT_{nc} \times 365 \times RfD_{ABS}}$$

Source: U. S. EPA, RAGS Vol. I Part E, 2004, Page 3-9

where,

$IELCR_{ds}$ = Individual's excess lifetime cancer risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in soil through dermal absorption[-]

$HQ_{ds}$ = Hazard quotient for a chemical in soil due to dermal absorption [-]

$C_s$ = Contaminant concentration in soil [mg/kg]

$BW$ = Body weight [kg]

$AT_c$ = Averaging time for carcinogens [year]

$AT_{nc}$ = Averaging time for non-carcinogens [year]

$ED$ = Exposure duration [year]

$EF$ = Exposure frequency [day/year]

$SA_{soil}$ = Skin surface area available for contact with soil [$cm^2$]

$EV_{soil}$ = Event frequency [event/day]

$AF$ = Soil to skin adherence factor [$mg/cm^2$-event]

$ABS_d$ = Chemical-specific dermal absorption fraction [-]

$SF_{ABS}$ = Chemical-specific dermal cancer slope factor [$(mg/kg\text{-}day)^{-1}$]

$RfD_{ABS}$ = Chemical-specific dermal reference dose [mg/kg-day]

$365$ = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

$10^{-6}$ = Converts mg to kg [kg/mg]

## INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL AND CONSTRUCTION SOIL (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

Carcinogenic effects

$$IELCR_{inhs} = \frac{C_{soil} \times ED \times EF \times ET_{out} \times IUR \times \left(VF_s + VF_p\right) \times 1000}{AT_c \times 365 \times 24}$$

Non-carcinogenic effects

$$HQ_{inhs} = \frac{C_{soil} \times ED \times EF \times ET_{out} \times \left(VF_s + VF_p\right)}{AT_{nc} \times 365 \times 24 \times RfC}$$

Source: U. S. EPA Regional Screening Table – User’s Guide, May, 2013

where:

$IELCR_{inhs}$ = Individual's excess lifetime cancer risk or the increased chance of developing cancer over a lifetime due to exposure to vapors and particulates from soil [-]

$HQ_{inhs}$ = Hazard quotient due to exposure to vapors and particulates from soil [-]

$C_{soil}$ = Contaminant concentration in soil [mg/kg]

$AT_c$ = Averaging time for carcinogens [year]

$AT_{nc}$ = Averaging time for non-carcinogens [year]

*ED* = Exposure duration [year]

*EF* = Exposure frequency [day/year]

$ET_{out}$ = Outdoor Exposure time [hr/day]

*IUR* = Chemical-specific inhalation unit risk [(ug/m$^3$)$^{-1}$]

*RfC* = Chemical-specific inhalation reference concentration [mg/m$^3$]

*365* = Converts $AT_c$, $AT_{nc}$ in years to days [day/year]

*24* = Converts days to hours [hr/day]

*1000* = Converts micrograms to milligrams [µg/mg]

$VF_s$ = Volatilization factor for vapor emissions from soil [(mg/m$^3$-air)/(mg/kg-soil)]

$VF_p$ = Volatilization factor for particulate emissions from soil [(mg/m$^3$-air)/(mg/kg-soil)]

*Note: The depth to surficial soil for a construction worker is up to the typical construction depth.*

# INGESTION OF, DERMAL CONTACT WITH, AND INHALATION OF VAPORS AND PARTICULATES FROM SURFICIAL SOIL AND CONSTRUCTION SOIL
## (CHILD AND ADULT RESIDENT, COMMERCIAL WORKER, AND CONSTRUCTION WORKER)

Carcinogenic effects

$$IELCR_s = IELCR_{ings} + IELCR_{ds} + IELCR_{inhs}$$

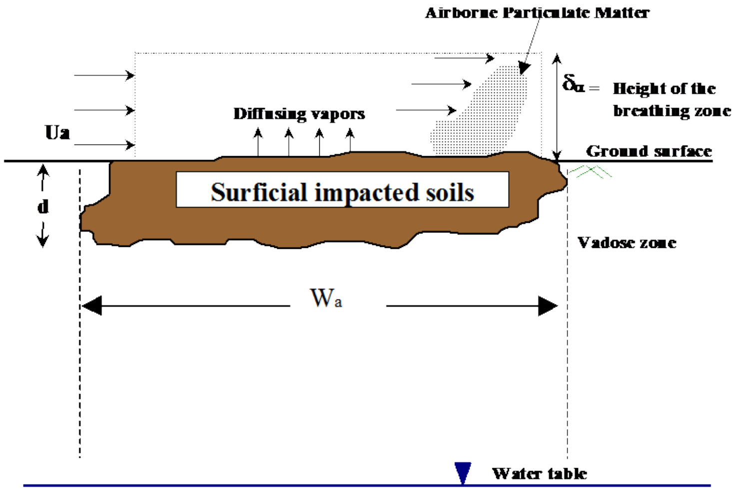
Non-carcinogenic effects

$$HI_s = HQ_{ings} + HQ_{ds} + HQ_{inhs}$$

where,

$IELCR_s$ = Cumulative individual excess lifetime cancerrisk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in soil [-]
$HI_s$ = Hazard index for a chemical in soil [-]
$IELCR_{ings}$ = Individual's excess lifetime cancer risk for a chemical by ingestion of a chemical in soil [-]
$IELCR_{ds}$ = Individual's excess lifetime cancer risk for a chemical by dermal exposure to a chemical in soil [-]
$IELCR_{inhs}$ = Individual's excess lifetime cancer risk for a chemical by inhalation of a chemical in soil [-]
$HQ_{ings}$ = HQ for a chemical by ingestion of a chemical in soil [-]
$HQ_{ds}$ = HQ for a chemical by dermal exposure to a chemical in soil [-]
$HQ_{inhs}$ = HQ for a chemical by inhalation of a chemical in soil [-]

Source: U. S. EPA Regional Screening Table – User's Guide, May 2013



## GROUNDWATER SOURCE CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$C_w = C_{ss} \times LF_{SW}$$

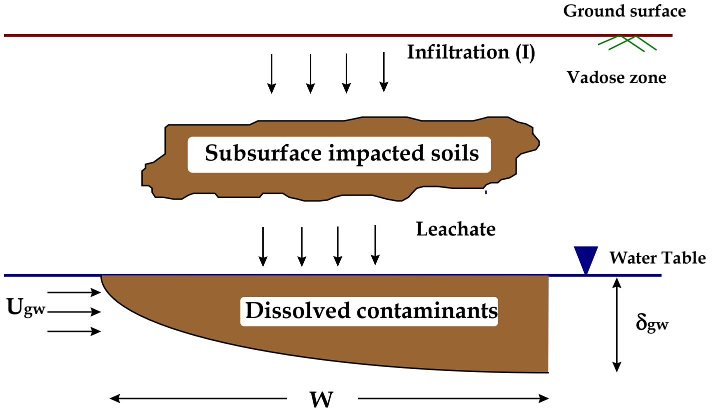
where:

$C_w$ = Groundwater source concentration for groundwater resource protection [mg/L-water]

$C_{ss}$ = Subsurface soil concentration for groundwater resource protection [mg/kg-soil]

$LF_{SW}$ = Leaching Factor (from subsurface soil to groundwater) [(mg/L-H2O)/(mg/kg-soil)]

Source: ASTM, 1995, E1739-95



## LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

$$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_{sv}\rho_s + H \times \theta_{as}] \times \left(1 + \frac{U_{gw} \times \delta_{gw}}{IW}\right)}$$

Source: ASTM, 1995, E1739-95

where:

$LF_{SW}$ = Leaching factor from subsurface soil to groundwater [(mg/L-$H_2O$)/(mg/kg-soil)]

$\rho_s$ = Dry soil bulk density [g-soil/$cm^3$-soil]

$\theta_{ws}$ = Volumetric water content in vadose zone soils [$cm^3$-$H_2O$/$cm^3$-soil]

$K_{sv}$ = $f_{ocv} \times K_{oc}$

= Chemical-specific soil-water sorption coefficient for the unsaturated zone [$cm^3$-$H_2O$/g-soil]

$f_{ocv}$ = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]

$H$ = Chemical-specific Henry's Law constant [(L-$H_2O$)/(L-air)]

$\theta_{as}$ = Volumetric air content in the vadose zone soils [$cm^3$-air/$cm^3$-soil]

$U_{gw}$ = Groundwater Darcy Velocity [cm/year]

$\delta_{gw}$ = Groundwater mixing zone thickness [cm]

$I$ = Infiltration rate of water through soil [cm/year]

$W$ = Length of source area parallel to groundwater flow [cm]

## SATURATION CONCENTRATION IN SOIL VAPOR AND SOIL

**$C_v^{SAT}$** : Soil vapor concentration at which dissolved phase becomes saturated [mg/m$^3$-air]

Single Component

$$C_v^{SAT} = \frac{P^s \times MW}{R \times T} \times 10^6$$

Multiple Components

$$C_v^{SAT} = \frac{x_i \times P_i^s \times MW_i}{R \times T} \times 10^6$$

where,

$C_v^{SAT}$ = Soil vapor concentration at which vapor phase become saturated [mg/m$^3$-air]
$P^s$ = Saturated vapor pressure [atm]
$P_i^s$ = Effective vapor pressure of component *i* in water = $x_i \times P^s$ [atm]
$R$ = Ideal gas constant [0.08206 atm•L/mol•K]
$T$ = Temperature [K]
$S_{ei}$ = Effective solubility of component *i* in water = $x_i \times S$ [mg/L-water]
$x_i$ = Mole fraction of component *i* = $(w_i \times MW_{\text{avg}})/MW_i$ [-]
$w_i$ = Weight fraction of component *i* [-]
$MW_{\text{avg}}$ = Average molecular weight of mixture [g/mole]
$MW_i$ = Molecular weight of component *i* [g/mole]
$\rho_s$ = Vadose zone dry soil bulk density [g-soil/cm$^3$-soil]
$10^6$ = Conversion factor [(g/L)/(mg/m$^3$)]

Source: ASTM, 1995, E1739-95

**$C_s^{SAT}$** : Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]

Single Component

$$C_s^{sat} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \rho_s]$$

Multiple Components

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

where:

$C_s^{SAT}$ = Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
$S$ = Pure component solubility in water [mg/L-water]
$S_{ei}$ = Effective solubility of component *i* in water = $x_i \times S$ [mg/L-water]
$x_i$ = Mole fraction of component *i* = $(w_i \times MW_{\text{avg}})/MW_i$ [-]
$w_i$ = Weight fraction of component *i* [-]
$MW_{\text{avg}}$ = Average molecular weight of mixture [g/mole]
$MW_i$ = Molecular weight of component *i* [g/mole]
$\rho_s$ = Vadose zone dry soil bulk density [g-soil/cm$^3$-soil]
$H$ = Chemical-specific Henry's Law constant [L-water/L-air]
$\theta_{as}$ = Volumetric air content in the vadose zone soils [cm$^3$-air/cm$^3$-soil]
$\theta_{ws}$ = Volumetric water content in vadose zone soils [cm$^3$-water/cm$^3$- soil]
$K_{sv}$ = $f_{ocv} \times K_{ocv}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm$^3$-water/g-soil]
$f_{ocv}$ = Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM, 1995, E1739-95

# DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\,\alpha_x}\left[1-\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-vt)\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]}{2\sqrt{\alpha_x\times v\times t}}\right]\times$$

$$\left[erf\left[\frac{(y+Y/2)}{2\sqrt{\alpha_y\,x}}\right] - erf\left[\frac{(y-Y/2)}{2\sqrt{\alpha_y\,x}}\right]\right]\times\left[erf\left[\frac{(z+\delta_{gw})}{2\sqrt{\alpha_z\,x}}\right] - erf\left[\frac{(z-\delta_{gw})}{2\sqrt{\alpha_z\,x}}\right]\right]$$

where:

$C$ = Dissolved-phase concentration [mg/L]

$C_o$ = Dissolved-phase concentration at the source (at x=y, $0 \le z \le \delta_{gw}$) [mg/L]

$v$ = Retarded seepage velocity [cm/year]

$\lambda$ = First order decay rate [1/year]

$\alpha_x$ = Longitudinal dispersivity [cm]

$\alpha_y$ = Lateral dispersivity [cm]

$\alpha_z$ = Vertical dispersivity [cm]

$x, y, z$ = Spatial coordinates [cm]

$t$ = Time [year]

$x$ = Distance along the centerline from the downgradient edge of dissolved-plume source zone or source well [cm]

$Y$ = Width of soil source perpendicular to the groundwater flow direction [cm]

$\delta_{gw}$ = Groundwater mixing zone thickness [cm]

$DAF$ = $C_o/C(x)$

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)

At the centerline, for steady-state (after a long time) the DAF can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\,\alpha_x}\left[1-\sqrt{1+\frac{4\,\lambda\,\alpha_x}{v}}\right]\right]\times erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right]\times erf\left[\frac{\delta_{gw}}{2\sqrt{\alpha_z\,x}}\right] \qquad (1)$$

At the centerline, for steady-state, the DAF without decay can be obtained by setting y = 0, z = 0, x << vt, and $\lambda = 0$ as:

$$\frac{1}{DAF} = \frac{C(x)}{C_o} = erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right]\times erf\left[\frac{\delta_{gw}}{2\sqrt{\alpha_z\,x}}\right] \qquad (2)$$

Note: Comparing to ASTM E1739-95, p. 31, where $Y = S_w$, $\delta_{gw} = S_d$, $v = u$, and $C_o = C_{source}$

At the centerline, for steady-state, the DAF with decay can be calculated using Equation (1). In Equation (1), the retarded seepage velocity ($v$) is calculated as:

$$v = (K\,i)/(R_s\ \theta_{TS})$$

where:

$K$ = Hydraulic conductivity [cm/year]

$i$ = Hydraulic gradient [--]

$\theta_{TS}$ = Total porosity in the saturated zone [cm$^3$/cm$^3$-soil]

$R_s$ = Retardation factor in the saturated zone [--]

## SOIL AND GROUNDWATER SOURCE CONCENTRATIONS AT SENTRY WELL AND POE FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Groundwater concentration at the sentry well} = \textit{Groundwater source concentration at the } POE \times DAF_{SW}$$

$$\text{Groundwater concentration at the POE} = \textit{Groundwater source concentration at the } POE \times DAF_{POE}$$

where:

$POE$ = Point of exposure

$SW$ = Sentry well

$DAF_{POE}$ = Dilution Attenuation Factor between the point of exposure and the source

$DAF_{SW}$ = Dilution Attenuation Factor between the sentry well and the source

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate} = \frac{0.693}{Half\,Life}$$

$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right) \qquad K_{ss} = f_{ocs} \times K_{oc}$$

$$\text{Retardation Factor for Metals in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{d}}{\theta_{TS}}\right)$$

where:

$\rho_{ss}$ = Saturated zone soil bulk density [g-soil/cm$^3$-soil]

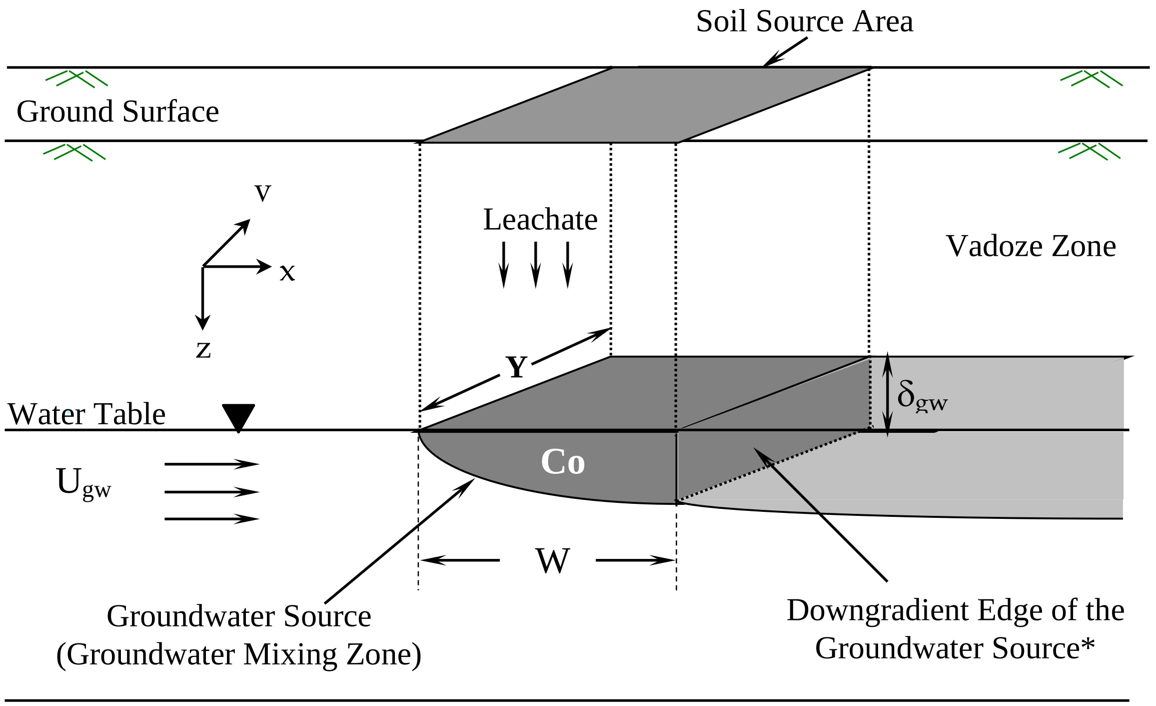
$K_{ss}$ = Chemical-specific soil-water sorption coefficient in the saturated zone [cm$^3$-H$_2$O/g-soil]

$K_d$ = Chemical-specific soil-water distribution coefficient for metals in the saturated zone [mL/g]

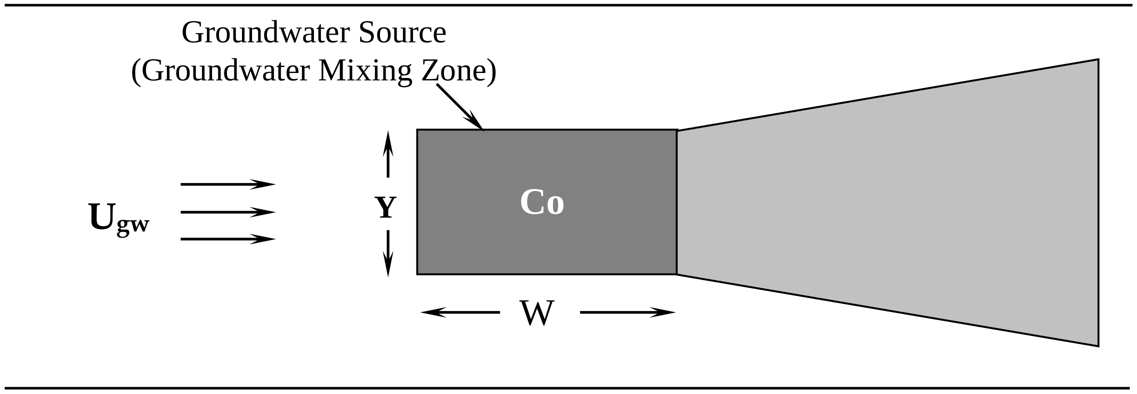
$\theta_{TS}$ = Total porosity in the saturated zone [cm$^3$/cm$^3$-soil]

$f_{ocs}$ = Fractional organic carbon content in the saturated zone [g-C/g-Soil]

## SCHEMATIC DESCRIPTION OF DOMENICO'S MODEL



**SECTION**



**PLAN**

**Note:**

(* Assumes only vertical leaching, i.e., there is no horizontal spreading in the unsaturated zone.)

## SURFACE WATER CONCENTRATION AT THE EDGE OF THE MIXING ZONE

$$C_{str} = \frac{C_{gw}Q_{gw} + C_{su}Q_{sw}}{\left(Q_{gw} + Q_{sw}\right)}$$

$$Q_{gw} = \left(Z + \sqrt{\alpha_z X_s}\right) \times \left(Y + 2\sqrt{\alpha_y X_s}\right) \times U_{gw}$$

where,

$Q_{gw}$ = Impacted groundwater discharge into the stream [$ft^3$/day]
$Q_{sw}$ = Stream flow upstream of the point of groundwater discharge (stream flow rate) [$ft^3$/day]
$C_{str}$ = Concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
$C_{gw}$ = Groundwater concentration at the point of discharge into the stream [mg/L]
$C_{su}$ = COC concentration upstream of the groundwater plume discharge [mg/L]
$Y$ = GW source dimension perpendicular to GW flow direction [ft]
$Z$ = GW source (mixing zone) thickness [ft]
$\alpha_y$ = Lateral dispersivity [ft]
$\alpha_z$ = Vertical dispersivity [ft]
$X_s$ = Distance from the downgradient edge of the groundwater source to the stream [ft]
$U_{gw}$ = Darcy velocity [ft/day]

# APPENDIX G
# DEVELOPMENT OF A SITE-SPECIFIC BIODECAY RATE

# APPENDIX G
# DEVELOPMENT OF A SITE-SPECIFIC BIODECAY RATE

## G.1 BACKGROUND

The application of the ARBCA process at petroleum-impacted sites in Alabama ultimately results in remedial and/or risk-management decisions based on the cumulative risk determined for all of the complete routes of exposure. At all sites, if the cumulative risk is exceeded, the ARBCA process suggests the development of RBTLs protective of all direct and indirect pathways. These target levels may be developed using site-specific biodegradation rates provided that there is sufficient site-specific evidence to confirm that biodegradation is occurring and that sufficient data is available to estimate a site-specific biodegradation rate. This appendix provides the methodology for determining site-specific biodecay rates. Please note that the terms biodecay and biodegradation are used interchangeably in this document. The use of biodecay is not allowed in an RM-1 Evaluation.

This appendix contains guidance on the development of a site-specific biodegradation rate for use in estimating soil and groundwater RBTLs protective of groundwater resources. The estimation of site-specific biodegradation rates is an evolving science and the ARBCA Evaluator is encouraged to review publicly available literature for current approaches to estimate site-specific biodegradation rates.

The soil and groundwater concentrations protective of the groundwater resource can be estimated using either of two ways. One way is without biodegradation - using a dilution attenuation factor (DAF) in the saturated zone that does not consider biodegradation of the chemical of concern. The second way is with biodegradation, which allows the use of a saturated-zone DAF that incorporates user-specified, site-specific, chemical specific, biodegradation rates.

The choice to utilize biodecay in calculating Groundwater Resource Protection RBTLs must be justified. At a site with little to no evidence of biodegradation, the ARBCA Evaluator should not use this option to calculate the concentrations protective of the groundwater resource. When properly justified, a site-specific biodecay rate is an appropriate choice.

The Department will accept ARBCA Evaluations using the biodegradation rate only if (1) adequate evidence is presented that indicates that biodegradation is occurring at the site, and (2) the calculated biodegradation rate is technically correct. Even at sites where the ARBCA Evaluator proposes the application of the biodegradation rate, an evaluation without the application of the biodegradation rate should be presented in the event the evaluation utilizing the biodegradation rate is not acceptable.

The following two sections contain information and procedures for applying a site-specific biodegradation rate. The first section contains information on how the site data itself must be evaluated to determine if biodecay is a significant process at the site. The second section contains a procedure to calculate the site-specific biodecay rate.

- Section G.2 presents a discussion of the type of information that should be evaluated to demonstrate that biodegradation is occurring at the site.

- Section G.3 discusses the method used to calculate a site-specific biodecay rate for use in the equations in Appendix E on page E-14.

## G.2 HOW TO JUSTIFY NATURAL ATTENUATION WITH BIODEGRADATION

Several parameters (hydrocarbons, electron acceptors, microorganisms, nutrients, and carbon dioxide) may be measured to demonstrate the occurrence of biodegradation.

These measurements are typically divided into three tiers, or “lines of evidence”, to demonstrate Natural Attenuation (NA). These include: (i) primary, (ii) secondary, and (iii) tertiary lines of evidence. Data collected under each line of evidence can be evaluated qualitatively or quantitatively as discussed in the following sections. A discussion of the interpretation of the most common primary and secondary lines of evidence for the occurrence of natural attenuation is given in the ASTM Standard on the topic (1999).

### G.2.1 Primary Lines of Evidence

The primary line of evidence for the occurrence of NA, not specifically biodegradation, is data demonstrating the loss of chemical mass through evaluation of measured petroleum hydrocarbon concentrations. Of all the methods available to demonstrate the occurrence of NA, this is perhaps the simplest and most useful to demonstrate reduction in site-specific risks. Site-specific application of the primary lines of evidence requires: (i) an adequate number of correctly installed sampling points (monitoring wells), (ii) adequate duration and frequency of chemical data collected from these points, and (iii) proper evaluation of this data.

Although the primary line of evidence can show whether a contaminant plume is attenuating based on chemical concentrations, it does not demonstrate whether the decrease in concentrations, or attenuation, is due to destructive mechanisms, *e.g.*, biodegradation or dilution. A secondary line of evidence is necessary to determine whether the decrease is due to biodegradation.

Statistical tests may be used to establish and characterize the trend in concentrations over time. These tests can be used to test a null hypothesis vs. an alternative hypothesis. An example of a null hypothesis is that there is no trend in the concentrations vs. distance. The alternate hypothesis is that there is a downward or upward trend. Application of a statistical test would then result in the acceptance or rejection of the null hypothesis at a specified level of significance.

If the concentration vs. time or concentration vs. distance data indicates a decreasing or increasing trend, a regression analysis may be used to estimate the slope of the best-fit line and determine whether or not the trend is significant. The slope of the best-fit line for the data can be used to estimate the natural attenuation or the biodegradation rate. For additional information on regression analysis, refer to any statistics textbook.

### G.2.2 Secondary Lines of Evidence

Secondary lines of evidence of the occurrence of biodegradation refer to the measurements of electron acceptors and products of metabolism and their comparison with concentrations in the unimpacted area of the aquifer, where no biodegradation activity would be expected to occur. These parameters are also referred to as geochemical indicators or intrinsic indicators of biodegradation. Parameters that are typically measured in the field include: (i) dissolved oxygen, (ii) carbon dioxide, (iii) dissolved nitrates, (iv) manganese, (v) ferrous iron, (vi) sulfate, and (vii) methane. These parameters should be measured at upgradient locations, inside the plume near the source, and in the downgradient locations. The distribution and occurrence of these parameters that is indicative of biodegradation is discussed in the ASTM standard on the topic (1999).

As chemicals are consumed by microorganisms, there is a corresponding decrease of the compounds that serve as electron acceptors. Thus, the concentration of these compounds decreases in the portion of the plume where biodegradation is occurring. For example, under aerobic biodegradation, the concentration of oxygen would decrease, assuming oxygen is not being added to the plume. Similarly, under anaerobic conditions, a depletion of nitrate, ferric (III) iron, sulfate, and carbon dioxide may be anticipated.

It should be noted that the secondary lines of evidence demonstrate the occurrence of biodegradation only. It does not provide any data on the occurrence of other NA processes.

### G.2.3 Tertiary or Optional Lines of Evidence

Tertiary or optional lines of evidence involve the performance of microbiological studies such as the identification and counting of the microorganisms present in the formation. Thus, the objectives of the measurement of secondary and tertiary lines of evidence are similar. Although petroleum-degrading microbes are ubiquitous in soil and groundwater, microbes at a site may not be able to degrade certain compounds, for example MTBE. In the portion of the plume where biodegradation is occurring, the ratio of petroleum degrading bacteria to the total number of bacteria is expected to be higher. Tertiary lines of evidence are seldom required at petroleum hydrocarbon impacted sites, hence, they are not discussed further here.

### G.2.4 Documentation of Biodegradation in the ARBCA Report

If the secondary or tertiary (rarely measured) lines of evidence indicate that biodegradation is occurring, at a minimum, the following information should be submitted as justification:

1. Table of historical intrinsic indicators of biodegradation
2. Graphs of historical values of intrinsic indicators of biodegradation plotted as time vs. concentration per well
3. A series of contour map(s) illustrating trends of pertinent indicators of biodegradation over time
4. Include comparisons of site concentrations with RBTLs with and without biodegradation
5. Table of decay rate input/output values
6. Table of calculated attenuation and biodecay rates including ranges and averages
7. Copy of the computational software input and output, if software was used

## G.3 ESTIMATION OF SITE-SPECIFIC CHEMICAL HALF-LIVES

The following step-by-step procedure may be used to develop a site-specific biodegradation rate or half life for use in the Groundwater Resource Protection Evaluation. Note, the procedure should be repeated for each chemical of concern that exceeds any Groundwater Resource Protection or Surface Water Protection site-specific target level (SSTL). It is not necessary to compute half lives for chemicals that do not exceed Groundwater Resource Protection or Surface Water Protection SSTLs.

Step 1: Determine the groundwater flow directions based on the water level measurements for each monitoring event.

Step 2: For each monitoring event, identify the wells located along the directions of flow, *i.e.*, along the plume centerline(s). Note, since the flow direction may vary, different wells may be used for different monitoring events.

Step 3: Tabulate the concentrations of the chemicals of concern and calculate the natural log of the concentrations.

Step 4: For each monitoring event, plot the natural log of the concentrations on the Y-axis and the distance along the X-axis. A separate plot should be made for each event.

Step 5: For each plot, calculate the slope of the best-fit line and test whether or not the null hypothesis can be rejected at the .05 level of significance. The null hypothesis in this case is that the slope of the regression line is zero, indicating no relationship between the natural log of concentration and distance.

Step 6: Estimate the retarded groundwater seepage velocity and the longitudinal dispersivity.

Step 7: Multiply the slope of the best-fit line calculated in Step 5 by the seepage velocity to estimate $k$ (see Buscheck and Alcantar, 1995).

The result would represent the overall NA rate. This NA rate represents the reduction in concentration due to the combined influence of the various NA processes mentioned in Section G.2. Note that this overall NA rate ($k$) should not be confused with the biodegradation rate ($\lambda$) that is an input to the Groundwater Resource Protection model used in ARBCA (see page E-14).

Step 8: Estimate the biodegradation rate ($\lambda$) using Equation I.1 derived by Buscheck and Alcantar (1995, equation 9) based on the solution of the one-dimensional transport equation with biodegradation.

$$\lambda = \frac{v}{4\alpha_x}\left\{\left[1+2\alpha_x\left(\frac{k}{v}\right)\right]^2 - 1\right\} \qquad \text{(I.1)}$$

*Where:*

$\lambda$ = Biodegradation rate (1/year)

$\alpha_x$ = Longitudinal dispersivity (x/10)(cm)

x = Distance from the source to the POE (cm)

*k* = Attenuation Rate (unitless)

*v* = Seepage velocity (retarded) (cm/year) (K x i) / ($\theta_{TS}$ x $R_s$)

$R_s$ = Retardation Factor for Organics in the saturated zone ($R_s$) $= 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right)$

$$K_{ss} = f_{ocs} \times K_{oc}$$

$R_s$ = Retardation Factor for Metals in the saturated zone ($R_s$) $= 1 + \left(\frac{\rho_{ss} \times K_d}{\theta_{TS}}\right)$

where:

$\rho_{ss}$ = Saturated zone soil bulk density (g-soil/cm$^3$-soil)

$K_{ss}$ = Chemical-specific soil-water sorption coefficient in the saturated zone (cm$^3$-$H_2O$/g-soil)

$K_d$ = Chemical-specific soil-water distribution coefficient for metals in the saturated zone (mL/g)

$\theta_{TS}$ = Total porosity in the saturated zone (cm$^3$/cm$^3$-soil)

Steps 1 through 8 should be completed for each relevant groundwater monitoring event, for example, all those within the period over which representative concentrations have been calculated. The results should be presented as a range of NA and biodecay rates, *k* and $\lambda$, respectively. The latter is used as an input to the Domenico model to estimate the saturated zone dilution-attenuation factor. Due to confounding factors such as seasonal variations in groundwater velocity, water-level fluctuations, errors in sampling and analysis methods, the NA and biodegradation rates may vary significantly between events. Therefore, it is best to present the range as well as the average rates.

Professional judgement must be used to determine the most representative $\lambda$ for use in the calculation of the chemical half-lives.

Step 9: Calculate a half-life for each chemical using the equation, $\lambda$ = .693/half-life. $\lambda$ should be written as 1/days for this calculation. Equation I.1 occasionally produces negative half-lives. Negative half-lives are artifactual and should not be used. You may average the half-lives for one chemical.

Utilize the derived site-specific half-lives to calculate the Groundwater Resource Protection with Biodegradation RBTLs for soil and groundwater. The half-lives for each chemical of concern that exceeds a target level without biodegradation should be stated in the report. Using the average half-life for a COC (not using any negative half-lives), the ARBCA Evaluator should compute new DAFs and new soil and groundwater concentrations to meet in the source area and in any sentry wells that exceeded SSTLs without biodegradation. The new RBTLs should be stated in the report. For comparison, the corresponding RBTLs without biodegradation should also be listed.

## G.4 REFERENCES

ASTM, 1999, Designation E 1943-98 Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites, in: *ASTM Standards on Assessment and Remediation of Petroleum Release Sites*, ASTM Committee E-50 on Environmental Assessment, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, 19428-2959, pages 82-123.

Buscheck, T. E., and C. M. Alcantar, 1995. Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation, in Hinchee, R. E., J. T. Wilson, and D. C. Downey, editors, 1995, *Intrinsic Bioremediation*, Battelle Press, Columbus, Ohio, pages 109 - 116.