Alabama Department of Environmental Management

ARBCA: ALABAMA RISK-BASED CORRECTIVE ACTION FOR UNDERGROUND STORAGE TANKS

GUIDANCE MANUAL
REVISION 1.0

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1.0
BACKGROUND AND INTRODUCTION

1.1 INTRODUCTION

The **Alabama Department of Environmental Management (ADEM)** has determined that a **Risk-Based Corrective Action (RBCA)** program is appropriate for managing petroleum releases at **Underground Storage Tank (UST) sites**. The current Chapter 15 UST regulations allow for the use of **Alternate Corrective Action Limits (ACALs)** under Rules 335-6-15-.32 and .33. This guidance manual describes a systematic approach for the development of ACALs for soil and groundwater under the current State of Alabama Underground Storage Tank program. It is anticipated that the current Chapter 15 regulations will be modified in the future to fully integrate a risk-based approach for evaluating and managing UST releases.

Two issues have motivated the ADEM to develop and implement this risk-based approach for a consistent and protective risk-based process for the management of UST petroleum releases. First, during the course of evaluating and managing the UST sites since 1988, the ADEM has gained considerable knowledge and information on the behavior of hydrocarbons in soil and groundwater. The ADEM would like to incorporate some of the “lessons learned” into their current regulations and guidance manual. Secondly, the large number of known UST releases and likely future releases necessitates better use of limited financial, human, and technological resources. The Groundwater Branch of the ADEM began tracking UST releases around 1988. To date over 10,000 release reports have been received. Of these, over 3,500 releases have required additional site-specific soil and/or groundwater assessments. Tank owner, consultant, and regulatory resources are stretched thin with the increasing number of releases being discovered. In addition, site-specific variations result in a lack of remedial technologies available for cost effective remediation of every site to be remediated to the current Corrective Action Limits (CALs).

During the period 1996 to 1998, the ADEM spent considerable time and resources to understand the RBCA process as described in the ASTM Standard E1739-95 entitled “**Risk-Based Corrective Action Applied at Petroleum Release Sites**” and supported by the **United States Environmental Protection Agency (U.S. EPA)**. Several training programs, demonstration projects, and other state RBCA programs were evaluated. Based on the knowledge and experience gained through this process, the ADEM has developed the **Alabama Risk-Based Corrective Action (ARBCA)** process for the UST program that was published in 1998. At that time, the ADEM anticipated that modifications and enhancements to this guidance might be necessary. This document represents the first revision of the ARBCA guidance document, software, and report forms.

This process recognizes and balances (i) the need to protect public health, water resources, and the environment of the State, (ii) variations 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 ARBCA process. State-specific default values have been selected which are appropriate for sites located in Alabama.

1.2 APPLICABILITY

The intent of the **Alabama Risk-Based Corrective Action (ARBCA)** process for USTs is to develop site-specific ACALs protective of current and potential future (i) human health, (ii) environment, (iii) nuisance conditions, and (iv) explosive type situations.
While regulations have existed since 1989 that allow for a risk assessment to be performed to establish site-specific ACALs, the lack of a written protocol has hindered the widespread and consistent use of risk assessment. This document fills that void by providing a technically defensible procedure for establishing ACALs for petroleum releases at UST sites.

Although this guidance manual is focused on petroleum releases at UST sites, it may be appropriate to apply this procedure to petroleum releases from other sources (pipelines, refineries, aboveground storage tanks, etc.). Petroleum contaminated sites should be reported to the appropriate agency and/or program area according to the regulatory and statutory requirements which pertain to each of the programs.

Sites with releases from USTs that contain non-petroleum products can also request ACALs. Since this guidance manual focuses primarily on petroleum products, please contact the ADEM for further guidance on developing risk-based screening levels and/or site-specific target levels for any non-petroleum product releases.

This document has been developed for environmental professionals with working knowledge and experience in the areas of site assessment, site investigation, risk assessment, and remedial actions. Technical information is included that describes the ARBCA program and its elements, including site assessment, risk assessment, corrective action, and closure process as developed by the ADEM. Since the development of risk-based target levels is an integral part of the overall process of risk management and has not been described earlier in other state guidance documents it is described at length in this manual. **However, this manual is not intended as a general guide to every aspect of the risk assessment practice.** Prior experience or training will be necessary for an individual to correctly implement the risk assessment as part of the overall site management process.

A list of acronyms used in this document is available in Appendix A.

CURRENT CORRECTIVE ACTION LIMITS

Table 2-1 lists the corrective action limits for soil and groundwater as per the current regulations (the ADEM Admin. Code R. 335-6-15-.30 and .31).

TABLE 2-1

CORRECTIVE ACTION LIMITS AS PER THE ADEM ADMINISTRATIVE CODE RULE 335-6-15-.30 AND .31

Soil	
Petroleum Contaminated Soils	100 ppm Total Petroleum Hydrocarbons
Regulated substances other than Petroleum	Contaminant-Specific
Groundwater	
The Maximum Contaminant Levels or Health Advisories issued by the Office of Water of the U.S. Environmental Protection Agency (U.S. EPA),March 2001 (See Table 2-2).	

A listing of the current **maximum contaminant levels (MCLs)** or health advisories for the **chemicals of concern (COCs)** relevant to the UST program is shown in Table 2-2. Please note that these limits are subject to change and an owner/operator or consultant should verify that the values are current. Please contact the ADEM or U.S. EPA for the most current listing of the MCLs and/or Health Advisories.

The ARBCA process establishes several categories of ACALs. These include the **Initial Screening Levels (ISLs), Risk-Based Screening Levels (RBSLs),** and **Site-Specific Target Levels (SSTLs)** [Refer to the subsequent chapters for details]. Each of these ACALs, when correctly applied to UST sites, will satisfy the target risk level requirements established by the ADEM. Further, these ACALs will differ from the corrective action limits specified in Table 2-1 because (i) chemical-specific values will be developed for soil and groundwater, and (ii) the RBSLs and SSTLs 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 ACALs is described in subsequent sections.

3.0
OVERVIEW OF ALABAMA UST RBCA 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 ADEM determines that the residual site-specific concentrations are protective of human health and the environment. Upon completion of this process, the ADEM will issue a **"No Further Action (NFA)"** letter provided that (i) the ARBCA process is correctly implemented, and (ii) the future use of the site is consistent with the assumptions used in the ARBCA evaluation.

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 chemical concentrations protective of human health and the environment. Each element of the process is important and has to be correctly applied for the adequate protection of human health and the environment.

The ARBCA process is applicable at all UST sites irrespective of the current phase of activities being conducted at the site. 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. Sites in the corrective action phase should be evaluated to determine if the CALs proposed in the previously accepted **Corrective Action Plan (CAP)** are appropriate based on the ARBCA process.

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 the consideration of owner-imposed institutional controls after the ACALs have been established. Institutional controls include, but are not limited to, land use restrictions, receptor removal or relocation, and communication with potentially affected parties. Risk management issues are discussed in detail in Chapter 10.

The ARBCA process will continue to use **Remediation by Natural Attenuation (RNA)** as an element of corrective action. RNA may be appropriate as the sole corrective action at sites where (i) immediate threats to human health, safety, and the environment do not exist or have been mitigated and are unlikely to occur, and (ii) site evidence indicates that RNA will achieve the ACALs within a reasonable time frame. Please refer to the ***"Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual"*** for additional information on the use of natural attenuation as a remedial technique.

3.2 TYPES OF RISK-BASED CONCENTRATION LEVELS

The tiered ARBCA process results in the following three types of ACALs:

Initial Screening Levels (ISLs) are the lowest (for the various exposure pathways) of the Tier 1 Risk-Based Screening Levels (RBSLs) for a commercial or residential area for a particular COC. These values are used strictly for screening purposes (not as remedial target levels) and do not allow for any site-specific determination of exposure pathways. These levels may be applied at UST closure site assessments and environmental site assessments where an adequate characterization of the source area(s) (but not the entire impacted area) has been performed.

Risk-Based Screening Levels (RBSLs) are generic target concentrations of a COC for an exposure medium (i.e. soil, groundwater, surface water, or air) which would not pose an unacceptable risk to human health and the environment. RBSLs depend on (i) the COC, (ii) the receptor, and (iii) the route of exposure. RBSLs have been developed using conservative assumptions and are used for a Tier 1 evaluation.

Site-Specific Target Levels (SSTLs) are the site-specific concentrations of a COC for an exposure medium (i.e. soil, groundwater, surface water, or air) which would not pose an unacceptable risk to human health based on the complete routes of exposure and site-specific characteristics. SSTLs are developed by the owner/operator and require the consideration of several site-specific characteristics. Depending on the amount of site-specific information and the methodology used, Tier 2 and/or Tier 3 SSTLs may be developed.

3.3 THE OVERALL INVESTIGATION PROCESS WITH ARBCA

Figure 3-1 presents a simplified flowchart that illustrates the ARBCA process for underground storage tanks or similar petroleum releases. As shown in Figure 3-1, the ARBCA process is a combination of data collection and data evaluation to identify the receptors that are present, exposure pathways that are complete, and site-specific ACALs 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 perhaps an **Environmental Assessment (EA)**. As an initial screen, maximum soil and groundwater concentrations are compared to existing CALs and/or ISLs. If the concentrations exceed the existing CALs or ISLs 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 data for a site-specific risk-based evaluation. A description of the type of data, which should be obtained, is listed in Sections 5 and 6.

After an adequate site characterization has been performed (See Section 5), a comparison of site concentrations to Tier 1 RBSLs is conducted. Should the representative concentrations exceed the Tier 1 RBSLs for any complete pathway or site characteristics significantly differ from the assumptions used to develop Tier 1 RBSLs, then additional data may have to be collected to perform a Tier 2 evaluation. Note, at sites where the impacts are localized, Tier 1 levels may be accepted as the remedial target levels. The ADEM will issue an NFA after Tier 1 levels have been achieved.

For sites that proceed to a Tier 2 evaluation, Tier 2 SSTLs have to be calculated and compared with representative concentrations. After performing a Tier 2 evaluation, one of four options are usually available: (i) no further action, (ii) remediation to meet Tier 2 SSTLs, (iii) compliance monitoring, or (iv) Tier 3 evaluation.

Tier 2 SSTLs can be calculated at any stage of the ARBCA process. The only requirements are that the **Site Conceptual Exposure Model (SCEM)** be developed prior to SSTL calculation (all current and reasonable future receptors and all routes of exposure have been identified) and relevant data are available. The comparison of site data to the established SSTLs, however, should only be performed after adequate site characterization has been done and sufficient monitoring data has been obtained. The amount of monitoring data that should be collected is discussed in Appendix B and requires site-specific professional determination.

For sites that proceed to a Tier 3 evaluation, Tier 3 SSTLs are calculated based on additional site-specific data and fate and transport modeling. After the completion of a Tier 3 evaluation, the ADEM may grant an NFA if the Tier 3 levels are not exceeded or require site-specific risk management activities to achieve Tier 3 levels.

The ARBCA process is a progressive approach which allows for additional site data collection to support a site-specific risk-based evaluation without compromising protection of human health and the environment. A comparative evaluation of the three tiers is presented in Table 3-1. The ADEM anticipates that some sites will receive "No Further Action" upon comparison with the existing CALs. Sites exceeding the CALs will move into the tiered process and subsequently receive a NFA based on Tier 1, Tier 2, or Tier 3 evaluation after appropriate corrective actions have been completed.

3.4 THE ARBCA PROCESS STEP-BY-STEP

Figure 3-2 shows a detailed view of the ARBCA process and the procedures to be utilized for a typical release. Please note that this flowchart is a general guideline. Detailed requirements for certain required actions are located in the ADEM Division 6 Chapter 15 rules and in other Chapters of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual***". In many cases, references to the rules and the Guidance Manual are made to enable the reader to locate the regulatory requirement for the activity or to find more detailed information. A new release can enter the flowchart at Step 1, whereas an existing release may enter the process at any point along the way.

The ARBCA process begins with the first discovery of a release followed by the performance of an adequate site assessment, the performance of initial abatement measures as needed, selection and development of RBSLs and SSTLs, site remediation when warranted, confirmation of site remediation by monitoring, and finally the issuance of "No Further Action".

3.5 ANTICIPATED IMPACTS ON SITE COSTS

As a site moves through the ARBCA process, additional costs may initially be incurred in order to conduct an adequate ARBCA evaluation. The following impacts on costs and resulting benefits may occur:

- Collection of additional site-specific data may increase the cost of data collection and analysis, but there will be a reduction in the overall uncertainty about the site.
- The need for additional analysis to develop SSTLs is likely to be an additional cost over the use of generic cleanup levels.
- In general, the calculated Tier 2 SSTLs will be higher than the Tier 1 RBSLs because lower tier levels are designed to be more conservative than higher tier levels. Thus, the cost of corrective action to achieve the target levels should be lower.
- The need for and the extent of regulatory oversight and review for the establishment of site-specific ACALs will increase due to the added evaluation efforts.
- The level of uncertainty will decrease due to the availability of more site-specific data.
- In general, the cost of assessments may increase, but the overall cost of corrective action should decrease.

Note that all complete routes of exposure and chemicals of concern have to be evaluated in Tier 1 and Tier 2. However those pathways and COCs that satisfy the Tier 2 SSTLs may not be necessarily evaluated in Tier 3. Despite the above differences among the three tiers, 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 ADEM. [Refer to Section 6.7.1].

3.6 ARBCA EVALUATOR QUALIFICATIONS

Determining ACALs requires that the personnel evaluating the site and performing the risk-based evaluations be experienced in the concepts and procedures of risk assessment and risk management. Those persons who perform the evaluations should have completed, at a minimum, 24 hours of risk-based corrective action training recommended by the ADEM.

The ADEM will require that the ARBCA reports are signed by both a Geologist or an Alabama Registered Professional Engineer and the tank owner/operator (see Section (a) on ARBCA Report Form No. 2).

4.0
SITE CLASSIFICATION AND INITIAL RESPONSE ACTIONS

4.1 INTRODUCTION

The ADEM's current regulations regarding initial abatement measures, Rule 335-6-15-.25, outline the applicable initial abatement measures. The ARBCA process includes this critical step and as appropriate, abatement measures should be performed. With the exception of emergency situations, the identification of the need for initial response and/or initial abatement measures is identified through the completion of the UST Site Classification Checklist. The site classification process classifies sites based on the threat to human health and the environment. The Department has used this classification system since May 1995 and will continue to use this system within the ARBCA process.

4.2 SITE CLASSIFICATION SYSTEM

[ARBCA REPORT FORM NO. 3]

The classification system is a qualitative indicator of the degree to which human health and the environment may be impacted by a release from a UST system. The classification system and the appropriate initial response action for each site type are presented in Table 4-1. Note the site classification system currently assigns letters A through I to all UST release sites based on known site conditions. Sites with highest-alphabet classifications (i.e., A) are sites that pose the highest immediate threat to human health and the environment.

Upon confirmation of a release, the release should be classified based on known site information. In order to facilitate the classification, a ***"UST SITE CLASSIFICATION SYSTEM CHECKLIST"*** form is included as ARBCA Report Form No. 3. Based on the classification, appropriate initial response actions must be undertaken.

The "***UST SITE CLASSIFICATION SYSTEM CHECKLIST"*** form should be completed for each site by personnel experienced in the identification of and response to situations that may pose a threat to human health or the environment. The checklist has to be updated as new conditions are revealed at the site, or where remedial action reduces the threat of the release. The completed checklist should be submitted to the ADEM with routine submittals such as assessment plans and reports.

4.3 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 U.S. Geological Survey Water-Resources Investigations Reports entitled "***Geohydrology and Susceptibility of Major Aquifers to Surface Contamination in Alabama; Areas 1 -13"*** 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 for purchase from the ADEM or the **U.S. Geological Survey (USGS)**. These reports are currently being revised and will be available on CD-ROM from the ADEM.

The recommended initial response actions on Table 4-1 should be used as a general decision-making guide to reduce or eliminate the threat of exposure. These actions are not substitutes for regulatory requirements or other actions necessary 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 "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual*"** Section II and ADEM Admin. Code R. 335-6-15-.24 and .25.

The classification system does not apply to the presence of excavated soil material nor to contaminated groundwater that has been removed from the subsurface and is being treated or stored on site. Recommendations for reducing the risk of exposure to these situations are provided in various sections of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual"***.

4.4 UPDATING THE SITE CLASSIFICATION

The updating of the site classification system and the appropriate response actions is a dynamic process that should be modified at the completion of each major assessment or corrective action. For instance, a site with free product and no other immediate threat to human health may be classified as a "C" site. Upon removal of the free product, the site should be re-classified as a lower-alphabet classification (i.e., I).

4.5 FREE PRODUCT REMOVAL

[ARBCA REPORT FORM NO. 8]

The requirement to remove free product to the maximum extent practicable remains a component of the site corrective action. Current ADEM Admin. Code R. 335-6-15-.27 regulations indicate the type of activities that are to be performed at a site where free product is present. Free product is defined in ADEM Admin. Code R. 335-6-15-.02(x) as “a regulated substance that is present as a nonaqueous phase liquid (e.g., liquid not dissolved in water)”. Note, a visible sheen present on the groundwater or in soils is considered free product.

Sites with free product may be evaluated to determine relevant Tier 1 RBSLs or Tier 2 SSTLs. However, the site must continue to undergo free product removal. Groundwater compliance monitoring will be necessary during and after the free product removal to verify that site conditions do not pose an unacceptable level of risk.

Appendix B includes information on how free product is considered in the development of representative concentrations for soil and groundwater.

4.6 THREATS TO UTILITIES

[ARBCA REPORT FORM NO. 4]

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 a petroleum release site.

The location of free product at a site which is in contact with an underground utility line/ conduit or which has the potential to be in contact with the line/conduit will require that free product be removed in accordance with the free product removal regulations. In addition to the removal of the free product, it may be necessary to perform risk management activities such as replacing vulnerable portions of the line/conduit with a material that can withstand the impacts of petroleum or relocating the line/conduit.

A discussion of the type of data to be obtained to determine whether impacts to utilities have or might occur in the future is provided in Section 5.6.

5.0
SITE ASSESSMENT AND INVESTIGATION

This section highlights key aspects of the site assessment process and the data needs to implement a risk-based corrective action evaluation at UST sites with releases. Division 6, Chapter 15 of the ADEM regulations includes the existing rules and requirements for performing the **Preliminary Investigation (PI)** and **Secondary Investigation (SI)**. Detailed guidance on the various types of investigations is in Sections III, IV, and V of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual***".

The existing rules and guidance for the Preliminary and Secondary Investigations are geared towards utilizing existing CALs (Section 2.0) as the target clean-up goals. However, to develop ACALs (i.e. ISLs, RBSLs, and SSTLs) as per the ARBCA process, these investigations must be modified to ensure that a sufficient quantity and quality of data is being collected.

This section discusses several modifications to the investigations (Closure Site Assessments, Preliminary Investigations, and Secondary Investigations) necessary to perform a technically defensible ARBCA evaluation.

5.1 CHEMICALS OF CONCERN (COCs)

The ADEM Admin. Code R. 335-6-15 requires that an owner or operator address a release of a regulated substance from an underground storage tank system. The regulated substances include but are not limited to:

- Gasoline
- Diesel/Light Fuel Oils
- Product Jet Fuel
- Kerosene
- Heavy Fuel Oils
- Waste/Used Oil

Each of these products is composed of a variety of hydrocarbon compounds and additives whose physical and chemical properties and percent composition in the product vary considerably. Further, the environmental behavior (mobility, persistence, and inter-media transport) of the product and the adverse environmental and human health effects depend on the properties of each constituent and their concentration in the product.

While evaluating sites impacted by these products, the ADEM focuses on a limited set of chemicals that pose the majority of the risk for each product. These are known as the **chemicals of concern (COCs)**. The meaning of the term COCs used in this manual may differ from its use in other programs/documents.

Table 5-1 contains the major product types found in UST systems in Alabama and the corresponding COCs for each confirmed or suspected product type released at a site. This table should be utilized in the planning and implementation of site assessments and ARBCA evaluations, i.e., soil and groundwater impacted media should be sampled for these COCs and alternate CALs developed for each COC listed in Table 5-1.

The recommended analytical methods for determining the concentrations of the chemicals of concern are also shown in Table 5-1. These methods should be utilized unless specific authorization has been granted by the ADEM to utilize an alternate analytical method.

5.2 CLOSURE SITE ASSESSMENT, PRELIMINARY INVESTIGATION, AND ENVIRONMENTAL ASSESSMENTS

Details regarding these types of assessments are in the ADEM Admin Code R. 335-6-.26 and in Sections III, IV, and V of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual***". These investigations have typically utilized the CALs of 100 mg/kg (ppm) TPH for soil and the **maximum contaminant levels (MCLs)** for groundwater (see Section 2.0).

These assessments are generally geared towards detecting a release or determining if soil and/or groundwater has been impacted by a release from an underground storage tank system. Therefore, the assessment activities are performed to determine if soil and/or groundwater impacts have occurred in the likely source areas and to determine the extent of soil and/or groundwater impacts. Because little information is known about the site, more conservative and protective ACALs are applied to these sites as discussed below.

5.2.1 Closure Site Assessment (CSA)

With the ARBCA process, an owner/operator may choose to utilize Initial Screening Levels (ISLs) to evaluate the results of a Closure Site Assessment (CSA). This will require the collection of samples and their analysis for the COCs from the most likely source areas. The frequency and number of samples are the same as for the existing CSA (See Section III of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual"***). Where COCs have been measured in the stockpiled soil, the ISLs may be used as target levels.

The Initial Screening Levels (ISLs) are conservative ACALs that distinguish only between the commercial or residential land use and are not pathway specific. These values are presented in Table 5-2 for commercial and residential land use. The appropriate ISLs should be selected based on the current land use and the most likely future land use (see Section 6.1). The ADEM may grant an NFA if the maximum site concentrations do not exceed the ISLs. Since very little site data is available from a Closure or Preliminary Investigation, it is appropriate to use these conservative limits as screening levels.

5.2.2 Preliminary Investigation (PI)

The Preliminary Investigation (PI) should be performed to obtain the necessary soil and groundwater COC data, soil properties data, land use information, and to develop the **Site Conceptual Exposure Model (SCEM)** for the ARBCA process.

When performing a PI where soil and groundwater samples are collected, the ISLs or RBSLs can be used. The ISLs are conservative values which reflect only commercial or residential land use and are not pathway specific, whereas the chemical-specific RBSLs depend on both the receptor type, and the complete exposure pathways.

The site-specific soil and groundwater concentrations measured during the PI will be compared with the ISLs or RBSLs (as appropriate) to determine if the site warrants an NFA, a Secondary Investigation, Interim Remedial Action, or a Corrective Action Plan. In general, if the site-specific maximum concentration of any COC exceeds the ISL or RBSL for soil or water, the site may require a Secondary Investigation.

5.2.3 Environmental Assessment (EA)

When performing an Environmental Assessment where soil and groundwater samples are obtained, the ISLs or RBSLs can be utilized in the same manner as for the Preliminary Investigation.

5.3 SECONDARY INVESTIGATION (SI)

The SI should be performed to obtain (i) adequate data to classify each site to determine initial response actions, and (ii) adequate information to perform a Tier 1 and Tier 2 evaluation at the release site.

The SI should be conducted in accordance with the ADEM Rule 335-6-15-.28. The primary guidance on the performance of the SI is provided in Sections IV and V of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual***". The SI is geared towards defining the horizontal and vertical extent of contamination and determining the hydraulic properties of the site. However, for a site undergoing an ARBCA evaluation, the SI should be enhanced to provide adequate site data to perform a Tier 1 and a Tier 2 evaluation.

The key components of the SI are:

- Identification of the soil and groundwater areas impacted by COCs appropriate to the type of product released (see Table 5-1) so that accurate representative soil and groundwater concentrations can be determined.

- Identification of the horizontal and vertical extent of impacts to soil and groundwater. Unless otherwise directed by the ADEM, the extent of impact should be defined to the ISLs. An ARBCA evaluation requires that a thorough assessment of source areas be performed to ensure that maximum 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, compliance monitoring, and to determine background levels of COCs.

- Determination of the hydraulic properties of the site including depth to groundwater, groundwater flow direction and rate, and hydraulic conductivity of the site (this may be obtained from literature sources).

- 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 concentration data for comparison to Tier 1 RBSLs and to calculate Tier 2 SSTLs. The assessment should be performed such that the Tier 1 RBSLs are considered throughout the assessment process to define the extent of investigation necessary to assess the horizontal and vertical extent of impacts. If it becomes apparent during the SI that the Tier 1 RBSLs will be met, then no additional information may be needed at the site. However, if the concentrations are likely to exceed the Tier 1 values or site conditions are significantly different than the Tier 1 default values, the SI should be performed such that all data necessary to perform a Tier 2 evaluation are obtained as expeditiously as possible.

5.4 REVIEW OF SITE CONDITIONS [ARBCA REPORT FORM NOS. 4-6, 9-12, and 17]

An evaluation of the following site conditions is an integral part of the ARBCA process. The level of effort should be sufficient to accurately complete the relevant ARBCA report forms.

- Ground Surface Condition (ARBCA Report Form No. 4): Determine percentage of the site that is paved. Also note the general condition of the pavement.

- Land Use (ARBCA Report Form No. 5): Detailed survey of the current and likely future use of the land within 500 feet of the site should be performed. The survey should identify the current status of the properties as residential or commercial. The most likely future use of the impacted or potentially impacted properties should also be determined. (See Section 6.1).

- Receptors (ARBCA Report Form Nos. 4, 5, 10, 11, 12, and 17): Determine the human and ecological receptors present in the area of the site. Receptors include adults, children, construction workers, wells, surface waters, etc. (See Section 5.5).

- Source History (ARBCA Report Form No. 6): Determine the history of the site. Evaluate the location(s) of previously installed USTs, **Aboveground Storage Tanks** (**ASTs**), dispensers, and piping. 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 USTs, ASTs, dispensers, piping, and subsurface utilities. 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 (ARBCA Report Form No. 9): Review the regional hydrogeology to determine soil types and aquifer characteristics. Published literature as well as investigations previously conducted on adjacent release sites will yield important information for the hydrogeological characterization.

- Groundwater Use (ARBCA Report Form No. 10): Determine whether there is groundwater use for public water supply within a one-mile radius and for 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 (ARBCA Report Form No. 11): Locate surface water bodies within 500 feet of the site which could be potentially impacted by the site release.

- Review the facility files for any environmental data.

5.5 PERFORMANCE OF RECEPTOR SURVEY

[ARBCA REPORT FORM NOS. 4, 5, 10, 11, and 12]

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

- Land Use (ARBCA Report Form No. 5): 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 (ARBCA Report Form No. 4): Identify the location and depth of all subsurface utilities and other subsurface pathways, which may serve as preferential conduits for migration of the chemicals. Identify the flow direction of the material (water, sewage, etc.) within the utility line.

- Water Well Inventory (ARBCA Report Form No. 10): 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.

- Ecological Receptors (ARBCA Report Form No. 12): The determination of ecological receptors within a 500-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 impacted will undergo a Tier 3 evaluation.

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

[ARBCA REPORT FORM NO. 4]

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, use of 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 located within the area of known or likely soil and groundwater impacts, for both onsite and any offsite properties to which the release may have migrated or to which the 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 free product and 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 removed to the maximum extent practicable.

- Where dissolved contamination is present, an evaluation of potential impacts 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

[ARBCA REPORT FORM NOS. 9, 13, 14, 16, and 20]

The subsurface site investigation should be guided by the scope of work prepared during the preliminary planning stage, however, appropriate adjustments to the scope of work and modifications to the SCEM 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.

- <u>Geologic Description (ARBCA Report Form No. 9)</u>: 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 must be submitted for each hole drilled at the site.

The logs must 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 COCs in Soil (ARBCA Report Form Nos. 13 and 14): The vertical and horizontal extent of subsurface impacts should be defined during the site assessment. At a minimum, discrete samples should be obtained every five feet to 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 COCs. Additional samples may be necessary to fully characterize the soil chemical distribution and to quantify exposures for a Tier 2 or Tier 3 evaluation or for the development of a remedial action plan. Where evidence exists that a surface spill or a shallow release has occurred, surficial samples in the release source area from the 0 to 1 foot level should also be obtained.

- Sampling for Physical Soil Properties (ARBCA Report Form No. 9): For those sites which need to move to a Tier 2 or Tier 3 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) soils through which the COCs migrate to reach groundwater, (iii) soils through which COC vapors migrate to reach the surface, and (iv) saturated soils for groundwater contaminant migration evaluations. For further information refer to ASTM Standard 1587.

  - Fractional organic carbon (foc) samples must be determined using soil samples not impacted 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 COCs, or if the COCs are contained within multiple lithologies. Both a vadose zone fractional organic carbon (foc) sample and a saturated zone fractional organic carbon (foc_s) sample should be collected when it appears these two zones may differ at a site.

  - Samples taken 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 COCs, or if the COCs are contained within multiple lithologies. Both a vadose zone total porosity (θ_T) and a saturated zone total porosity (θ_{TS}) should be collected when it appears these two zones may differ at a site.

  - Samples taken for dry bulk density (ρ_s) 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 COCs, or if the COCs are contained within multiple lithologies.

- Sampling for COCs in Surface Water (ARBCA Report Form No. 20): Appropriate samples should be collected when COC 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. In addition, sediment samples and an additional stream sample collected at the groundwater discharge point should be collected if the site conditions warrant.

- Sampling for COCs in Groundwater (ARBCA Report Form No. 16): If the groundwater has been impacted, temporary sampling points may be used to screen the levels of groundwater impacts and to assist in determining the optimal location of permanent monitoring wells. A sufficient number of monitoring wells should be installed (a minimum of four for a Tier 1 evaluation) to document COC migration and groundwater flow. Well placement and design should consider:
  - Concentration of COCs 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 surficial soil data (0 to 1 foot below ground surface) are necessary where there was a surface spill or overfill and it is likely that surficial soils have been impacted. These data are used to evaluate the exposure pathways associated with the surficial soil. These pathways include direct contact or 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 **below ground surface (bgs)** may not be available. Therefore, the following guidance should be used to determine what samples need to be obtained.

For sites where the soil assessment *has been completed*:

- Do not take surface soil samples when the site is paved and likely to remain so.

- For sites where the only COCs are volatiles (BTEX) neglect the exposure pathways associated with surficial soil.

- For unpaved sites where the COCs are non-volatile (PAHs or metals), and there is evidence of a surficial spill or a shallow piping leak, collect surficial soil samples.

- For sites where the COCs are non-volatile (PAHs or metals), and there is evidence of a surficial spill or a shallow piping leak, and the site *is* paved, collect surficial soil samples only if the pavement may be removed.

For sites *currently* under soil assessment:

- When sampling from boreholes, collect one soil sample for laboratory analysis at a depth of one foot below the surface or two inches below the impervious (concrete or asphalt) pavement, whichever is shallower. Note that in some cases, very permeable material may be located two inches below the pavement. Care should be taken to collect a representative sample.

5.9 REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

The application of a Tier 1 and/or Tier 2 evaluation at a site results in the selection of soil and/or groundwater RBSLs or the development of SSTLs. For site-specific risk management decisions, it is necessary to compare these levels with the representative soil/groundwater 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 EXISTING SITES WITH INADEQUATE COC DATA

5.10.1 Sites With Predominantly TPH Data

There are about 1,000 UST sites in Alabama where only TPH data for soils are available. At these sites soil COC data are not available. Since TPH data cannot be used for the ARBCA evaluation, soil COC confirmatory data should be collected at those sites where having the data may affect the risk management decision.

The flowchart in Figure 5-1 should be used as a decision-making tool to determine when additional soil COC data are necessary. Note this procedure only applies to those sites where site investigations have already been completed. For all newly discovered sites, or sites where soil and groundwater assessments are currently underway, BTEX and other appropriate COC data should be collected as part of the site investigation.

5.10.2 Sites With Inadequate Metals Data

There are several UST sites where soil and groundwater data for metals may not be available. At these sites, the ADEM may use the following considerations to determine whether or not it is necessary to collect soil and groundwater data for metals:

- At sites where investigation activities have been completed and available information indicates the possibility of metal contamination, the ADEM will require the analysis of groundwater samples from existing monitoring wells for total metals. If these levels are below the MCLs or site-specific background levels, no further evaluation or measurement of metals will be necessary. However, if these levels exceed the MCLs or background levels, continued groundwater sampling for metals and additional soil samples to be analyzed for metals may have to be collected. Depending on the SCEM, both surficial and subsurface samples may be necessary. This data will then be used in the ARBCA tiered evaluation process.

- At sites currently in the investigation phase, where metals are COCs as per Table 5-1, soil and groundwater samples should be analyzed for metals. Depending on site-specific data and the site conditions, it may not be necessary to analyze all future groundwater samples for metals.

- If metals concentrations in groundwater are below MCLs, no further sampling will likely be required.

5.11 RECOMMENDED LABORATORY ANALYTICAL METHODS

The site investigation should be conducted to obtain both analytical data for COCs and physical properties of soil. The acceptable analytical methods for determining concentrations of COCs in soil, groundwater, and surface water are shown in Table 5-1. Tier 1 evaluations use conservative soil properties for evaluation. If a Tier 2 or Tier 3 evaluation is to be performed, site-specific soil data should be obtained. Acceptable laboratory methods for determining the following soil properties are:

Dry Bulk Density (g/cc) (ASTM Method D2937-94, Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method) is the dry weight of soil sample divided by the field volume of the soil sample. An accurate measurement of bulk density requires weighing or determining the dry weight and 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 volume of the soil sample. Many laboratories use dry bulk density and specific gravity data to determine porosity using the following:

$$n = 1 - \rho_s/\rho_p \qquad (5\text{-}1)$$

where,

n = porosity (cc/cc)
ρ_s = dry bulk density of soil (g/cc)

ρ_p = specific gravity or particle density (g/cc)

The "Standard Test Method for Specific Gravity of Soil" ASTM Method D854, may be used to determine specific gravity. If specific gravity is not available, then 2.65 g/cc 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 volume of water to the volume of soil. The ASTM Method D2216-92 (Standard Test Method for Laboratory Determination of Water [Moisture] Content of Soil and Rock) 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:

$$\theta_{wv} = \theta_{wg} * \rho_s / \rho_l \tag{5-2}$$

where,

θ_{wv} = volumetric water content (cc water / cc soil)
θ_{wg} = gravimetric water content (g of water / g of soil)
ρ_s = dry bulk density of soil (g of dry soil/cc of soil)
ρ_l = density of water (g/cc)

Refer to Section 1.4 of the method for special instructions 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 will be too small. Refer to Section 8 of Method 2937.

Further, if porosity is calculated using the equation in Todd (1976),

Porosity = 1 – (dry bulk density/specific gravity x 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 divided by the weight of the soil and is often expressed as a ratio.

The Walkley Black Method, Page et al (1982) is a chemical oxidation method (rapid dichromate oxidation) for determining fractional organic carbon content in soil. The results are usually reported as percent organic carbon. The reported value can be converted to a fraction by dividing by 100.

If only the fractional organic matter content is available, it has to be divided by 1.724 to estimate the fractional organic carbon content. Typically, fractional organic matter content is estimated using ASTM Method 2974 (Standard Test Method for Moisture Ash and Organic Matter of Peat and Other Organic Soils).

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 ADEM.

Site-specific values for hydraulic conductivity, if necessary, should be determined using accepted field test procedures. These include slug tests and/or pump tests. Under certain circumstances the ADEM may direct the owner and/or 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

An ARBCA evaluation requires the consideration of several factors common to Tier 1, 2 and 3. The calculation of SSTLs allows for site-specific input parameters to be utilized. These issues are discussed in this section.

6.1 LAND USE

[ARBCA REPORT FORM NO. 5]

The characterization of the population and the activities near a UST release site is a critical component of the ARBCA process. The target levels vary depending on whether the land use is commercial or residential. The characterization of the population should initially be determined during the CSA or the PI. 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 as either residential or commercial. Of these, residential land use generally results in lower target levels. Thus, cleanup to residential standards will usually allow unrestricted land use. Examples of residential and commercial land use as utilized in the ARBCA evaluations are presented below.

- **Residential**: Includes but is not limited to schools, dwellings, homes, hospitals, childcare centers, nursing homes and any other areas/structures with sensitive human activity. Typically a location where someone is present for more than 8 hours a day.

- **Commercial**: Includes gas stations, industrial operations, stores, businesses, fleet operations, etc., where employees work but do not reside on a continuing basis. Typically a location where someone is onsite less than 10 hours a day. Hotels, motels, and other transient activities are included in the commercial definition.

The land use status should be clearly illustrated on maps submitted to the ADEM identifying the current land use of the site and the adjacent properties. A land use map with a radius of 500 feet should be prepared.

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. As appropriate, zoning maps, state or local zoning boards, the U.S. Bureau of the Census, topographic, land use, housing and other types of maps, and aerial photographs can provide information for determining land use.

A common sense approach should be utilized in determining the land use. For instance, if a potentially exposed population is likely to be exposed for approximately 8 hours a day, then the site can be classified as commercial. If the potentially exposed population is likely to be exposed for more than 8 hours a day, then the site should be classified as residential.

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, then the commercial classification may be appropriate. However, if the setting is more rural and the land use is mixed, the undeveloped land should be considered residential.

6.1.2 Determine Most Likely Future Land Use

Knowledge about the most likely future use of the site and adjacent properties is necessary to identify exposure points, exposure pathways, and exposure factors. Consideration of these pathways in the ARBCA process ensures that the site-specific decisions are 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 future uses of the land and groundwater at the site. The future groundwater use should be consistent with the most likely future land use.

The objective is to determine if any activities associated with the current land use are likely to be different in the future. This determination should be based on available information and the use of good professional judgment. While the residential land use scenario is generally the most conservative, it must be justified and there should be a good probability that the land will be used for a residential purpose.

Future land use is uncertain and may be influenced by owner-imposed institutional controls. Most likely future uses and activities must be identified based on local zoning 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.

6.2 ONSITE AND OFFSITE

All ARBCA evaluations must consider the impact of the chemicals to both the onsite receptors and offsite receptors. Thus, the SCEM must clearly identify all complete pathways, routes of exposure, and receptors that may be impacted by COCs located onsite and offsite. Within each area (onsite/offsite) there may be multiple land uses and multiple receptors. For example, a plume may have migrated offsite below a residential and a commercial area. In this case, both offsite residential and commercial receptors have to be considered while developing the SCEM. For simplification, the following definitions should be used:

- **Onsite**: 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.

- **Offsite**: The property(s) of concern located outside the property boundaries of the onsite property where the source of the release is located. This includes the soil, groundwater, surface water, and air located offsite.

The characterization of the release will include a determination of the onsite and offsite areas of impact. These areas are considered in determining the exposure domain of the receptor(s). The **exposure domain** is the area over which the receptor may be exposed to the contaminated medium. Determination of the exposure domain is critical in developing representative concentrations separately for groundwater and soil for onsite and offsite properties. Appendix B provides details regarding the development of representative concentrations for onsite and offsite properties.

Where there are multiple offsite properties, which have been impacted, the ARBCA evaluator must evaluate each property separately. The ARBCA report forms only allow for one representative concentration to be compared for the offsite property evaluation. Where there are multiple offsite properties, which are contaminated (above ISLs), then the evaluator must prepare separate ARBCA report forms for various offsite properties. The name of the offsite property should be indicated on the form in the Facility I.D. field or handwritten at the bottom of the form page. Remember that in evaluating offsite properties, only that data applicable to that offsite property should be used in that property's representative concentration calculations (Forms 13, 14 and 16). SCEM Form 17 must be completed to address each offsite property so that the appropriate RBSLs and SSTLs are determined for the offsite property as is noted on Forms 21b and 29b. Documentation of the evaluation of each property must be submitted in the Tier 1 and 2 ARBCA reports. Maps should be submitted which clearly identify the separate offsite properties of concern.

6.3 RECEPTORS

[ARBCA REPORT FORM NO. 17]

The objective of a risk assessment is to quantify the adverse health effects to the current 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 500 feet of the site. For residential receptors, risk to both adults and children should be evaluated. Adults working at a commercial location and adult construction workers will be considered in the ARBCA evaluation.

The human receptors are listed below:

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

It is anticipated that the above receptors will be the most exposed human receptors. Other human receptors such as visitors or maintenance workers will generally have less exposure and therefore are not considered further.

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 receptor types should be evaluated under Tier 3. The ADEM should be contacted to obtain additional guidance on these issues.

Surface water bodies should be evaluated to determine the impacts of discharging groundwater or surface runoff from the release site. At a minimum, information on the location, flow rates, depth, flow direction, and water use of surface water bodies should be evaluated.

Onsite as well as offsite 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 contaminant plumes extend or are likely to extend beyond 500 feet of the site property boundary, any additional receptors beyond 500 feet 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 contaminant plumes on groundwater resources within 500 feet of the legal site boundary, or 1,000 feet from the source, whichever is closer.

6.4 HUMAN EXPOSURE PATHWAYS

[ARBCA REPORT FORM NO. 17]

A receptor comes in contact with COCs 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, (iii) a medium through which a chemical travels from the point of release to the receptor location, and (iv) a route of exposure by which the chemical enters the receptors body and causes potential adverse health effects. Items (i), (ii) and (iii) are critical in determining the exposure domain of the receptor(s). The ADEM 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 inhalation of vapors at a site either indoors or outdoors. Depending on the toxicity of the chemical, unacceptable exposures may occur at concentrations below the odor threshold levels.

An evaluation should be performed to determine the necessity of taking air samples at a site. Recent complaints regarding vapors in enclosed spaces or outside of buildings, which might be contributed by soil and/or groundwater contamination, can serve as justification to perform indoor air measurements.

In most cases, the source for these vapors is the presence of volatile chemicals in soil and/or groundwater. Chemicals may volatilize from the soil and/or groundwater and diffuse through the overlying capillary fringe, unsaturated zone, and cracks in the floor/foundation to indoor or outdoor air where the exposure occurs. To quantitatively evaluate this pathway, concentrations may be measured in the indoor or outdoor air and compared with the SSTLs for indoor and outdoor air respectively. It is anticipated that indoor air measurements will be performed at very few sites due to several technical difficulties associated with accurately measuring the indoor air concentration contributed by soil and/or groundwater impacts. Such cases shall be evaluated under Tier 3.

For Tier 1 and Tier 2 evaluations, mathematical models are used to relate the allowable air concentrations with the measured soil or groundwater concentrations. Thus, soil and groundwater concentrations protective of indoor or outdoor inhalation (RBSLs or SSTLs) will be used for Tier 1 and Tier 2 evaluations.

In certain cases it may be appropriate to measure soil vapor concentrations and compare these measured values with soil vapor target levels. Appendix H addresses the field measurement and evaluation of soil vapor target levels.

6.4.2 Pathways for Surficial Soils (0 - 1 foot below ground surface)

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

- Leaching to groundwater and potential ingestion of groundwater
- Ingestion of soil, outdoor inhalation of vapors and particulates from soil emissions, and dermal contact with soil

To evaluate these pathways, sufficient soil samples should be obtained from the impacted area. These measured concentrations are used to estimate the representative concentration(s) that are compared to the RBSLs or SSTLs for the complete pathways.

6.4.3 Pathways for Subsurface Soils (1 foot below ground surface to the water table)

Subsurface soils are defined as soils below one foot below ground surface and extending to the water table. The exposure pathways associated with subsurface soils include:

- Indoor inhalation of vapor emissions
- Outdoor inhalation of vapor emissions
- Leaching to groundwater and potential ingestion of groundwater

To evaluate these pathways, sufficient soil samples should be taken in the impacted area. Representative subsurface soil concentrations are then compared with the RBSLs or SSTLs.

6.4.4 Pathways for Groundwater

Potentially complete exposure pathways for the impacted groundwater include:

- Indoor inhalation of vapor emissions
- Outdoor inhalation of vapor emissions
- Ingestion of water onsite or offsite
- Future ingestion of water (groundwater resource protection)
- Impacts to surface waters (surface water protection)

To evaluate these pathways sufficient groundwater samples should be obtained onsite and offsite. The representative groundwater concentrations are then compared with the target concentrations.

Each of the above exposure pathways must be evaluated as part of the exposure assessment. However, in some cases it may be determined that one or more of these routes of exposure are incomplete and therefore, they will not be considered.

Other significant routes of exposure, such as ingestion of produce grown in impacted soils, or use of groundwater for irrigation purposes should be evaluated under Tier 3. The owner or operator should contact the ADEM for further guidance.

6.5 SITE CONCEPTUAL EXPOSURE MODEL (SCEM)

[ARBCA REPORT FORM NO. 17]

The information obtained during the site assessment phase is used to develop a site conceptual exposure model (SCEM). The SCEM 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.). The SCEM requires a basic understanding of the following characteristics:

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

When conducting the ARBCA evaluation, a qualitative evaluation must be performed to identify the mechanisms by which COCs will move from affected source media to the point of exposure (POE) where contact with the receptor occurs. If this 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 COC concentrations will not pose any risk. The exposure domain of all receptors must be considered. The exposure domain is the area over which the receptor may be exposed to the contaminated medium (surficial soil, subsurface soil, and groundwater). The exposure domain must be established for the onsite scenario as well as any offsite impacted or potentially impacted properties. Separate domains may also exist for current scenarios versus future scenarios. Appendix B provides a detailed discussion on developing representative soil and groundwater concentrations, which requires identification of the exposure domain.

An SCEM is required for Tier 1, Tier 2, and Tier 3 evaluations. At some sites, where there are multiple offsite properties, which have been impacted, more than one SCEMs may have to be developed.

Throughout the CSA, PI, SI, and the ARBCA evaluation process, the SCEM should be evaluated and revised to reflect accurate site conditions. Figure 6-1 is a graphical presentation that may be used as a worksheet to develop an SCEM. ARBCA Form No. 17 is the SCEM that should be submitted with the ARBCA Report. Table 6-1 is a template for the tabular representation of an SCEM 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. Remember that there may be multiple SCEMs if there are multiple offsite impacted properties. It is recommended that the ARBCA evaluator review Appendix H for additional information about the indoor inhalation pathway.

6.6 POINT OF EXPOSURE

[ARBCA REPORT FORM NOS. 18, 19, 20, 26, 27 and 28]

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

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 closest downgradient residential property boundary where a water well may be installed. Determination of likely installation of a well and resulting POE will 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 setting. However, in no case will the POE for Tier 1 and Tier 2 be greater than 500 feet from the property boundary (not the source location) or 1000 feet from the source, whichever is less. In a Tier 3 evaluation, the POE may be located at an alternate or greater distance if thoroughly justified based on site-specific conditions, and agreed upon by the ADEM.

A **point of compliance (POC)** is a monitoring well(s) that must be located between the COC source area and the POE. Target levels will be developed for the POC that will be compared to the groundwater representative concentrations. The POC serves as a sentry or guard well for the protection of the POE. For most sites, several POCs should be selected for the groundwater resource evaluation. For sites with radial flow, multiple POEs and POCs may have to be evaluated.

Note that the 500 feet distance to the POE for groundwater established using the above criteria is from the property boundary and not the source location. The distance from the soil source, that is input to the ARBCA program to back-calculate allowable soil and groundwater concentrations at the source and at compliance wells, is the sum of the distance from the soil source to the property boundary and the distance from the property boundary to the POE.

6.7 CALCULATION OF ALTERNATE CORRECTIVE ACTION LIMITS (ACALs)

Alternate corrective action limits (ACALs) termed as the RBSLs in the Tier 1 evaluation and SSTLs in the Tier 2 and Tier 3 evaluations, are the allowable concentrations back-calculated using the procedure described in Appendix D. This procedure requires quantitative values of (i) target risk levels, (ii) chemical-specific toxicological factors, (iii) receptor-specific exposure factors, (iv) fate and transport parameters, (v) physical and chemical properties of the COCs, and (vi) mathematical models. Each of these factors is discussed below. For Tier 1 evaluations, the RBSLs have been calculated by the ADEM for each of the COCs (refer to Section 5.1), the receptors (refer to Section 6.3), and the commonly encountered complete routes of exposure (refer to Section 6.4) using conservative assumptions applicable to most Alabama sites. These RBSLs are presented in Tables 7-2 to 7-4. For chemicals that have both carcinogenic and non-carcinogenic toxicity values, RBSLs are calculated for both effects and the lower of the two is presented in Tables 7-2 to 7-4. This also applies to the calculation of SSTLs.

For Tier 2 and Tier 3 evaluations, the risk evaluator will calculate the SSTLs using technically justifiable site-specific data and pathway-specific models. For Tier 2 evaluations, the models used for developing the Tier 1 RBSLs have to be used. A Tier 3 evaluation may include different models, if approved by the ADEM.

For each site, ACALs have to be selected from Tables 7-2 to 7-4 (Tier 1 evaluation) or developed (Tier 2 or 3 evaluation) for all the relevant receptors and complete routes of exposure. For example, at a site where the groundwater plume is located below a commercial building and has migrated offsite below residences, groundwater concentrations protective of indoor inhalation for an onsite commercial worker will be protective for the onsite plume whereas, concentrations protective of a resident will be applicable to the offsite plume.

6.7.1 Target Risk Level

A risk-based decision making process requires the specification of a target risk level for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, the ADEM UST program will use an **individual excess lifetime cancer risk (IELCR) of 1×10^{-5}** as the target risk for both current and future receptors. For non-carcinogenic effects, the acceptable level is a hazard quotient of one (1) for current and future receptors.

The target risk level of 1×10^{-5} was selected in the ARBCA process for several reasons. The chosen risk level of 1×10^{-5} is within the risk range for carcinogens (1×10^{-4} to 1×10^{-6}) generally used to evaluate CERCLA actions. The 1×10^{-5} level is protective based on the overall generally conservative nature of the exposure scenarios used in the ARBCA process and the underlying health criteria. Evidence is available that petroleum constituents in soil and groundwater are subject to natural attenuation processes which continue to reduce the concentrations of COCs over time at many UST sites and therefore reduces the risk of unacceptable exposure to COCs. The ARBCA process utilizes one target risk level (1×10^{-5}), rather than a range, as an effort to streamline the decision-making process while remaining protective of human health and the environment. While the selection of one target risk level removes some of the flexibility of having a target risk range, utilizing one target risk level is a key component of streamlining the ARBCA process and provides a level of cleanup consistency in regards to risk level.

While this target risk level is being utilized in the ADEM UST ARBCA process, other ADEM programs such as the RCRA or CERCLA programs may utilize a range of target risk levels in the implementation of their respective programs. The use of any target risk level in risk-based decision making within those programs must be acceptable to the respective ADEM program administrators.

Since there are a limited number of COCs at most regulated underground storage tank release sites and the ARBCA process uses conservative exposure values, the ADEM will not require the estimation of cumulative risk or the hazard index (sum of hazard quotients). Thus, the risk and hazard quotients from different chemicals will not be added. Likewise, risk and hazard quotients from different routes of exposure will not be added except for the routes of exposure associated with the surficial soil.

For the ingestion of groundwater, the above target risk and hazard quotient values are not required, instead the chemical-specific concentrations at the POE should not exceed the MCLs, health advisories or the calculated RBSLs for groundwater ingestion. Concentrations at the POE can be determined either by site-specific sampling or by using a fate and transport model. If the concentrations exceed the groundwater ingestion values, compliance monitoring (at a minimum) or corrective action will be required.

Similarly, for impacts to surface water bodies the above target risks do not apply. The target surface water concentrations are based on determinations made by the ADEM Water Division Industrial Section. (Also refer to Appendix C, Section 6.10 and Table 7-3.)

6.7.2 Quantitative Toxicity Factors

The toxicity of chemicals is quantified using slope factors (or potency value) for chemicals with carcinogenic adverse health effects. For chemicals that cause non-carcinogenic adverse health effects, toxicity is typically quantified by reference dose and reference concentrations. One of the most reliable sources of information for toxicity factors is the U.S. EPA database called IRIS – Integrated Risk Information System.

Toxicity values for the COCs are presented in Table 6-2. The ADEM requires that the most recent toxicity values recommended by the U.S. EPA be used for ARBCA evaluations. The values listed in Table 6-2 represent the most recent values as researched during April 2000 and should be used for both Tier 1 and Tier 2 evaluations. Typically, these toxicity values will also be used for Tier 3 evaluations.

To check the current toxicity values, an ARBCA evaluator should consult the following sources in the order listed:

- State recommended values
- Integrated Risk Information System (IRIS)

- Health Effects Assessment Summary Tables (HEAST)
- Agency for Toxic Substance and Disease Registry (ATSDR)
- Direct communication with the appropriate U.S. EPA personnel
- Review of literature by qualified professionals to develop toxicity factors. Consult the appropriate Regional U.S. EPA Office and the ADEM for specific recommendations.

6.7.3 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
- Hourly inhalation rates
- Exposure times for indoor/outdoor inhalation
- Dermal relative absorption factor
- Skin surface area for dermal contact with soil
- Soil-skin adherence factor
- Oral relative absorption factor

A list of the exposure factors and the Tier 1 and Tier 2 values to be used in these evaluations are presented in Table 6-3. The exposure factors are typically estimated based on literature, and site-specific measurements are not obtained. For a Tier 3 evaluation, site-specific values of the exposure factors, other than default values, may be used with thorough justification.

For possible Tier 3 evaluations, a source of exposure information is the U.S. EPA's recently published **Exposure Factors Handbook Volume 1 –** ***General Factors*** **(*August 1997*).** Other sources of exposure factor data may be utilized with approval of the ADEM**.**

6.7.4 Fate and Transport Parameters

[ARBCA REPORT FORM NOS. 24 and 25]

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For a Tier 1 evaluation, the ADEM has selected typical and conservative default values that are listed in Table 6-4. For a Tier 2 evaluation, a combination of site-specific and default values for these parameters may be used. However, the value of each parameter used, whether site-specific or default, must be justified based on site-specific conditions. Where site-specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used. For a Tier 3 evaluation, the specific fate and transport parameters required to calculate the target levels will depend on the choice of models.

6.7.4.1 Soil Parameters

A brief discussion of the soil parameters is presented below:

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

  Tier 1 assumes a length of 1500 cm (the default value of W_a).

  Tier 2 allows for direct measurement of the length of the soil source area parallel to wind. 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 W.

- L_s - Depth to Subsurface Soil Sources (cm)

  Tier 1 assumes 30.48 cm, which by definition is the shallowest possible depth to subsurface soil.

  Tier 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)

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

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

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

  Tier 1 assumes a thickness of 5 cm, which is representative of gravel.

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

- h_v -Thickness of Vadose Zone (cm)

  Tier 1 assumes the vadose zone thickness is 295 cm.

  The Tier 2 thickness of the vadose zone is calculated by subtracting the capillary fringe thickness from the depth to groundwater. Capillary fringe thickness + vadose zone thickness = depth to groundwater, $h_{cap} + h_v = L_{gw}$.

- ρ_s - Vadose Zone Dry Soil Bulk Density (g/cm^3)

  Tier 1 assumes 1.8 g/cm^3 dry soil bulk density for the vadose zone.

  Tier 2 allows for a direct measurement of dry soil bulk density in the vadose zone. See Section 5.11 for a discussion related to the determination of soil bulk density. If multiple measurements from the vadose zone are available, use the average value.

- foc - Fractional Organic Carbon Content in the Vadose Zone (g-c/g-soil)

  Tier 1 assumes fractional organic carbon is 0.01 g-C/g-soil.

  Tier 2 allows for direct measurement of foc in the vadose zone. See Section 5.11 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 5.11. If multiple values are available the average values may be used.

- θ_T - Total Porosity in the Vadose Zone (cm^3/cm^3 – soil)

  Tier 1 assumes a porosity of 0.3.

  Tier 2 allows for determination of total porosity in the vadose zone. In both Tier 1 and Tier 2, 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. See Section 5.11 for a discussion of proper determinative methods.

- θ_{ws} - Volumetric Water Content in Vadose Zone (cm^3/cm^3)

  The Tier 1 value is 0.1 (cm^3/cm^3).

  The Tier 2 value is typically measured as noted in Section 5.11. 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 5.11. Note that $\theta_{as} + \theta_{ws} = \theta_T$.

- θ_{as} - Volumetric Air Content in Vadose Zone (cm^3/cm^3)

  Tier 1 assumes that the volumetric air content in the vadose zone is approximately 67% of the total porosity. Since the total porosity is assumed to be .30 cm^3/cm^3, then the volumetric air content in the vadose zone is .20 cm^3/cm^3.

  Tier 2 allows for a calculated value 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, $\theta_{as} + \theta_{ws} = \theta_T$.

- θ_{wcap} - Volumetric Water Content in Capillary Fringe (cm^3/cm^3)

  Tier 1 assumes volumetric water content in the capillary fringe is 90% of total porosity. The sum of the air content and the water content would equal total porosity, $\theta_{wcap} + \theta_{acap} = \theta_T$.

  Tier 2 allows for a site-specific 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.

- θ_{acap} - Volumetric Air Content in Capillary Fringe (cm^3/cm^3)

  Tier 1 assumes that the volumetric air content in the capillary fringe is 10% of the total porosity in the vadose zone. Since the assumed porosity is 30%, the volumetric air content is .03 cm^3/cm^3.

  Tier 2 assumes that the volumetric air content in the capillary fringe is 10% of the total porosity in the vadose zone. Therefore, $\theta_{acap} + \theta_{wcap} = \theta_{T.}$

- θ_{wcrack} - Volumetric Water Content in the Foundation or Wall Cracks (cm^3/cm^3)

  Tier 1 assumes volumetric water content in the soil that fills the foundation or wall cracks is equal to the volumetric water content in the soil in the vadose zone. The default value is 0.1 cm^3/cm^3. The sum of the air content in the foundation or wall cracks and the water content in the foundation or wall cracks should equal total vadose zone soil porosity, $\theta_{wcrack} + \theta_{acrack} = \theta_T$. The default assumes that the soil is

33% water saturated. (This means that 33% of the available pore space is filled with water.)

Tier 2 assumes that the volumetric water content in the soil that fills the foundation or wall cracks is the same as the volumetric water content in the soil in the vadose zone. A site-specific value can be used, however, the volumetric water content in the foundation or wall cracks would be the same value as measured for the volumetric water content in the vadose zone.

- θ_{acrack} - Volumetric air content in foundation wall/cracks (cm^3/cm^3)

  Tier 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 .20 cm^3/cm^3.

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

6.7.4.2 Groundwater Parameters

A brief discussion of the groundwater parameters is presented below:

- L_{gw} - Depth to Groundwater (cm)

  Tier 1 assumes the depth to groundwater is 300 cm, or approximately 10 feet.

  When the depth to groundwater is significantly less than 10 feet, or the Tier 1 target levels are exceeded, site-specific depth to groundwater be utilized for a Tier 2 evaluation. Where the depth to groundwater 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)

  Tier 1 assumes that the width of the groundwater source area perpendicular to groundwater flow direction is 1500 cm.

Tier 2 allows for the site-specific width of the groundwater source area to be measured. In both Tier 1 and Tier 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 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 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" as Attachment 14.

For example, the evaluator may draw a boundary that encloses the area around the tanks, piping, and/or dispensers from where the release originated. Then the 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 as appropriate.

Attachment 14 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)

  Tier 1 assumes that the length of the groundwater source area parallel to groundwater flow direction is 1500 cm.

  Tier 2 allows for the site-specific length of the groundwater source area parallel to groundwater flow direction to be measured. In both Tier 1 and Tier 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". Attachment 14 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.

- θ_{TS} - Total Porosity in the Saturated Zone

  Tier 1 assumes that the total porosity in the saturated zone is .30 cm^3/cm^3. This is the same value assumed for the vadose zone total porosity.

  Tier 2 allows for a site-specific value to be utilized. In most cases, this value will be the same as the total porosity for the vadose zone. Both a vadose zone total porosity and a saturated zone total porosity should be collected when it appears that these two zones may differ at a site. An estimate of the total soil porosity in the saturated zone is essential when biodecay is used in the groundwater resource protection evaluation.

- ρ_{ss} - Saturated Zone Dry Soil Bulk Density (g/cm^3)

  Tier 1 assumes 1.8 g/cm^3.

  Tier 2 allows for a direct measurement of dry soil bulk density in the saturated zone. In most cases, this value will be the same as the unsaturated zone dry soil bulk density for the vadose zone. Both a vadose zone dry soil bulk density and a saturated zone dry soil bulk density should be collected when it appears that these two zones may differ at a site. An estimate of the total soil porosity in the saturated zone is essential when biodecay is used in the groundwater resource protection evaluation.

- foc_s - Fractional Organic Carbon Content in the Saturated Zone (g-C/g-soil)

  Tier 1 assumes foc_s is 0.01 g-C/g-soil.

  Tier 2 allows for direct measurement of foc_s in the saturated zone. In most cases, this value will be the same as the unsaturated zone foc. Both a vadose foc and a saturated zone foc_s should be collected when it appears that these two zones may differ at a site. An estimate of the foc_s in the saturated zone is essential when biodecay is used in the groundwater resource protection evaluation.

  See Section 5.11 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 5.11.

- δ_{gw} - Groundwater Mixing Zone Thickness (cm)

  Tier 1 assumes a thickness of 200 cm, which is basically the saturated length of a 10-foot well screen.

  Tier 2 allows for a site-specific value to be utilized. The 200 cm value should be considered a minimum. An equation to calculate the groundwater mixing zone thickness is located in the EPA Soil Screening Guidance (1996, page 45, equation 45). Other procedures for determining the mixing zone thickness may be utilized if approved by the ADEM.

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

  Tier 2 allows for a site-specific value to be used. Literature values may be used if the reference is acceptable to the ADEM. Site specific measurements may also be used as discussed in section 5.11. Typically, an average of the measured values may be used.

- i - Hydraulic gradient in the Saturated Zone

  Tier 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 the Darcy velocity may have to be estimated in more than one direction.

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

  Tier 1 assumes a groundwater Darcy velocity of 157.68 cm/yr.

  In Tier 1, groundwater Darcy velocity is used to estimate the mean-field mixing dilution attenuation factor using the Summer's model. The Tier 1 default value is 157.68 cm/yr.

  In Tier 2, a site-specific value of groundwater Darcy velocity has to be used. This value is calculated as the product of saturated zone hydraulic conductivity and hydraulic gradient.

- I - Infiltration Rate (cm/year)

  Tier 1 assumes 14.8 cm/yr. This is 10% of average rainfall based on rainfall normals from the years 1971-2000.

  Tier 2 allows a site-specific or regional specific value. The value is obtained from regional data. The infiltration rate 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. Refer to Bingham (1982) to obtain regional rainfall amounts. Additional 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 ADEM and properly listed in the justification of fate and transport parameters on ARBCA Form No. 25.

The estimation of the ACALs requires a few more parameters that are included in Table 6-4. These parameters (distance to the Point of Exposure (POE) and distance to a Compliance Well (POC)) have been discussed in other sections of this guidance document.

6.7.5 Physical and Chemical Properties of the COCs

To develop the target levels, the ARBCA evaluation requires selected physical and chemical properties of the COCs. The values of these parameters are listed in Table 6-5. Since several of these values are experimentally determined, their values may differ from some references. The ADEM requires the use of values tabulated in Table 6-5 for all ARBCA evaluations unless there are justifiable reasons to modify these values. If such reasons exist, the owner or operator must provide sufficient justification to the ADEM to utilize a different value. The use of different values would be allowed only under a Tier 3 evaluation. The proposal to use the different values should be submitted in the Tier 3 workplan prior to the use of the values in the evaluation. The ADEM may update the data in Table 6-5 as new information becomes available.

6.7.6 Mathematical Models

Two types of models or equations, namely (i) the uptake equations and (ii) the fate and transport models, are required to calculate the target levels. For Tier 1 and Tier 2 evaluations, the ADEM has selected the models and equations presented in Appendix E. These models have been programmed in the ARBCA Computational Software and were used to develop the Tier 1 target levels presented in Section 7.0. For Tier 2 evaluations, the ADEM requires the use of these equations and models. With the prior approval of the ADEM through the submittal of a Tier 3 workplan, a different set of models may be used for Tier 3 evaluations.

6.8 PROTECTION OF DEEPER GROUNDWATER

While performing ARBCA evaluations the potential impacts to deeper aquifers must also be evaluated. In some cases, qualitative evaluation based on the vertical flow gradients may be sufficient, however in other cases quantitative evaluation of potential vertical migration of COCs may be necessary. Such cases will be evaluated under Tier 3.

6.9 GROUNDWATER RESOURCE PROTECTION

[ARBCA REPORT FORM NOS. 19 and 27]

The use of groundwater as a current and a 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 offsite, a determination of allowable soil and groundwater contaminant levels must be made to protect the water supply well. Most UST release sites are not located in close proximity to an existing onsite or offsite water supply well, but the ADEM is requiring that the release 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 which will protect the groundwater at the POE. An evaluation of the groundwater concentrations at the source of the release as well as at compliance wells to determine what groundwater contaminant concentrations are acceptable for protection of the water supply well (POE) is also required. The closest water supply well should be picked as the POE, whether it is upgradient or downgradient.

- For sites where there are no current water supply wells (active or inactive), a hypothetical POE (location of potential water well) must be established at the most likely future location for a water supply well. The POE must be established at a distance no greater than 500 feet from the property boundary or 1000 feet from the source (whichever is closer) where concentrations should not exceed the MCL or equivalent. A POE located 1000 feet from the source is reserved for those large properties where the owner has control over most of the affected property. The ARBCA evaluator must use good professional judgement to determine the location of the hypothetical POE. In many cases, the POE may be less than 500 feet from the source due to the potential for the installation of a water supply well.

This offsite water supply well or hypothetical well is used to estimate the target soil concentrations and target source and compliance well concentrations protective of the POE. This evaluation requires the selection of a well(s) in the source area for comparison to the value calculated in the computational software under the heading "Allowable Groundwater Concentration at the Source Protective of a POE". In addition to a source compliance well, additional compliance wells located between the source area and the POE must be selected. The COC concentrations in these selected compliance wells are compared to the calculated values under the heading "Allowable Groundwater Concentration at a POC Protective of a POE". Additionally the ADEM will require that concentrations in the compliance wells show a definite decreasing trend. These conditions will ensure that in time the contaminated groundwater would be restored to the original condition.

An allowable soil concentration in the source area must be calculated which will not allow groundwater at the point of exposure to exceed the MCL or other acceptable value. This allowable soil concentration is calculated in the computational software under the heading "Allowable Soil Concentration Protective of GW at the POE".

For Tier 1 calculations, the computational software can be used and the distances to the POC and POE are input on the worksheet entitled "Tier 1 Groundwater Resource Protection Target Concentrations" Form No. 19. Fate and transport parameters utilize the defaults for a Tier 1 evaluation. The option to select "with biodegradation" is not allowed under Tier 1.

For Tier 2 calculations, the computational software must be used and the appropriate distances to the POC and POE are input on the worksheet entitled "Tier 2 Groundwater Resource Protection Target Concentrations" Form No. 27. Site-specific fate and transport parameters representative of the site should be utilized. The option to select "with biodegradation" is allowed under Tier 2, but must be clearly justified. Refer to Appendix I for calculating the site-specific biodegradation rate.

The Tier 1 and Tier 2 groundwater resource protection target levels and representative concentrations must be entered manually on ARBCA Report Form Nos. 19 and 27. The selection of appropriate representative concentrations is critical for the groundwater resource protection evaluation. See Appendix B for a detailed discussion of the proper selection of representative concentrations.

6.10 SURFACE WATER AND STREAM PROTECTION

[ARBCA REPORT FORM NOS. 11, 20, and 28]

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

Tier 1 RBSLs for surface water and stream protection have been established and are shown in Table 7-3 and these target levels represent the smallest of the suggested surface water quality criteria values being utilized by the ADEM for (i) freshwater acute exposure, (ii) freshwater chronic exposure, and (iii) human consumption of fish and water. These values should not be exceeded in the groundwater discharging/seeping into a stream.

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

(i) allowable soil source concentrations (C_{soil}),
(ii) allowable concentrations in groundwater at the source (C_{gws}), and
(iii) allowable concentrations in groundwater at different distances between the surface water and the source (C_{cw}).

Items (ii) and (iii) above are considered compliance well concentrations protective of the surface water. Details of this procedure are discussed in Appendix C. If the measured soil source or the compliance well concentration(s) exceeds the corresponding target concentrations, a Tier 2 stream impact evaluation is necessary. Or, if the Tier 1 fate and transport assumptions do not fit the site, a Tier 2 stream evaluation should be performed.

For a Tier 2 evaluation, the surface water target levels presented in Table 7-3 are applicable at the downstream edge of the mixing zone formed by the mixing of the discharge of the contaminated groundwater into the stream. The specific procedure to be used to calculate the allowable target soil source concentrations, groundwater source concentrations, and the compliance well concentrations is presented in Appendix C. Biodegradation in groundwater may be utilized in a Tier 2 evaluation if adequate justification is provided.

If soil source COC representative concentrations, groundwater source COC representative concentrations or compliance well COC representative concentrations exceed the Tier 2 SSTLs for the stream, then remediation may be required at the site or a Tier 3 evaluation may be performed. Under a Tier 3 evaluation, alternate fate and transport models may be used as discussed in Section 6.7.6 and 9.3. Also, alternate low flow (7Q10) estimates used for the determination of SSTLs may be used, provided the procedure used is acceptable to the ADEM. Prior approval of alternate procedures must be obtained from the ADEM.

6.11 ESTIMATING POINT OF COMPLIANCE WELL CONCENTRATIONS

[ARBCA REPORT FORM NOS. 19 and 27]

In the ARBCA evaluation, it is necessary to designate point of compliance (POC) wells either onsite and/or offsite to confirm that the concentrations at a selected point of exposure (POE) do not exceed the target levels in the groundwater or in a surface water or stream, if applicable. Monitoring of POC wells must occur, and the data obtained from the monitoring of those wells must be utilized as representative concentrations to compare with calculated Tier 1 or Tier 2 target levels. Monitoring of POC wells will be continued until the concentrations in the compliance wells stabilize below the calculated compliance well target levels.

The compliance well target concentrations can be estimated using the following relationship:

$$C_{target}^{CW} = C_{target}^{EW} \frac{DAF_{POE}}{DAF_{CW}} \qquad (6\text{-}1)$$

where,

C_{target}^{CW} = Target concentration in the compliance well [mg/l]

C_{target}^{EW} = Target concentration 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_{CW} = Dilution attenuation factor for the distance from the source to the compliance well [-]

Please note that the terms POC (Point of Compliance) and CW (Compliance Well) may be utilized interchangeably in the ARBCA evaluation.

In Equation 6-1, the DAFs represent the reduction in concentration as the chemical of concern travels from the source to the POE or the POC. 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 POC relative to the concentration at the source. The second way is to calculate the ratio of the measured concentrations at the source well and at the POE or POC. The second method can be used only at sites where the plume is stable and sufficient groundwater monitoring data are available.

For a Tier 1 evaluation, Table 7-5 lists some of the dilution attenuation factors (DAFs) that should be used to estimate the compliance point target concentration. DAFs for distances not in Table 7-5 may be calculated using the computational software. Tier 1 DAFs were estimated using the Domenico's model (Appendix E) implemented with default fate and transport parameters presented in Table 6-4. For Tier 2 and Tier 3 evaluation, site-specific DAFs may be calculated using site-specific data or a fate and transport model implemented using site-specific data.

An example calculation is presented below:

> The target concentration for a POE at 500 feet from the source and a compliance well located at 300 feet from the source, i.e., 200 feet upgradient from the POE, is estimated as follows:
>
> $$C_{target}^{CW} = C_{target}^{EW} \frac{DAF_{500}}{DAF_{300}} \tag{6-2}$$
>
> where,
>
> C_{target}^{CW} = Target concentration in the compliance well [mg/l]
> C_{target}^{EW} = Target concentration in the exposure well (groundwater standard) [mg/l]
> DAF_{500} = Dilution attenuation factor to the exposure well located at 500 feet from the source [(mg/l)/(mg/l)]
> DAF_{300} = Dilution attenuation factor to the compliance well located at 300 feet from the source [(mg/l)/(mg/l)]
>
> For benzene, using the DAFs from Table 7-5,
>
> $$C_{target}^{CW} = (0.005) \times \frac{(63.36)}{(23.17)} \tag{6-3}$$
>
> The calculated target compliance well concentrations of 0.0137 mg/l will be used to establish compliance point monitoring requirements.

An identical procedure can be used to develop compliance well target concentrations for the protection of surface waters. At sites where the compliance well concentrations are exceeded, the ADEM 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 ADEM.

Free product present at a site must be removed to the maximum extent practicable at every site, regardless of the calculated SSTLs. This requirement is consistent with the ADEM Admin. Code Rule 335-6-15-.27 (Also refer to Section 4.5).

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 ADEM (also refer to Section 5.6).

6.13 ECOLOGICAL EXPOSURE

[ARBCA REPORT FORM NO. 12]

Exposures to ecological receptors and habitats such as wetlands, sensitive environments, or threatened and/or endangered species should be thoroughly evaluated. ARBCA Report Form No. 12 should be utilized to perform a basic screening for those sites that may pose a threat to ecological receptors and habitats. Where an ecological threat may exist due to a release, an ecological evaluation should be performed as part of a Tier 3 evaluation. Note, within the ARBCA framework, protection of surface waters and streams is considered independent of the ecological risk evaluation.

One area of Alabama that is currently identified as a sensitive environment is Dauphin Island. If a release occurs on Dauphin Island, SSTLs should be calculated for that release to determine risks posed due to the shallow groundwater and water supply wells on the island. Other sensitive environments may be delineated over time and be required to perform a Tier 2 or Tier 3 evaluation.

6.14 DOCUMENTATION OF THE ARBCA EVALUATION

In an effort to streamline the report preparation for the ARBCA evaluation, two software packages were developed and are available for use. The software packages include: (i) ARBCA Report Forms, and (ii) a computational spreadsheet program to calculate Tier 2 and Tier 3 target levels. Along with this guidance document, these software packages have been revised. The revised software are referred to as the year 2001 revisions.

The Department requires that all Tier 1, 2, and 3 evaluations utilize the ARBCA Report Forms included in Appendix F. For Tier 2 site-specific computations, the ADEM encourages the use of the ARBCA computational software to reduce errors in calculations and to provide consistency in reporting. However, this does not preclude an evaluator from utilizing other appropriate computational tools, as accepted by the ADEM. ADEM must approve of the use of other computational tools before the ARBCA evaluation is conducted.

If an evaluator chooses to use an alternate computational tool, the ADEM may require verification of the results by performing one or more runs and comparing the results with the ARBCA Computational Software.

For Tier 1 evaluations, ARBCA Report Forms Nos. 1 - 23 should be completed in full. Attachments as indicated in the Table of Contents of the forms should also be included in the submitted report. The ARBCA evaluator may choose to submit additional information such as text, figures and/or tables as needed to fully support the conclusions of the evaluation.

For Tier 2 evaluations, ARBCA Report Form Nos. 1 - 30 should be completed in full. Attachments as indicated in the Table of Contents of the forms should also be included in the submitted report. In addition, the evaluator should include the ARBCA computational software worksheets that indicate specific parameters used in the computations and a printout of the results of the computations. Those worksheets, which do not include a site-specific parameter or a result of a computation, do not need to be submitted. The ARBCA evaluator may choose to submit additional information such as text, figures and/or tables as needed to fully support the conclusions of the evaluation.

For Tier 3 evaluations, the ARBCA Report Form Nos. 1 - 36 should be completed in full. Attachments as indicated in the Table of Contents of the forms should also be included in the submitted report. In addition, the evaluator should include the ARBCA computational software worksheets that indicate specific parameters used in the computations and a printout of the results of the computations. Those worksheets, which do not include a site-specific parameter or a result of a computation, do not need to be submitted. The ARBCA evaluator may choose to submit additional information such as text, figures and/or tables as deemed necessary to fully support the conclusions of the evaluation.

7.0
TIER 1 EVALUATION

The Tier 1 evaluation requires the comparison of site-specific representative soil and groundwater concentrations with the ADEM established Tier 1 RBSLs. A Tier 1 evaluation requires the following steps:

7.1 STEP 1: CHARACTERIZATION AND CLASSIFICATION OF THE SITE

[ARBCA REPORT FORM NOS. 1 through 16]

This process has been previously described in Sections 4 and 5.

7.2 STEP 2: DEVELOPMENT OF A SITE CONCEPTUAL EXPOSURE MODEL

[ARBCA REPORT FORM NO. 17]

The development of an SCEM has been described in Section 6.5. This step includes the location of the POE as per Section 6.6.

7.3 STEP 3: SELECTION OF RELEVANT TIER 1 RISK-BASED SCREENING LEVELS

For each complete exposure pathway identified in the SCEM in Section 6.5, RBSLs should be selected for each COC from the appropriate Tier 1 table. The ADEM has developed RBSLs for commonly encountered routes of exposure and receptors, presented in Table 7-1. The RBSLs are presented in Tables 7-2 through 7-4.

The Tier 1 target soil concentrations protective of groundwater depend on the distance to the POE from the source. For example, referring to Table 7-4, if the POE is 500 feet from the source, the allowable concentration of benzene in the soil source area is 0.535mg/kg. These target soil concentrations were 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, e.g., ingestion of water from a downgradient well impacted by leaching of chemicals from the soil), Tier 1 levels have been developed using conservative fate and transport models implemented with conservative and typical input parameters, listed in Tables 6-2 to 6-5. Details of the procedures utilized to back calculate the RBSLs are shown in Appendices D and E.

7.4 STEP 4: COMPARISON OF THE TARGET LEVELS SELECTED IN STEP 3 WITH SITE-SPECIFIC CONCENTRATIONS

[ARBCA REPORT FORM NO. 18]

After the Tier 1 target levels have been identified, they are compared with the representative site concentrations. Presence of free 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 onsite commercial building and has migrated offsite under a residential building, representative groundwater concentrations for onsite and offsite receptors would be different. Appendix B provides detailed procedures for determining exposure domains and for calculating representative concentrations.

In an effort to reduce evaluation time, the effort necessary to calculate the representative concentrations using area-weighted averaging or the last 1-2 year maximum values may be avoided by initially comparing the historical maximum media-specific concentrations relevant for each pathway with the target levels. If the historical maximum concentrations do not exceed the target levels, it would not be necessary to compute area-weighted concentrations or to determine the recent maximums.

The representative concentrations should be evaluated as follows:

7.4.1 Soils

For both surficial and subsurface soils, the selection of the representative concentration assumes the site is adequately assessed. Representative soil concentrations used to evaluate the protection of groundwater pathway should be calculated based on the soil data collected within the source area only as defined by the dimensions used in developing the target levels. Recent maximums and area-weighted averages should be determined as necessary and compared to the target levels.

The soil data from the most recent investigation (assuming it was a 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. This data should be obtained through the implementation of a data acquisition plan approved by the ADEM. Where only older (> 4 years old) data is available, the maximum value can be utilized, if there have been no additional releases since the data was collected. If a new release has occurred, soil assessment activities should occur to adequately characterize the extent of the new release.

7.4.1.1 Surficial Soil: The representative concentrations (recent maximum or area-weighted average) should be determined based on the available surficial soil concentration data. The maximum surficial soil concentrations from the most recent investigations should be identified and noted. Appendix B discusses the calculation of the area-weighted average. The Tier 1 RBSLs for surficial soil should be compared with both the site-specific area-weighted average and maximum surficial soil concentrations.

For the ADEM to consider an NFA at a site, the area-weighted average should not exceed the relevant Tier 1 target levels. Further, if the ratio of the maximum surficial soil concentration to the area-weighted average concentration exceeds 10, the ADEM may require further evaluation.

7.4.1.2 Subsurface Soil: The representative concentration should be calculated based on the available subsurface soil concentration data. The maximum subsurface soil concentrations from the most recent investigations should be identified and noted. Appendix B discusses the calculation of the area-weighted average. The Tier 1 RBSLs for subsurface soil should be compared with both the site-specific area-weighted average concentrations and maximum subsurface soil concentrations.

For the ADEM to consider an NFA at a site, the area-weighted average should not exceed the relevant Tier 1 target levels. Further, if the ratio of the maximum subsurface soil concentration to the area-weighted average concentration exceeds 10, the ADEM may require further evaluation.

7.4.2 Groundwater

Based on the site conceptual exposure model, a variety of 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 compliance wells, (iii) onsite representative concentrations to evaluate the protection of indoor inhalation, (iv) onsite representative concentrations to evaluate the protection of outdoor inhalation, (v) offsite representative concentrations to evaluate the protection of indoor inhalation, and (vi) offsite 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. Appropriate representative concentrations are entered on Form No. 18 for the inhalation and ingestion pathways. Appropriate representative concentrations are also entered on Forms 19 and 20 for the groundwater resource protection and surface water and stream protection pathways, respectively.

ARBCA evaluation can also be performed at sites where only minimal groundwater data (one or two sampling events) are available. However subsequent to the evaluation, the ADEM may require additional confirmatory data, before the final decision. If recent groundwater data has not been obtained, it may be appropriate to obtain this data and utilize current groundwater data. This data can be obtained through the implementation of a data acquisition plan approved by the ADEM.

The relevant Tier 1 groundwater RBSLs should be compared with site-specific area-weighted average and maximum groundwater concentrations. For a site to receive an NFA, the area-weighted average concentrations should be less than the RBSLs and none of the wells should have increasing concentrations or concentrations consistently above the RBSLs. Thus an important requirement for a Tier 1 NFA is that the plume must be stable or decreasing.

7.5 STEP 5: SELECTION OF THE NEXT COURSE OF ACTION [ARBCA REPORT FORM NO. 22]

The ADEM may issue an NFA letter if the following conditions are met:

- Representative concentrations meet the criteria established in Section 7.4 and Appendix B,
- No nuisance conditions exist at the site,
- Free product has been removed to the maximum extent practicable,
- The ADEM agrees with the overall Tier 1 evaluation, and
- The site-specific fate and transport parameters are not significantly different than the Tier 1 default values used to estimate the RBSLs.

If the site concentrations exceed the Tier 1 values, the following three risk management alternatives are available:

Alternative 1: **Localized Exceedences**. Site concentrations exceed the Tier 1 levels in a small portion of the site. The owner/operator, with the ADEM's approval, may choose to conduct interim remediation to meet Tier 1 levels. An example of this scenario is the presence of a small quantity of soil, which exceeds the Tier 1 levels. Removal or treatment of this small area of soil may be sufficient to allow the site to achieve target risk level and receive an NFA provided all other no further action conditions (mentioned above) are satisfied. This action is different from initial response action in that the latter focuses on the abatement of potential or real emergency conditions.

Alternative 2: **Selection of Tier 2 Analysis**. The owner/operator conducts a Tier 2 evaluation, which may require the acquisition of additional site data. A Tier 2 evaluation may also be necessary when the fate and transport assumptions used in the Tier 1 evaluation are significantly different from the known or suspected site-specific conditions, and those conditions make the Tier 1 RBSLs less conservative. For example, at sites where the depth to groundwater is less than the Tier 1 default depth of 300 cm, it will be necessary to develop Tier 2 SSTLs using the site-specific depth to groundwater. For fate and transport parameters used to estimate the RBSLs, refer to Table 6-4.

Alternative 3: **Remediation to Tier 1 Values**. The owner/operator may elect to develop a corrective action plan to remediate the site to Tier 1 RBSLs. The corrective action plan would have to be approved by the ADEM. The plan would have to meet the requirements of ADEM Admin. Code R. 335-6-15- .29 and the guidance presented in the latest version of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual".***

The owner/operator should carefully review the site conditions and recommend one of the three alternatives listed above. The selection of Alternative 1, 2, or 3 will most likely be based on technical feasibility and cost-benefit considerations. For example, where the cost of cleanup is low (relative to the cost of additional data collection and analysis under a Tier 2 evaluation), it may be most expeditious to adopt the Tier 1 RBSLs as the ACALs.

This section provides details for a Tier 2 evaluation that may be conducted (i) when Tier 1 RBSLs are exceeded and it is not appropriate to remediate the site to Tier 1 RBSLs, or (ii) Tier 1 assumptions are sufficiently different from site-specific conditions, so that Tier 1 RBSLs will not be conservative. The Tier 2 evaluation is very similar to the Tier 1 evaluation in that (i) it is conservative, (ii) broadly defined by the ADEM but allows for some flexibility, (iii) it uses relatively simple fate and transport algorithms (models), and (iv) uses Tier 1 default exposure factors.

The Tier 2 evaluation requires the following steps:

8.1 STEP 1: UPDATE THE SITE CLASSIFICATION

[ARBCA REPORT FORM NO. 3]

The owner/operator should update the site classification to determine if initial abatement measures are warranted and to determine the severity of the risks.

8.2 STEP 2: DEVELOPMENT OF SITE CONCEPTUAL EXPOSURE MODEL

[ARBCA REPORT FORM NO. 17]

The owner/operator should develop the SCEM if it has not already been developed and identify the complete exposure routes and pathways. All COCs and all complete routes of exposure should be evaluated under Tier 2 (even those that satisfy Tier 1 levels). Thus, the SCEM for Tier 2 will be exactly the same as the SCEM for the Tier 1 evaluation.

8.3 STEP 3: INPUT PARAMETERS [REFER TO SECTION 6.7]

For a Tier 2 evaluation, the ADEM requires the use of the same models and algorithms used to develop Tier 1 levels. Thus, the Tier 2 input parameter requirements are the same. The specific values to be used are presented below:

Exposure Factors: The ADEM requires that the exposure factors remain the same for Tier 1 and Tier 2 evaluations. The specific values are listed in Table 6-3.

Physical and Chemical Properties: The ADEM requires the physical and chemical properties of the COCs remain the same for Tier 1 and Tier 2 evaluations. These values are listed in Table 6-5.

Toxicity Values: The ADEM requires that the current toxicity values promulgated by U.S. EPA be used. These are the same values as for the Tier 1 evaluation and are listed in Table 6-2.

Fate and Transport Parameters [ARBCA REPORT FORM NOS. 24 and 25]: The ADEM requires representative site-specific fate and transport parameters to be used for Tier 2 evaluations. At a minimum, site measured values of soil source dimensions, depth to subsurface soil sources, thickness of capillary fringe, thickness of vadose zone, depth to groundwater, hydraulic gradient, hydraulic conductivity, and the distances to the point of exposure and point of compliance must be used. Where site-specific values are not available for a few parameters, professional judgment has to be used to determine whether to perform additional assessment or to use appropriate literature values. Documentation of all site-specific values should be provided on ARBCA Report Form No. 25. If additional data is necessary, a data acquisition workplan should be developed and approved by the ADEM prior to performing the Tier 2 evaluation.

The ADEM will allow the use of chemical-specific biodegradation rates based on site-specific evaluation of historical monitoring well data. A protocol for establishing a site-specific biodegradation rate is located in Appendix I. Note that the use of decay rates in Tier 2 evaluations must be justified based on site-specific information.

i. Consistent decreasing trend in the monitoring wells, and
ii. Measurement of natural attenuation parameters that provide evidence of biodegradation.

The Target Risk: The target risk for Tier 1 and Tier 2 evaluation is the same. For details refer to Section 6.7.1.

8.4 STEP 4: CALCULATION OF TIER 2 LEVELS

The calculation of Tier 2 SSTLs should be performed by utilizing the models presented in Appendix E and the input parameter values discussed above. For computational ease, the ADEM has computational software available for use in calculating Tier 2 levels and for use in the groundwater resource protection evaluation.

The ADEM is not disallowing the use of other appropriate RBCA tools, but it requires that models and input parameters presented in this guidance document be used. If an ARBCA evaluator uses alternative tools, the ADEM may require verification of the software.

8.5 STEP 5: CALCULATION OF REPRESENTATIVE SITE CONCENTRATIONS

[ARBCA REPORT FORM NOS. 26, 27 and 28]

The representative soil and groundwater concentrations are calculated as for the Tier 1 evaluation (see Section 7.4 and Appendix B). These representative site concentrations are compared with the Tier 2 SSTLs and the next course of action determined as discussed in Section 8.6 below. Tier 2 SSTLs are calculated using the ARBCA computational software. The calculated values must be entered manually on the Tier 2 report forms. The evaluator must manually enter the representative concentrations and targets on Forms 26, 27 and 28.

8.6 STEP 6: SELECTION OF THE NEXT COURSE OF ACTION

[ARBCA REPORT FORM NO. 30]

After the completion of a Tier 2 evaluation, the ADEM may issue an NFA if the following conditions are met:

- The representative site concentrations do not exceed the Tier 2 levels and the ratio of the maximum concentration in each medium to the representative concentration is less than 10,
- No nuisance conditions exist at the site,
- Free product has been removed to the maximum extent practicable, and
- The ADEM agrees with the Tier 2 evaluation and determines that additional confirmatory or compliance point monitoring is not necessary (see Section 10.1).

If the representative site concentrations exceed the Tier 2 levels, the following two alternatives are available:

Alternative 1: Remediation to Tier 2 levels. The owner/operator, with the ADEM's concurrence, may elect to remediate the site to Tier 2 SSTLs. A Corrective Action Plan will be required for the site in accordance with ADEM Admin. Code R. 335-6-15-.08 and .29 and in accordance with guidance included in the latest version of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual***".

Alternative 2: Selection of Tier 3 Analysis. The owner/operator, with the ADEM's concurrence, may opt to perform a Tier 3 analysis as per the guidance presented in Section 9. Note that only those complete routes of exposure and COCs that do not meet the Tier 2 requirements will have to be evaluated under Tier 3.

9.0
TIER 3 EVALUATION

Within the ARBCA process, Tier 3 Evaluation is the most complex and detailed site-specific evaluation that may be conducted when Tier 2 SSTLs are exceeded and it is not appropriate to remediate the site to Tier 2 SSTLs. The Tier 3 evaluation provides for the most flexibility for developing SSTLs based on the ADEM specified target risk levels. Also, due to the sophistication of the analysis, a Tier 3 evaluation will require additional regulatory review and oversight. This may extend the ARBCA process at the site.

The ADEM requires that the owner/operator submit a workplan for a Tier 3 evaluation. This workplan must be approved by the ADEM prior to conducting the analysis. Due to the flexibility available in this procedure, it is imperative that the ADEM concur with the owner/operator on the sufficiency of data, the applicability of the models, and the protocols to be used in the Tier 3 process.

The Tier 3 evaluation requires the following steps:

9.1 STEP 1: UPDATE THE SITE CLASSIFICATION

[ARBCA REPORT FORM NO. 3]

The owner/operator should update the site classification to determine if initial abatement measures are warranted and to determine the severity of the risk at the site.

9.2 STEP 2: DEVELOPMENT OF THE SITE CONCEPTUAL EXPOSURE MODEL

[ARBCA REPORT FORM NO. 17]

The owner/operator should develop the SCEM if it has not already been developed and identify the complete exposure pathways for current and most likely future conditions. The SCEM for Tier 3 will be very similar and in most cases exactly the same as the SCEM for the Tier 2 evaluation. Only those COCs and routes of exposure that do not satisfy the Tier 2 requirements need to be evaluated. All the pathways and routes being evaluated under Tier 3 should be clearly identified.

9.3 STEP 3: SELECTION OF TIER 3 MODELS

In Tier 3, the owner/operator may use any fate and transport model that is acceptable to the ADEM. The determination will be based upon the following characteristics:

- Must be peer reviewed
- Must be publicly available
- Must have history of use on similar projects
- Must be technically defensible

The ADEM may reject the use of any model for which the above mentioned criteria are not met. If a model cannot replicate site-specific conditions, then the model results may not be used for Tier 3 evaluation.

9.4 STEP 4: SELECTION OF INPUT PARAMETERS

Development of Tier 3 SSTLs will require several categories of input parameters. Each of these are discussed below:

Exposure Factors [ARBCA REPORT FORM NOS. 34 and 35]: Unless the site specific conditions justify use of alternative exposure values, the ADEM requires the use of exposure factors tabulated in Table 6-3. It is the ADEM's opinion that alternative exposure values can be justified in very rare situations.

Physical and Chemical Properties: The chemical-specific physical and chemical properties tabulated in Table 6-5 should be used unless alternative values can be justified. It is the ADEM's opinion that alternative values will be rarely justifiable.

Toxicity Values: The most recent toxicity values accepted by the U.S. EPA should be used. These would be the same values as used for Tier 1 and Tier 2 evaluation. These are available in Table 6-2.

Fate and Transport Parameters [ARBCA REPORT FORM NOS. 32 and 33]: Tier 3 evaluation will require the use of site-specific fate and transport parameters. The specific parameters will depend on the model selected for Tier 3 evaluation. As in Tier 2, the ADEM will allow the use of a site-specific biological decay rate developed using Appendix I. For a Tier 3 evaluation, the POE depends on site-specific conditions. Based on discussions with the ADEM and their concurrence, the POE may be located beyond 500 feet of the property boundary or 1000 feet from the source.

Target Risk: The same target risk and groundwater protective standards used for Tier 1 and Tier 2 evaluation will be used.

In addition to the above, site-specific soil and groundwater data consistent with the selected models should be used. The ADEM will require clear documentation of all data used to calculate the SSTLs and appropriate justification for each value used.

9.5 STEP 5: QUANTIFICATION OF TIER 3 EVALUATION

Tier 3 evaluation may be performed in the forward or the backward mode.

9.5.1 Forward Mode

In the forward mode the end result of the risk evaluation will be (i) the site-specific risk and hazard quotient values ($R_{calculated}$), and (ii) the estimated concentration at the nearest current or reasonable future groundwater receptor ($C_{calculated}$). The estimated risk and hazard quotient values have to be compared with the target risk and hazard quotient values established by the ADEM. Hazard quotients are not summed, and risks are not added. Also, the estimated concentrations in the nearest drinking water well should not exceed the MCLs, health advisories, or other groundwater protection levels (Table 2-2).

No further action will be necessary if (i) the estimated risk levels are below those established by the ADEM in Section 6.7.1, (ii) the groundwater receptor concentration ($C_{calculated}$) is below the MCLs, health advisories and groundwater protective levels (as appropriate), (iii) the ADEM is satisfied that sufficient data is available to support the Tier 3 evaluation, (iv) nuisance, explosive and ecological risks are within acceptable levels, and (v) the ADEM agrees with the evaluation.

If the target risk levels are exceeded, Tier 3 SSTLs can be established by using the following relationship for each COC and each route of exposure:

$$C_{target} = C_{calculated} \times \frac{TR}{R_{calculated}} \tag{9-1}$$

$$C_{target} = C_{calculated} \times \frac{THQ}{HQ_{calculated}} \tag{9-2}$$

C_{target} = Tier 3 SSTLs

$C_{calculated}$ = the actual representative site concentration used to estimate site-specific risk

$R_{calculated}$ = the site-specific calculated actual risk

TR = the target risk (1×10^{-5})

THQ = target hazard quotient per chemical, per pathway (1.0)

$HQ_{calculated}$ = the site-specific calculated Hazard Quotient

9.5.2 Backward Mode

The ADEM will also allow the direct calculation of Tier 3 SSTLs using the backward mode as in Tier 1 and Tier 2 evaluations. If the backward mode is used, the SSTLs will be compared with the representative soil and groundwater concentrations.

9.6 STEP 6: SELECTION OF THE NEXT COURSE OF ACTION

[ARBCA REPORT FORM NO. 36]

The ADEM may issue an NFA or require compliance monitoring if the following conditions are satisfied:

- The site concentrations do not exceed the SSTLs,
- The estimated risks and/or HQs do not exceed the acceptable levels,
- The site concentrations at the POE do not exceed the MCLs, health advisories, or groundwater protection levels (as appropriate),
- Free product does not exist at the site, and
- Nuisance conditions do not exist at the site.

If the above conditions are not met, then the ADEM will require the development of a Corrective Action Plan in accordance with the ADEM Admin. Code R. 335-6-15-.08 and .29 and the latest version of the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual.***" If the Tier 3 SSTLs are exceeded for a specific pathway, then the ADEM will consider owner imposed institutional controls that may make the pathway incomplete.

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 (i) to either remediate the site to the calculated ACALs 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 Tier 1, Tier 2 or Tier 3 evaluation, groundwater monitoring for confirmation of assumptions, compliance point 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 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) compliance monitoring. The specific amount of data required will vary from site to site and will require the ADEM'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 ADEM even when the concentrations do not exceed the site-specific target levels.

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

Typically one or more wells may be selected as the compliance point wells. Monitoring of compliance point wells should continue until the concentrations in these wells do not exceed the compliance well target concentrations as discussed in Section 6.11. The compliance well target concentrations are established so that the concentrations at the POE do not exceed the ACALs.

A detailed discussion of groundwater monitoring utilizing remediation by natural attenuation is in the **"*Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual*."** The components of the RNA monitoring should be utilized in the compliance monitoring of the site.

10.2 CORRECTIVE ACTION PLANS

Where the SSTLs for the site are exceeded, an owner or operator may be required to prepare a CAP for the site in accordance with ADEM Admin. Code R. 335-6-15-.08 and .29. Further guidance on the development of CAPs is located in the "***Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual*.**" A CAP may consist of a combination of remedial technologies, which may include remediation by natural attenuation. The calculated SSTLs for a site serve as the ACALs. Remedial technologies must be used which will adequately reduce the site concentrations below the ACALs.

10.3 OWNER IMPOSED INSTITUTIONAL CONTROLS

The ARBCA process will recognize the presence of existing controls in the development of the SCEM. Existing implicit or explicit institutional controls help determine the future land use. For example, existing right of ways, highways, and source water assessment areas will be considered in developing the SCEM prior to the selection of Tier 1 or Tier 2 target levels.

After the completion of Tier 1/Tier 2 evaluation, the ADEM may accept owner imposed institutional controls as a way to eliminate complete exposure pathways. The specific controls will be site-specific and it will be the owner/operator's responsibility to convince the ADEM of the need to impose the control and its long-term implications.

10.4 NOTIFICATION OF THE RELEASE

Under the ADEM Admin. Code R. 335-6-15-.34, for all confirmed releases, which require a CAP, the ADEM, must provide a notice to the public directly affected by the release and the planned corrective actions.

The above notification should be made using the following procedures:

1) Public Notice of the corrective actions to be applied at the site.

The ADEM will provide notice to the public through publication of the corrective actions to be taken in the local or regional newspaper.

2) Notification of NFA/corrective action to the Release Site Landowner

Where the land owner/operator is different from the tank owner/operator, the latter should provide the names and addresses of the owner(s) of the land where the release occurred to the ADEM (see ARBCA Report Form No. 2). The tank owner and/or his/her consultant should notify the current landowner of the results of the ACALs accepted by the ADEM. The ADEM will also try to notify the landowner.

10.5 NO FURTHER ACTION PROCEDURE

When the ARBCA evaluation has been performed and the site has been remediated to the established levels or site conditions are otherwise acceptable to the ADEM, a letter of "**No Further Action**" or a letter of "**No Further Action with Conditions**" may be issued. The letter indicates that, based on the information submitted to the ADEM, 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.

10.6 UST INCIDENT LIST

As required in the ADEM Admin. Code R. 335-6-15-.34, the ADEM must ensure that site release information and decisions concerning the CAP are made available to the public for inspection upon request. Files are available for review which document the ARBCA evaluations.

In addition to maintaining files on each site, the ADEM has established a " Leaking UST Incident List" which is a list of site locations which have been issued an UST Incident Number. The list, at a minimum, contains the following information:

- Site Name
- Site Facility ID Number
- UST Incident Number
- Site Address
- Site Owner
- Site Owner Address
- Status in regards to issuance of an NFA

The list is currently available on paper, diskette, or can be obtained by e-mail from the ADEM Groundwater Branch at (334) 270-5655.

11.0
REFERENCES

ADEM, June 1994, *ADEM Water Division – Water Quality Program, Volume II Division 335-6-15 and 16*, Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, January 2001, *ADEM Water Division – Water Quality Program, Volume I Division 335-6-10,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, May 1995, *Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual,* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, September 1998, *UST Guidance for Remediation by Natural Attenuation (RNA),* Alabama Department of Environmental Management, Montgomery, Alabama.

ADEM, April 1998, *ARBCA: Alabama Risk Based Corrective Action for Underground Storage Tanks - Guidance Manual*, Alabama Department of Environmental Management, Montgomery, Alabama.

API, May 1994, *Decision Support System for Exposure and Risk Assessment*, version 1.0, prepared for the American Petroleum Institute, under contract, by Du Pont Environmental Remediation Services and Woodward-Clyde Consultants.

ASTM, 1994, Designation D 5314 – 93 Standard Guide for Soil Gas Monitoring in the Vadose Zone, in: *ASTM Standards on Groundwater and Vadose Zone Investigations*, second edition, ASTM Committee D – 18 on Soil and Rock, American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania, 19428-2959, pages 333 – 363.

ASTM, November 1995, *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*, Designation: E 1739-95, from *The Annual Book of ASTM Standards*, ASTM, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428.

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.

ASTM, 1999a, Designation D 854 - 92 Standard Test Method for Specific Gravity in Soils, in *1999 Annual Book of ASTM Standards*, Section 4 - Construction, Volume 04.08 Soil and Rock (I): D 420 - D 4914, ASTM, West Conshohocken, PA.

ASTM, 1999b, Designation D 2216 - 98 Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass, in *1999 Annual Book of ASTM Standards*, Section 4 - Construction, Volume 04.08 Soil and Rock (I): D 420 - D 4914, ASTM, West Conshohocken, PA.

ASTM, 1999c, Designation D 2937 - 94 Standard Test Method for Density of Soil In Place by the Drive Cylinder Method, in *1999 Annual Book of ASTM Standards*, Section 4 - Construction, Volume 04.08 Soil and Rock (I): D 420 - D 4914, ASTM, West Conshohocken, PA.

ASTM, 1999d, Designation D 2974 - 87 Standard Test Method for Moisture, Ash, and Organic Matter of Peat and other Soils, in *1999 Annual Book of ASTM Standards*, Section 4 - Construction, Volume 04.08 Soil and Rock (I): D 420 - D 4914, ASTM, West Conshohocken, PA.

Atkins, J. B. and Pearman, J. L., 1994, *Low-Flow and Flow-Duration Characteristics of Alabama Streams*, Water-Resources Investigations Report 93-4186, United States Department of the Interior, Geological Survey, in cooperation with the Alabama Department of Environmental Management and the Tennessee Valley Authority, Tuscaloosa, Alabama.

Bingham, R. H., 1982, *Low-Flow Characteristics of Alabama Streams*, Geological Survey Water-Supply Paper 2083, United States Geological Survey, in cooperation with the Geological Survey of Alabama, United States 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, *Ground Water*, volume 20, number 3, pages 303 - 311.

Domenico, P. A. and F.W. Schwartz, 1990, *Physical and Chemical Hydrogeology*, John Wiley and Sons, New York, New York, 824 pages.

Fetter, C. W., 1994, *Applied Hydrogeology*, Third Edition, Prentice Hall, Upper Saddle River, New Jersey, 691 pages.

Gustafson, John B., Joan G. Tell, and Doug Orem, 1997, Appendix A in: Selection of representative TPH fractions based on fate and transport considerations, volume 3 of *Total Petroleum Hydrocarbon Criteria Working Group Series*, July 1997, Amherst Scientific Publishers, 150 Fearing Street, Amherst, Massachusetts, 01002, 102 pages.

Hansen, K. C., Z. Zhoo, C. L. Yaws, and T. M. Aminabhavi, 1993, Determination of Henry's Law constants of organics in dilute aqueous solutions, *Journal of Chemical Engineering Data*, volume 3, pages 546 – 550.

Johnson, P. C., and R. A. Ettinger, 1991, Heuristic model for predicting the intrusion rate of contaminant vapors into buildings, *Environmental Science and Technology*, volume 25(8), 1445-52.

Lucius, J. E., 1987, *Physical and Chemical Properties and Health Effects of Thirty-Three Toxic Organic Chemicals*, United States Geological Survey, Open File Report 87-428, 137 pages.

Page, A.I., Miller, R.H., and Keeney, D.R., 1982, Methods *of Soil Analysis, Part 2, Chemical and Microbiological Properties*, Second edition, American Society of Agronomy, Inc. and Soil Science Society of America, Inc., Madison, Wisconsin, p. 561-579.

Salhotra, A., 1990, *pH-Dependent* K_d *Values for Metals*, United States Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia.

U.S. EPA, *IRIS, Integrated Risk Information System*, Office of Research and Development, National Center for Environmental Assessment, Cincinnati, Ohio. For information, contact the Risk Information Hotline, (513) 569-7254.

U.S. EPA, 1982, *Test Methods - Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater*, EPA-600/4-82-057, July 1982, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio.

U.S. EPA, 1983, *Methods for Chemical Analysis of Water and Wastes*, EPA-600/4-79-020, Environmental Monitoring and Support Laboratory, Cincinnati, Ohio, 45268.

U.S. EPA, October 1986, *Superfund Public Health Exposure Manual*, Office of Emergency and Remedial Response, EPA/540/1-86/060, Superintendent of Documents Number EP1.8:Su7/3, Washington, D.C.

U.S. EPA, 1986, *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods*, EPA 530/SW-846, 3rd edition, 4 volumes, includes December 1996 (a.k.a., June 1997) Update. Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA, 1988, *Superfund Exposure Assessment Manual*, EPA/540/1-88/001, Office of Remedial Response, Washington, D. C.

U.S. EPA, March 1989, *Risk Assessment Guidance for Superfund, Volume II Environmental Evaluation Manual, Interim Final*, EPA/540 1-89/001, Office of Emergency and Remedial Response, Washington, D.C.

U.S. EPA, December 1989, *Risk Assessment Guidance for Superfund, Volume I Human Health Evaluation Manual (Part A) Interim Final*, EPA/540/1-89/002, Superintendent of Documents Number EP1.8:Su7/3/989, Office of Emergency and Remedial Response, Washington, D.C.

U.S. EPA, January 1991, *Health Effects Assessment Summary Tables Annual FY-1991*, OSWER (OS-230), ORD(RD-689), OERR 9200.6-303(91-1), Superintendent of Documents Number EP1.2:H34/13/, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA, December 1991, *Risk Assessment Guidance for Superfund, Volume I Human Health Evaluation Manual (Part B, Development of Risk-Based Preliminary Remediation Goals) Interim*, EPA/540/R-92-003, Superintendent of Documents Number EP1.8:R49/2/v.1/Pt.B, Office of Research and Development, Washington, D.C.

U.S. EPA, March 1993, *Health Effects Assessment Summary Tables Annual Update*, EPA 540-R-93-058, Superintendent of Documents Number EP1.2:H34/13/993/Update, Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA, December 1992, Memorandum by Ms. Joan S. Dollarhide. *Dermal Absorption Factors for Multiple Chemicals*. Office of Research and Development, Environmental Criteria and Assessment Office, Cincinnati, Ohio.

U.S. EPA, July 1992, *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons*, EPA/600/R-93/089, Superintendent of Documents Number EP1.23/6:660/R-93/089, Office of Research and Development, Washington, D.C.

U.S. EPA, 1994, *Air Emissions Models for Waste and Wastewater*, EPA-453/R-94-080A, November, 1994, Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina.

U.S. EPA, 1996, Method 5035, Closed-System Purge-and-Trap and Extraction for Volatile Organics in Soil and Waste Samples, in *Test Methods for Evaluating Solid Waste: Physical/Chemical Methods, EPA 530/SW-846,* 3rd edition, 4 volumes, includes December 1996 (a.k.a., June 1997) Update. Office of Solid Waste and Emergency Response, Washington, D.C.

U.S. EPA, 1996, Region III, January-June 1996, *Risk-Based Concentration Table,* Office of RCRA, Philadelphia, Pennsylvania.

U.S. EPA, 1996, *Soil Screening Guidance: Technical Background Document*, EPA/540/R-95-128, May 1996, Office of Solid Waste and Emergency Response, Washington, D. C.

U.S. EPA, July 1996, Risk Assessment Issue Paper For: Derivation of a Provisional Subchronic Inhalation RfC for Benzene (CASRN 71-43-2), Superfund Technical Support Center, National Center for Environmental Assessment, Cincinnati, Ohio.

U.S. EPA, 1997, *Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl-tertiary-Butyl Ether (MtBE)*, EPA 822-F-97-008, Office of Water, Washington, D. C.

U.S. EPA, 1997, *Exposure Factors Handbook Volume - 1 General Factors*, EPA/600/P-95/002Fa, August 1997, Office of Research and Development, National Center for Environmental Assessment, Washington, D. C.

U.S. EPA, 1997, *Exposure Factors Handbook Volume 2 - Food Ingestion Factors*, EPA/600/P-95/002Fb, August 1997, Office of Research and Development, National Center for Environmental Assessment, Washington, D. C.

U.S. EPA, 1997, *Exposure Factors Handbook Volume 3 Activity Factors*, EPA/600/P-95/002Fc, August 1997, Office of Research and Development, National Center for Environmental Assessment, Washington, D. C.

U.S. EPA, March 2001, *National Primary Drinking Water Standards,* EPA 816-F-01-007, Office of Water, Washington, D. C.

United States Geological Survey, 1989, *Geohydrology and Susceptibility of Major Aquifers To Surface Contamination in Alabama*, Areas 1 through 13 consecutive, Water Resources Investigations Report 88-**** - variously numbered, in cooperation with the Alabama Department of Environmental Management, Tuscaloosa, Alabama.

TABLE 2-2

GROUNDWATER MCLs AND HEALTH ADVISORIES

Chemical of Concern	Target Levels [mg/L]	Explanation
ORGANICS		
Benzene	0.005	MCL
Toluene	1	MCL
Ethylbenzene	0.7	MCL
Xylenes (Total)	10	MCL
Methyl-tert-Butyl-Ether	0.02[†]	Drinking Water Advisory
Anthracene	-	-
Benzo(a)anthracene	-	-
Benzo(a)pyrene	0.0002	MCL
Benzo(b)fluoranthene	-	-
Benzo(g,h,i)perylene	-	-
Benzo(k)fluoranthene	-	-
Chrysene	-	-
Fluoranthene	-	-
Fluorene	-	-
Naphthalene	0.02	Lifetime Health Advisory
Phenanthrene	-	-
Pyrene	-	-
METALS		
Arsenic	0.05	MCL
Barium	2.0	MCL
Cadmium	0.005	MCL
Chromium (VI)	0.1[††]	MCL
Lead	0.015	TT Action Level
Zinc	2.0	Lifetime Health Advisory

MCL	Maximum Contaminant Level.
TT	Treatment Technique.
†	U. S. Environmental Protection Agency (EPA) Office of Water. December 1997. Drinking Water Advisory: Consumer Acceptability Advice and Health Effects Analysis on Methyl-tertiary-Butyl-Ether (MtBE). EPA 822-F-97-008.
††	MCL for Total Chromium.
Source	U.S. Environmental Protection Agency (EPA) Office of Water. March 2001. National Primary Drinking Water Standards. EPA 816-F-01-007.

TABLE 3-1

COMPARISON OF THE THREE TIERS

FACTORS	INITIAL SCREEN	TIER 1	TIER 2	TIER 3
Exposure Factors	Default	Default	Default	Site-Specific or default
Toxicity Factors	Default	Default	Default	Default or ADEM accepted values
Physical and Chemical Properties	Default	Default	Default	Default or ADEM accepted values
Fate and Transport Parameters	Default	Default	Site-Specific	Site-Specific
Fate and Transport Models	Tier 1	Tier 1	Tier 1	Acceptable to the ADEM
Representative Concentrations for Soil and Groundwater	Maximum	Area-weighted Average Maximum not to exceed 10 times the area average	Area-weighted Average Maximum not to exceed 10 times the area average	Area-weighted Average Maximum not to exceed 10 times the area average
Target Risk	$1\text{x}10^{-5}$	$1\text{x}10^{-5}$	$1\text{x}10^{-5}$	$1\text{x}10^{-5}$
Groundwater Ingestion	MCL or target levels	MCL or target levels	MCL or target levels	MCL or target levels
Hazard Quotient	1	1	1	1
Ecological Risk	NA	NA	NA	Detailed Evaluation
Outcome of Evaluation	NFA, Tiered Evaluation	NFA, Tier 2 Evaluation, Compliance Monitoring, or Remediation	NFA, Tier 3 Evaluation, Compliance Monitoring or Remediation	NFA, Remediation, or Compliance Monitoring

TABLE 4-1 *(Page 1 of 3)*

SITE CLASSIFICATION AND INITIAL RESPONSE ACTIONS

CLASSIFICATION	DESCRIPTION	RESPONSE ACTION: Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
CLASS A		
A.1	Vapor concentrations at or approaching explosive levels that could cause health effects are present in a residence or building.	• Evacuate occupants and perform abatement measures that will remove explosive vapors from structure. Contact local public safety officials.
A.2	Vapor concentrations at or approaching explosive levels are present in subsurface utility system(s), but no building or residences are impacted.	• Evacuate immediate vicinity and begin abatement measures such as ventilation. Contact local public safety officials.
CLASS B		
B.1	An active public water supply well, public water supply line, or public surface water intake is impacted or immediately threatened.	• Notify user(s), provide alternate water supply, notify water supply system operators, assess extent of contamination, hydraulically control contaminated water, and/or treat water at point of use.
B.2	An active domestic water supply well, domestic water supply line or domestic surface water intake is impacted or immediately threatened.	• Notify user(s), provide alternate water supply, assess extent of contamination, hydraulically control contaminated water, and evaluate potential for hooking to a public water supply system.
B.3	The release is located within a designated Source Water Assessment Area I.	▪ Notify local water utilities. Use F.3 for Response Action.
CLASS C		
C.1	Ambient vapor/particulate concentrations exceed concentrations of concern from an acute exposure, or safety viewpoint.	• Install vapor barrier, remove source, and/or restrict access to affected area.
C.2	Free product is present on the groundwater at ground surface, on surface water bodies, in utilities other than water supply lines, or in surface water runoff.	• Perform free product removal activities and restrict area access.

TABLE 4-1 *(Page 2 of 3)*

SITE CLASSIFICATION AND INITIAL RESPONSE ACTIONS

CLASSIFICATION	DESCRIPTION	RESPONSE ACTION: Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
CLASS D		
D.1	There is a potential for explosive levels, or concentrations of vapors that could cause acute effects, to accumulate in a residence or other building.	• Assess the potential for vapor migration through monitoring and modeling, remove source where necessary, and/or install vapor migration barrier.
D.2	A non-potable water supply well is impacted or immediately threatened.	• Notify owner/user(s) and evaluate the need to install point-of-use water treatment, hydraulic control, or alternate water supply.
D.3	Shallow contaminated surface soils are open to public access, and dwellings, parks, playgrounds, day care centers, schools or similar use facilities are within 500 feet of these areas.	• Remove soils, cover soils, and restrict access.
CLASS E		
E.1	A sensitive habitat or sensitive resources (sport fish, economically important species, threatened and endangered species, etc.) are impacted and affected.	• Minimize extent of impact by containment measures and implement habitat management to minimize exposure.
CLASS F		
F.1	Groundwater is impacted and a public water well is located within one (1) mile of the site.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required. Sample water supply well if needed.

TABLE 4-1 *(Page 3 of 3)*

SITE CLASSIFICATION AND INITIAL RESPONSE ACTIONS

CLASSIFICATION	DESCRIPTION	RESPONSE ACTION: Notify appropriate authorities, property owners, and potentially affected parties, and evaluate the need to:
F.2	Groundwater is impacted and a domestic well is located within 1,000 feet of the site.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required. Sample water wells where needed.
F.3	Contaminated soils and/or groundwater are located within designated Source Water Assessment Area II.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required. Sample water wells where needed.
CLASS G		
G.1	Contaminated soils and/or groundwater are located within areas vulnerable to contamination from surface sources.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required.
CLASS H		
H.1	Impacted surface water, stormwater or groundwater discharges within 500 feet of a surface water body used for human drinking water, whole body water-contact sports, or habitat to a protected or listed endangered plant and/or animal species.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required.
CLASS I		
I.1	Site has contaminated soils and/or groundwater but does not meet any of the above mentioned criteria.	• Assess the extent of contamination, institute groundwater monitoring and evaluate to determine if remediation by natural attenuation is sufficient or if hydraulic control and more active remediation is required.

TABLE 5-1 (*Page 1 of 2*)

CHEMICALS OF CONCERN FOR DIFFERENT PRODUCT RELEASES

CHEMICAL		**Gasoline**	**Diesel/ Light Fuel Oils**	**Product Jet Fuel**	**Kerosene**	**Heavy Fuel Oils**	**Waste/ Used Oil**	**Analytical Methods**	
ORGANICS								**Groundwater**	**Soil**
Benzene	a	X	X	X	X	NC	X	8021, 8260^1, 602^6, 624	8021, 8260^1
Toluene	n	X	X	X	X	NC	X	8021, 8260^1, 602, 624	8021, 8260^1
Ethylbenzene	n	X	X	X	X	NC	X	8021, 8260^1, 602, 624	8021, 8260^1
Xylenes (mixed)	n	X	X	X	X	NC	X	8021, 8260^1, 602, 624	8021, 8260^1
Methyl-tert-Butyl-Ether	n	X	NC	NC	NC	NC	NC	8021, 8260^1	8021, 8260^1
Anthracene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Benzo(a)anthracene	b	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Benzo(a)pyrene	b	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Benzo(b)fluoranthene	b	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Benzo(k)fluoranthene	b	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Benzo(g,h,i)perylene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Chrysene	b	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Fluoranthene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Fluorene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Naphthalene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Phenanthrene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3
Pyrene	n	NC	X	X	X	X	X	8310^2, 8270^7, 8100^3, 610^4	8310^2, 8270^7, 8100^3

TABLE 5-1 (*Page 2 of 2*)

CHEMICALS OF CONCERN FOR DIFFERENT PRODUCT RELEASES

CHEMICAL	**Gasoline**	**Diesel/ Light Fuel Oils**	**Product Jet Fuel**	**Kerosene**	**Heavy Fuel Oils**	**Waste/ Used Oil**	**Analytical Methods**
METALS							**Soil and Groundwater**
Arsenic a	NC	NC	NC	NC	NC	X	206.2, 206.3, 206.4, 6020, 7000, 7062
Barium n	NC	NC	NC	NC	NC	X	208.1, 208.2, 6010, 6020, 7000, 7080
Cadmium b	NC	NC	NC	NC	NC	X	213.2, 6010, 6020, 7000, 7130, 7131
Chromium (VI) a	NC	NC	NC	NC	NC	X	218.4, 218.5, 7195[5], 7197[5], 7198
Lead b	X*	NC	NC	NC	NC	X	239.2, 6020, 7421
Zinc n	NC	NC	NC	NC	NC	X	289.1, 289.2, 6010, 6020, 7000, 7950, 7951

Note:

X	Chemical of concern to be analyzed
NC	Not a Chemical of Concern
*	Chemical of concern for leaded gasoline and aviation gas release
1	For 8260 and 8021, use extraction Method 5035 for soil, promulgated June 1997.
2	For 8310, must use High Performance Liquid Chromatography (HPLC) version.
3	For 8100 must use capillary column, not packed column.
4	For 610 must use HPLC version.
5	7195, 7197 use a new digestion, 3060, promulgated June 1997.
6	Method #s < 1000 are from older EPA Method book: US EPA, March 1983, Methods for Chemical Analyses of Water and Wastes, Environmental Monitoring and Support Laboratory, Cincinnati, OH.
7	For 8270 where a detection limit lower than the Estimated Quantitation Limit is required, measures to increase the sensitivity of the method should be taken.
a	Human carcinogen (Group A under EPA weight of evidence classification system for carcinogenicity)
b	Probable human carcinogen (Group B1 or B2 under EPA weight of evidence classification system for carcinogenicity)
n	Non-carcinogen

Sources:

- U. S. Environmental Protection Agency, November 1986, *Test Methods for Evaluating Solid Waste*, SW-846, Third Edition. Office of Solid Waste and Emergency Response, Washington D.C.
- See footnote 6.
- Methods Information Communication Exchange, Office of Solid Waste, (703) 821-4690.
- U.S. Environmental Protection Agency, July 1982, *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater*, EPA-600/4-82-057. Environmental Monitoring and Support Laboratory, Cincinnati, OH 45263.

TABLE 5-2

INITIAL SCREENING LEVELS (ISLs)

CHEMICAL	RESIDENTIAL		COMMERCIAL	
	Soil † [mg/kg]	**Groundwater ‡** [mg/L]	**Soil †** [mg/kg]	**Groundwater ‡** [mg/L]
ORGANICS				
Benzene	8.45E-3	5.00E-3	8.45E-3	5.00E-3
Toluene	3.60	1.00	3.60	1.00
Ethylbenzene	3.61	7.00E-1	3.61	7.00E-1
Xylenes (Total)	1.32E+1	1.00E+1	6.24E+1	1.00E+1
Methyl-tert-Butyl-Ether	8.62E-3	2.0E-2	8.62E-3	2.0E-2
Anthracene	1.02E+1	4.34E-2	1.02E+1	4.34E-2
Benzo(a)anthracene	9.51	1.17E-3	1.01E+1	1.17E-3
Benzo(a)pyrene	9.52E-1	2.00E-4	2.24	2.00E-4
Benzo(b)fluoranthene	9.50	1.17E-3	1.85E+1	1.17E-3
Benzo(g,h,i)perylene	1.11E+1	7.00E-4	1.11E+1	7.00E-4
Benzo(k)fluoranthene	9.52	8.00E-4	9.84	8.00E-4
Chrysene	6.37	1.60E-3	6.37	1.60E-3
Fluoranthene	1.01E+2	2.06E-1	1.01E+2	2.06E-1
Fluorene	1.53E+2	1.46	1.53E+2	1.46
Naphthalene	5.79E-1	2.00E-2	5.79E-1	2.00E-2
Phenanthrene	1.41E+2	1.00	1.41E+2	1.00
Pyrene	9.18E+1	1.35E-1	9.18E+1	1.35E-1
METALS				
Arsenic	6.05	5.00E-2	7.76	5.00E-2
Barium	1.99E+2	2.00	1.99E+2	2.00
Cadmium	9.08E-1	5.00E-3	9.08E-1	5.00E-3
Chromium (VI)	4.61	1.00E-1	4.61	1.00E-1
Lead	4.43	1.50E-2	4.43	1.50E-2
Zinc	3.00E+2	2.00	3.00E+2	2.00

† Lower of all (surface/sub-surface) soil RBSLs.
‡ Lower of MCLs for ingestion or RBSLs for inhalation exposures.
Soil concentrations are presented on a dry weight basis.

TABLE 6-1
EXAMPLE OF TABULAR FORMAT FOR SITE CONCEPTUAL EXPOSURE MODEL

Potentially Exposed Population	Exposure Route, Medium, and Exposure Point	Pathway Selected for Evaluation ?	Reason for Selection or Non-Selection
Onsite Commercial Worker	Indoor inhalation of air vapors	Yes	Inhalation of air vapor is possible.
	Outdoor inhalation of air vapors	Yes	Inhalation of air vapor is possible.
	Inhalation (vapors & particulates), dermal contact and ingestion of surficial soil	No	The site is paved.
	Leaching to groundwater from surficial soil	Yes	Leaching of chemicals to groundwater is possible.
	Indoor inhalation of vapor emissions from subsurface soil	No	Subsurface soil under the building is not impacted.
	Outdoor inhalation of vapor emissions from subsurface soil	Yes	Vapor emissions from impacted soils and migration through cracks in cover is possible.
	Inhalation (vapors & particulates), dermal contact and ingestion of subsurface soil	No	The site is paved.
	Leaching to groundwater from subsurface soil	Yes	Leaching of chemicals to groundwater is possible.
	Indoor inhalation of vapor emissions from groundwater	No	The groundwater plume is not under the building.
	Outdoor inhalation of vapor emissions from groundwater	Yes	Vapor emissions from groundwater and migration through cracks in cover is possible.
	Ingestion of groundwater	No	No drinking water well on-site.
Offsite Commercial Worker	Indoor inhalation of air vapors	Yes	Groundwater under the building is impacted.
	Outdoor inhalation of air vapors	Yes	Volatilization from impacted groundwater is possible.
	Inhalation (vapors & particulates), dermal contact and ingestion of surficial soil	No	Off-site surficial soil is not impacted.
	Leaching to groundwater from surficial soil	No	Off-site surficial soil is not impacted.
	Indoor inhalation of vapor emissions from subsurface soil	No	Off-site subsurface soil is not impacted.
	Outdoor inhalation of vapor emissions from subsurface soil	No	Off-site subsurface soil is not impacted.
	Inhalation (vapors & particulates), dermal contact and ingestion of subsurface soil	No	Off-site subsurface soil is not impacted.
	Leaching to groundwater from subsurface soil	No	Off-site subsurface soil is not impacted.
	Indoor inhalation of vapor emissions from groundwater	Yes	Groundwater under the building is impacted.
	Outdoor inhalation of vapor emissions from groundwater	Yes	Plume has migrated off-site.
	Ingestion of groundwater	Yes	A drinking water well may be located at the off-site location.

TABLE 6-2 *(Page 1 of 2)*

TOXICITY PARAMETERS

	Slope Factor [kg-d/mg]				Reference Dose [mg/kg-d]			
CHEMICAL	**Oral**	**Source**	**Inhalation**	**Source**	**Oral**	**Source**	**Inhalation**	**Source**
ORGANICS								
Benzene	0.055	1	0.027	1	NA	NA	0.0017	8
Toluene	NA	NA	NA	NA	0.20	1	0.11	1
Ethylbenzene	NA	NA	NA	NA	0.10	1	0.29	1
Xylenes (Total)	NA	NA	NA	NA	2.00	1	0.086 **	5
Methyl-tert-Butyl-Ether	NA	NA	NA	NA	0.005 **	6	0.86	1
Anthracene	NA	NA	NA	NA	0.30	1	0.30	2
Benzo(a)anthracene	0.73	3	0.61	2	NA	NA	NA	NA
Benzo(a)pyrene	7.3	1	6.1	5	NA	NA	NA	NA
Benzo(b)fluoranthene	0.73	3	0.61	2	NA	NA	NA	NA
Benzo(g,h,i)perylene	NA	NA	NA	NA	0.03	*	0.03	*
Benzo(k)fluoranthene	0.73	3	0.61	2	NA	NA	NA	NA
Chrysene	0.0073	3	0.0061	2	NA	NA	NA	NA
Fluoranthene	NA	NA	NA	NA	0.04	1	0.04	2
Fluorene	NA	NA	NA	NA	0.04	1	0.04	2
Naphthalene	NA	NA	NA	NA	0.02	1	0.0009	1
Phenanthrene	NA	NA	NA	NA	0.03	*	0.03	*
Pyrene	NA	NA	NA	NA	0.03	1	0.03	2

TABLE 6-2 *(Page 2 of 2)*

TOXICITY PARAMETERS

	Slope Factor [kg-d/mg]				Reference Dose [mg/kg-d]			
CHEMICAL	**Oral**	**Source**	**Inhalation**	**Source**	**Oral**	**Source**	**Inhalation**	**Source**
METALS								
Arsenic	1.5	1	15.05	1	0.0003	1	NA	NA
Barium	NA	NA	NA	NA	0.07	1	0.000143	4
Cadmium	NA	NA	6.3	1	0.0005	1	NA	NA
Chromium (VI)	NA	NA	42.00	1	0.003	1	0.000002	1
Lead	NA	NA	NA	NA	NA	NA	NA	NA
Zinc	NA	NA	NA	NA	0.3	1	0.01	7

NOTES:

NA Not Applicable/Not Available
* Based on pyrene surrogate RfD
** Still awaiting best values for these parameters. In the interim, for xylenes, the smaller values are presented, and these values will be revised as more information is available.

Sources:

1 U.S. EPA . April 2000. Integrated Risk Information System (IRIS).
2 Route Extrapolation.
3 U.S. EPA. 1992. *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons*. Washington, D.C. Office of Research and Development. EPA/600/R-93/089.
4 U.S. EPA. 1993. *Health Effects Assessments Summary Tables (HEAST)*. Washington, D.C. Office of Solid Waste and Emergency Response. EPA 540/R-93-058.
5 U.S. EPA. 1991. *Health Effects Assessments Summary Tables (HEAST)*. Washington, D.C. Office of Solid Waste and Emergency Response. OERR 9200.6-303(91-1).
6 U.S. EPA. April 1996. Risk-Based Concentration Table, January-June 1996. US EPA Region III, Office of RCRA, Philadelphia, PA.
7 U.S. EPA. October 1986. *Superfund Public Health Evaluation Manual*. Washington, D.C. Office of Emergency and Remedial Response. EPA/540/1-86/060.
8 U.S. EPA. Superfund Technical Support Center, July 1996. Cincinnati, OH. *Risk Assessment Issue Paper for: Derivation of a Provisional Subchronic Inhalation RfC for Benzene* (CASRN 71-43-2).

TABLE 6-3 (*Page 1 of 2*)

TIER 1 AND 2 DEFAULT EXPOSURE FACTORS

EXPOSURE PARAMETER	SYMBOL	UNITS	ADEM DEFAULT VALUE	REFERENCE
Averaging Time - Carcinogen	AT_c	years	70	EPA, 1989
Averaging Time - Noncarcinogen (equals exposure duration):	AT_n	years	Receptor dependent = ED	EPA, 1989
Body Weight				
Adult Receptors, Commercial, Construction	BW	kg	70	EPA, 1989
Child Receptors	BW	kg	15	EPA, 1989
Exposure Duration				
Resident (child)	ED	years	6	EPA, 1989
Resident (adult)	ED	years	30	EPA, 1989
Commercial Worker	ED	years	25	EPA, 1989
Construction Worker	ED	years	1	ADEM, 1997
Exposure Frequency				
Residents	EF	days/yr	350	EPA, 1989
Commercial Worker	EF	days/yr	250	EPA, 1989
Construction Worker	EF	days/yr	250	ADEM, 1997
Soil Ingestion Rate				
Resident (child)	IR_{soil}	mg/day	200	EPA, 1989
Resident (Adult)	IR_{soil}	mg/day	100	EPA, 1989
Commercial Worker	IR_{soil}	mg/day	50	EPA, 1989
Construction Worker	IR_{soil}	mg/day	100	ADEM, 1997
Daily Water Ingestion Rate (IRW)				
Resident (Adult)	IR_w	L/day	2	EPA, 1989
Hourly Indoor Inhalation Rate†				
Resident (Child)	IR_{air} - indoor	m^3/hr	0.417	EPA, 1997
Resident (Adult)	IR_{air} - indoor	m^3/hr	0.633	EPA, 1997
Commercial Workers	IR_{air} - indoor	m^3/hr	1.5	EPA, 1997
Construction Worker	IR_{air} - indoor	m^3/hr	1.5	EPA, 1997
Exposure Time for Indoor Inhalation				
Resident (Child)	ETin	hr/day	24	ADEM, 1997
Resident (Adult)	ETin	hr/day	24	ADEM, 1997
Commercial and Construction Workers	ETin	hr/day	10	ADEM, 1997

TABLE 6-3 (*Page 2 of 2*)

TIER 1 AND 2 DEFAULT EXPOSURE FACTORS

EXPOSURE PARAMETER	SYMBOL	UNITS	ADEM DEFAULT VALUE	REFERENCE
Hourly Outdoor Inhalation Rate†				
Resident (Child)	IR_{air} - outdoor	m^3/hr	1.0	EPA, 1997
Resident (Adult)	IR_{air} - outdoor	m^3/hr	1.5	EPA, 1997
Commercial and Construction Workers	IR_{air} - outdoor	m^3/hr	1.5	EPA, 1997
Exposure Time for Outdoor Inhalation				
Resident (Child and Adult)	ETout	hr/day	10	ADEM, 1997
Commercial and Construction Workers	ETout	hr/day	10	ADEM, 1997
Soil to skin adherence factor	M	mg/cm^2	0.5	ASTM, 1995
Oral relative absorption factor	RAF_o	---	1	ASTM, 1995
Dermal relative absorption factor				
Volatiles	RAF_d	---	0.5	ASTM, 1995
PAHs	RAF_d	---	0.05	ASTM, 1995
Metals	RAF_d	---	0.001	EPA, 1992
Skin surface area for dermal contact with soil †				
Adult receptors	SA	cm^2/d	5000	EPA, 1997
Child receptors	SA	cm^2/d	2500	EPA, 1997
Target Risk				
Hazard Quotient for individual constituents/routes	THQ	---	1	ADEM - UST Program
Individual Excess Lifetime Cancer Risk for constituents/routes	TR	---	$1x10^{-5}$	ADEM - UST Program

Sources

- US EPA. 1989. *Risk Assessment Guidance for Superfund, Volume 1, Human Health Evaluation Manual, Part A.,Interim Final*. Washington D. C., Office of Emergency and Remedial Response. EPA/540/1-89/002.
- American Society for Testing and Materials, 1995. *Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites*, Designation: E1739-95. ASTM, 100 Barr Harbor Dr., West Conshohocken, PA 19428.
- Alabama Department of Environmental Management. 1997. RBCA Module 3 Training and Policy Meetings.

† Derived from general factors in Exposure Factors Handbook, Volume I. August 1997. EPA/600/P-95/002Fa.

TABLE 6-4 (*Page 1 of 2*)
TIER 1 DEFAULT FATE AND TRANSPORT PARAMETERS

Parameter	Symbol	Unit	Tier 1 Values
SOIL PARAMETERS:			
Length of Soil Source Area Parallel to Wind Direction	W_a	cm	1500
Depth to Subsurface Soil Sources	L_s	cm	30.48
Lower Depth of Surficial Soil Zone	d	cm	30.48
Thickness of Capillary Fringe	h_{cap}	cm	5
Thickness of Vadose Zone*	h_v	cm	295
Dry Soil Bulk Density in the Vadose Zone	ρ_s	g/cm^3	1.8
Fractional Organic Carbon Content in the Vadose Zone	foc	g-C/g-soil	0.01
Total Soil Porosity in the Vadose Zone	θ_T	cm^3/cm^3-soil	0.3
Volumetric Water Content in Vadose Zone	θws	cm^3/cm^3	0.1
Volumetric Air Content in Vadose Zone*	θas	cm^3/cm^3	0.2
Volumetric Water Content in Capillary Fringe	θwcap	cm^3/cm^3	0.27
Volumetric Air Content in Capillary Fringe*	θacap	cm^3/cm^3	0.03
Volumetric Water Content in Foundation or Wall Cracks	θwcrack	cm^3/cm^3	0.1
Volumetric Air Content in Foundation/Wall Cracks*	θacrack	cm^3/cm^3	0.2
GROUNDWATER PARAMETERS:			
Depth to Groundwater	L_{gw}	cm	300
Width of GW Source Perpendicular to the GW Flow Direction	Y	cm	1500
Length of the GW Source Parallel to the GW Flow Direction	W	cm	1500
Total Soil Porosity in the Saturated Zone	θ_{TS}	cm^3/cm^3-soil	0.3
Dry Soil Bulk Density in the Saturated Zone	ρ_{ss}	g/cm^3	1.8
Fractional Organic Carbon Content in the Saturated Zone	foc_s	g/g	0.01
Groundwater Mixing Zone Thickness	δ_{gw}	cm	200
Hydraulic Conductivity in the Saturated Zone	K	cm/year	31536
Hydraulic Gradient in the Saturated Zone	i	--	0.005
Groundwater Darcy Velocity*	U_{gw}	cm/year	157.68
Infiltration Rate	I	cm/year	14.8
STREAM PARAMETERS:			
Stream Flow Rate (Calculated per Appendix C)	Q_{sw}	ft^3/day	-
AMBIENT AIR PARAMETERS:			
Breathing Zone Height	δ_a	cm	200
Wind Speed within the Breathing Zone	U_a	cm/s	225
ENCLOSED SPACE PARAMETERS:			
Enclosed Space Air Exchange Rate:			
Residential	ER	1/sec	0.00014
Commercial/Construction Worker	ER	1/sec	0.00023
Enclosed Space Volume/Infiltration Area Ratio:			
Residential	L_B	cm	200
Commercial/Construction Worker	L_B	cm	300

TABLE 6-4 (*Page 2 of 2*)
TIER 1 DEFAULT FATE AND TRANSPORT PARAMETERS

Parameter	Symbol	Unit	Tier 1 Values
ENCLOSED SPACE PARAMETERS (Continued):			
Enclosed Space Foundation or Wall Thickness			
Residential	Lcrack	cm	15
Commercial/Construction Worker	Lcrack	cm	15
Areal Fraction of Cracks in Foundation/Walls			
Residential	η	cm^2/cm^2	0.01
Commercial/Construction Worker	η	cm^2/cm^2	0.01
PARTICULATE EMISSION RATE:			
Residential and Commercial	Pe	g/cm^2sec	6.90E-14
Construction Worker	Pe	g/cm^2sec	6.90E-09
AVERAGING TIME FOR VAPOR FLUX:			
Resident Child	τ	sec	1.89E+08
Resident Adult	τ	sec	9.46E+08
Commercial Worker	τ	sec	7.88E+08
Construction Worker	τ	sec	3.15E+07
GROUNDWATER RESOURCE PROTECTION PARAMETERS:			
Distance from the Downgradient Edge of the Groundwater Source to the Point of Exposure	Xpoe	ft	Variable
Longitudinal Dispersivity*	α_x	ft	Xpoe/10
Transverse Dispersivity*	α_y	ft	Xpoe/30
Vertical Dispersivity*	α_z	ft	Xpoe/200
Distance from the Downgradient Edge of the Groundwater Source to the Point of Compliance	Xpoc	ft	Variable
Longitudinal Dispersivity*	α_x	ft	Xpoc/10
Transverse Dispersivity*	α_y	ft	Xpoc/30
Vertical Dispersivity*	α_z	ft	Xpoc/200
STREAM PROTECTION PARAMETERS:			
Distance from the Downgradient Edge of the Groundwater Source to the Stream	Xs	ft	Variable
Longitudinal Dispersivity*	α_x	ft	Xs/10
Transverse Dispersivity*	α_y	ft	Xs/30
Vertical Dispersivity*	α_z	ft	Xs/200
Distance from the Downgradient Edge of the Groundwater Source to the Point of Compliance	Xspoc	ft	Variable
Longitudinal Dispersivity*	α_x	ft	Xspoc/10
Transverse Dispersivity*	α_y	ft	Xspoc/30
Vertical Dispersivity*	α_z	ft	Xspoc/200

Note:
* = Calculated value

TABLE 6-5
PHYSICAL AND CHEMICAL PROPERTIES

CHEMICAL	**MOL. WT.**	**Koc**	**Ref**	**Henry's Constant**	**Ref**	**Diffusion Coefficient in Air**	**Ref**	**Diffusion Coefficient in Water**	**Ref**	**Pure Product Solubility**	**Ref**
ORGANICS	[g/mole]	[mL water/g carbon]		[Lwater/Lair]		[cm^2/s]		[cm^2/s]		[mg/l]	
Benzene	78	6.17E+01	4	2.28E-01	2	8.80E-02	3	9.80E-06	3	1.75E+03	2
Toluene	92	1.40E+02	4	2.72E-01	2	8.70E-02	3	8.60E-06	3	5.26E+02	2
Ethylbenzene	106	2.04E+02	4	3.23E-01	2	7.50E-02	3	7.80E-06	3	1.69E+02	2
Xylenes (Total)	106	2.49E+02	4	2.76E-01	2	7.80E-02	3	8.75E-06	3	1.75E+02	2
Methyl-tert-Butyl-Ether	88.15	1.20E+01	1	2.27E-02	9	1.02E-01	9	1.05E-05	9	4.80E+04	1
Anthracene	178	2.35E+04	4	2.67E-03	2	3.24E-02	3	7.74E-06	3	4.34E-02	2
Benzo(a)anthracene	228	3.58E+05	4	1.37E-04	2	5.10E-02	3	9.00E-06	3	9.40E-03	2
Benzo(a)pyrene	252	9.69E+05	4	4.63E-05	2	4.30E-02	3	9.00E-06	3	1.62E-03	2
Benzo(b)fluoranthene	252	1.23E+06	6	4.55E-03	2	2.26E-02	3	5.56E-06	3	1.50E-03	2
Benzo(g,h,i)perylene	276	1.58E+06	1	2.22E-06	5	2.16E-02	11	5.31E-06	11	7.00E-04	1
Benzo(k)fluoranthene	252	1.23E+06	6	3.40E-05	2	2.26E-02	3	5.56E-06	3	8.00E-04	2
Chrysene	228	3.98E+05	6	3.88E-03	2	2.48E-02	3	6.21E-06	3	1.60E-03	2
Fluoranthene	202	4.91E+04	4	6.60E-04	2	3.02E-02	3	6.35E-06	3	2.06E-01	2
Fluorene	166	7.71E+03	4	2.61E-03	2	3.63E-02	3	7.88E-06	3	1.98E+00	2
Naphthalene	128	1.19E+03	4	1.98E-02	2	5.90E-02	3	7.50E-06	3	3.10E+01	2
Phenanthrene	178	1.41E+04	1	6.61E-03	5	3.24E-02	7	7.74E-06	7	1.00E+00	1
Pyrene	202	6.80E+04	4	4.51E-04	2	2.72E-02	3	7.24E-06	3	1.35E-01	2
METALS											
Arsenic	74.9	6.41E+01	8	0.00E+00		na		na		na	
Barium	137.3	4.1E+01	10	0.00E+00		na		na		na	
Cadmium	112.4	7.5E+01	10	0.00E+00		na		na		na	
Chromium (VI)	52	1.9E+01	10	0.00E+00		na		na		na	
Lead	207.2	1.22E+02	8	0.00E+00		na		na		na	
Zinc	65.4	6.2E+01	10	0.00E+00		na		na		na	

1 ASTM Standard E 1739-1995. *Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites*. Table X1.2.
2 U.S. EPA, May 1996. *Soil Screening Guidance Technical Background Document*. EPA/540/R-95/128, Table 36.
3 U.S. EPA, May 1996. *Soil Screening Guidance Technical Background Document*. EPA/540/R-95/128, Table 37.
4 U.S. EPA, May 1996. *Soil Screening Guidance Technical Background Document*. EPA/540/R-95/128, Table 39 geometric mean of measured Koc values.
5 U.S. EPA, October 1986. *Superfund Public Health Exposure Manual*. EPA/540/1-86/060. Office of Emergency and Remedial Response, Washington, D.C. 20460. Converted at 20° C
6 U.S. EPA, May 1996. *Soil Screening Guidance Technical Background Document*. EPA/540/R-95/128, Table 39 (calculated values).
7 Assumed same as anthracene because of identical molecular weight.
8 pH-dependent Kd values experimentally derived using the regression relationship developed by U.S. EPA's Environmental Research Laboratory, Athens, GA. March 1990.
9 U.S. EPA, November 1994. *Air Emissions Model for Waste and Wastewater*, EPA-453/R-94-080A, Table C-1.
10 U.S. EPA, May 1996. *Soil Screening Guidance Technical Background Document*. EPA/540/R-95/128, Table 46 at pH=6.8.
11 Estimated from the diffusion coefficient and molecular weight for Benzo(b)fluoranthene. Diffusion coefficient in air = 2.26E-02 x $(252/276)^{0.5}$; Diffusion coefficient in water = 5.56E-06 x $(252/276)^{0.5}$. U.S. EPA, April 1988. *Superfund Exposure Assessment Manual*. EPA/540/1-88/001, Office of Remedial Response, Washington, D.C., page 17.

TABLE 7-1

TIER 1 EXPOSURE PATHWAYS FOR DIFFERENT MEDIA AND RECEPTORS

RECEPTOR	AIR	SURFICIAL SOIL	SUBSURFACE SOIL	GROUNDWATER
Resident Adult	Inhalation	Outdoor Inhalation (vapor and particulates), Ingestion and Dermal Contact	Indoor Inhalation of Vapors	Indoor Inhalation of Vapors
		Potential Leachate to Groundwater	Outdoor Inhalation of Vapors	Outdoor Inhalation of Vapors
			Potential Leachate to Groundwater	Ingestion of water
Resident Child	Inhalation	Outdoor Inhalation (vapor and particulates), Ingestion and Dermal Contact	Indoor Inhalation of Vapors	Indoor Inhalation of Vapors
		Potential Leachate to Groundwater	Outdoor Inhalation of Vapors	Outdoor Inhalation of Vapors
			Potential Leachate to Groundwater	Ingestion of water
Commercial Worker	Inhalation	Outdoor Inhalation (vapor and particulates), Ingestion and Dermal Contact	Indoor Inhalation of Vapors	Indoor Inhalation of Vapors
		Potential Leachate to Groundwater	Outdoor Inhalation of Vapors	Outdoor Inhalation of Vapors
			Potential Leachate to Groundwater	Ingestion of water
Construction Worker	Inhalation	Outdoor Inhalation (vapor and particulates), Ingestion and Dermal Contact	Indoor Inhalation of Vapors	Indoor Inhalation of Vapors
		Potential Leachate to Groundwater	Outdoor Inhalation of Vapors	Outdoor Inhalation of Vapors
			Potential Leachate to Groundwater	
Utilities:		See Sections 4.6, 5.6, and 6.12		
Ecological:		See Section 6.13		
Impacts to Surface Water:		See Section 6.10		
Groundwater Resource Protection:		See Section 6.6, 6.9, and 6.11		

TABLE 7-2(a)

RISK-BASED SCREENING LEVELS FOR A RESIDENT CHILD

CHEMICALS OF CONCERN	**AIR INHALATION**		**SURFICIAL SOIL**	**SUBSURFACE SOIL**		**GROUNDWATER**		
	Indoor [mg/m^3-air]	Outdoor [mg/m^3-air]	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/kg]	Outdoor Inhalation of Vapor Emissions [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/L]	Outdoor Inhalation of Vapor Emissions [mg/L]	Ingestion of Water [mg/L]
ORGANICS								
Benzene	2.66E-03	2.66E-03	3.80E+01	7.58E-02	1.62E+00	2.41E-01	1.44E+02	5.00E-03
Toluene	1.72E-01	1.72E-01	7.82E+02 *	8.85E+00	1.89E+02	1.40E+01	5.26E+02 #	1.00E+00
Ethylbenzene	4.53E-01	4.54E-01	3.60E+02 *	3.27E+01	3.60E+02 *	3.67E+01	1.69E+02 #	7.00E-01
Xylenes (mixed)	1.34E-01	1.35E-01	4.51E+02 *	1.32E+01	2.82E+02	1.18E+01	1.75E+02 #	1.00E+01
Methyl-tert-butyl-ether (MTBE)	1.34E+00	1.35E+00	9.47E+01	8.47E+01	1.81E+03	6.68E+02	4.80E+04 #	2.00E-02
Anthracene	4.69E-01	4.69E-01	1.02E+01 *	1.02E+01 *	1.02E+01 *	4.34E-02 #	4.34E-02 #	4.34E-02 #
Benzo(a)anthracene	2.99E-04	2.99E-04	9.51E+00	3.37E+01 *	3.37E+01 *	9.40E-03 #	9.40E-03 #	1.17E-03
Benzo(a)pyrene	2.99E-05	2.99E-05	9.52E-01	1.57E+01 *	1.57E+01 *	1.62E-03 #	1.62E-03 #	2.00E-04
Benzo(b)fluoranthene	2.99E-04	2.99E-04	9.50E+00	1.85E+01 *	1.85E+01 *	1.50E-03 #	1.50E-03 #	1.17E-03
Benzo(g,h,i)perylene	4.69E-02	4.69E-02	1.11E+01 *	1.11E+01 *	1.11E+01 *	7.00E-04 #	7.00E-04 #	7.00E-04 #
Benzo(k)fluoranthene	2.99E-04	2.99E-04	9.52E+00	9.84E+00 *	9.84E+00 *	8.00E-04 #	8.00E-04 #	8.00E-04 #
Chrysene	2.99E-02	2.99E-02	6.37E+00 *	6.37E+00 *	6.37E+00 *	1.60E-03 #	1.60E-03 #	1.60E-03 #
Fluoranthene	6.25E-02	6.26E-02	1.01E+02 *	1.01E+02 *	1.01E+02 *	2.06E-01 #	2.06E-01 #	2.06E-01 #
Fluorene	6.25E-02	6.26E-02	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.98E+00 #	1.98E+00 #	1.46E+00
Naphthalene	1.41E-03	1.41E-03	1.49E+02	1.18E+01	2.52E+02	1.33E+00	3.10E+01 #	2.00E-02
Phenanthrene	4.69E-02	4.69E-02	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.00E+00 #	1.00E+00 #	1.00E+00 #
Pyrene	4.69E-02	4.69E-02	9.18E+01 *	9.18E+01 *	9.18E+01 *	1.35E-01 #	1.35E-01 #	1.35E-01 #
METALS								
Arsenic	1.21E-05	1.21E-05	6.05E+00	NA	NA	NA	NA	5.00E-02
Barium	2.24E-04	2.24E-04	5.44E+03	NA	NA	NA	NA	2.00E+00
Cadmium	2.89E-05	2.90E-05	3.89E+01	NA	NA	NA	NA	5.00E-03
Chromium VI	3.13E-06	3.13E-06	2.33E+02	NA	NA	NA	NA	1.00E-01
Lead	NA	NA	4.00E+02 +	NA	NA	NA	NA	1.50E-02
Zinc	1.56E-02	1.56E-02	2.33E+04	NA	NA	NA	NA	2.00E+00

--: Not a chemical of concern

NA: Not Applicable

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#: Calculated RBSLs exceeded pure component water solubility and hence water solubilities are listed as RBSLs.

Soil concentrations are presented on a dry weight basis.

+ U.S. EPA, 1996 Soil Screening Guidance, page A-5

TABLE 7-2(b)

RISK-BASED SCREENING LEVELS FOR A RESIDENT ADULT

CHEMICALS OF CONCERN	**AIR INHALATION**		**SURFICIAL SOIL**	**SUBSURFACE SOIL**		**GROUNDWATER**		
	Indoor [mg/m^3-air]	Outdoor [mg/m^3-air]	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/kg]	Outdoor Inhalation of Vapor Emissions [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/L]	Outdoor Inhalation of Vapor Emissions [mg/L]	Ingestion of Water [mg/L]
ORGANICS								
Benzene	4.15E-03	4.21E-03	2.27E+01	1.18E-01	2.56E+00	3.76E-01	2.28E+02	5.00E-03
Toluene	5.29E-01	5.35E-01	7.82E+02 *	2.72E+01	5.88E+02	4.29E+01	5.26E+02 #	1.00E+00
Ethylbenzene	1.39E+00	1.41E+00	3.60E+02 *	1.01E+02	3.60E+02 *	1.13E+02	1.69E+02 #	7.00E-01
Xylenes (mixed)	4.13E-01	4.19E-01	4.51E+02 *	4.06E+01	4.51E+02 *	3.61E+01	1.75E+02 #	1.00E+01
Methyl-tert-butyl-ether (MTBE)	4.13E+00	4.19E+00	2.70E+02	2.61E+02	5.63E+03	2.05E+03	4.80E+04 #	2.00E-02
Anthracene	1.44E+00	1.46E+00	1.02E+01 *	1.02E+01 *	1.02E+01 *	4.34E-02 #	4.34E-02 #	4.34E-02 #
Benzo(a)anthracene	1.84E-04	1.86E-04	1.04E+01	3.37E+01 *	3.37E+01 *	9.40E-03 #	9.40E-03 #	1.17E-03
Benzo(a)pyrene	1.84E-05	1.86E-05	1.04E+00	1.57E+01 *	1.57E+01 *	1.62E-03 #	1.62E-03 #	2.00E-04
Benzo(b)fluoranthene	1.84E-04	1.86E-04	1.04E+01	1.85E+01 *	1.85E+01 *	1.50E-03 #	1.50E-03 #	1.17E-03
Benzo(g,h,i)perylene	1.44E-01	1.46E-01	1.11E+01 *	1.11E+01 *	1.11E+01 *	7.00E-04 #	7.00E-04 #	7.00E-04 #
Benzo(k)fluoranthene	1.84E-04	1.86E-04	9.84E+00 *	9.84E+00 *	9.84E+00 *	8.00E-04 #	8.00E-04 #	8.00E-04 #
Chrysene	1.84E-02	1.86E-02	6.37E+00 *	6.37E+00 *	6.37E+00 *	1.60E-03 #	1.60E-03 #	1.60E-03 #
Fluoranthene	1.92E-01	1.95E-01	1.01E+02 *	1.01E+02 *	1.01E+02 *	2.06E-01 #	2.06E-01 #	2.06E-01 #
Fluorene	1.92E-01	1.95E-01	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.98E+00 #	1.98E+00 #	1.46E+00
Naphthalene	4.32E-03	4.38E-03	3.71E+02 *	3.63E+01	3.71E+02 *	4.07E+00	3.10E+01 #	2.00E-02
Phenanthrene	1.44E-01	1.46E-01	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.00E+00 #	1.00E+00 #	1.00E+00 #
Pyrene	1.44E-01	1.46E-01	9.18E+01 *	9.18E+01 *	9.18E+01 *	1.35E-01 #	1.35E-01 #	1.35E-01 #
METALS								
Arsenic	7.45E-06	7.55E-06	1.11E+01	NA	NA	NA	NA	5.00E-02
Barium	6.87E-04	6.96E-04	4.98E+04	NA	NA	NA	NA	2.00E+00
Cadmium	1.78E-05	1.80E-05	3.56E+02	NA	NA	NA	NA	5.00E-03
Chromium VI	2.67E-06	2.70E-06	2.14E+03	NA	NA	NA	NA	1.00E-01
Lead	NA	NA	4.0E+02 +	NA	NA	NA	NA	1.50E-02
Zinc	4.81E-02	4.87E-02	2.14E+05	NA	NA	NA	NA	2.00E+00

--: Not a chemical of concern

NA: Not Applicable

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#: Calculated RBSLs exceeded pure component water solubility and hence water solubilities are listed as RBSLs.

Soil concentrations are presented on a dry weight basis.

+ U.S. EPA, 1996 Soil Screening Guidance, page A-5

TABLE 7-2(c)

RISK-BASED SCREENING LEVELS FOR A COMMERCIAL WORKER

CHEMICALS OF CONCERN	AIR INHALATION		SURFICIAL SOIL	SUBSURFACE SOIL		GROUNDWATER		
	Indoor [mg/m^3-air]	Outdoor [mg/m^3-air]	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/kg]	Outdoor Inhalation of Vapor Emissions [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/L]	Outdoor Inhalation of Vapor Emissions [mg/L]	Ingestion of Water [mg/L]
ORGANICS								
Benzene	7.07E-03	7.07E-03	3.95E+01	4.97E-01	4.30E+00	1.58E+00	3.82E+02	5.00E-03
Toluene	7.49E-01	7.49E-01	7.82E+02 *	9.51E+01	7.82E+02 *	1.50E+02	5.26E+02 #	1.00E+00
Ethylbenzene	1.98E+00	1.98E+00	3.60E+02 *	3.51E+02	3.60E+02 *	1.69E+02 #	1.69E+02 #	7.00E-01
Xylenes (mixed)	5.86E-01	5.86E-01	4.51E+02 *	1.42E+02	4.51E+02 *	1.26E+02	1.75E+02 #	1.00E+01
Methyl-tert-butyl-ether (MTBE)	5.86E+00	5.86E+00	3.93E+02	9.10E+02	7.88E+03	7.18E+03	4.80E+04 #	2.00E-02
Anthracene	2.04E+00	2.04E+00	1.02E+01 *	1.02E+01 *	1.02E+01 *	4.34E-02 #	4.34E-02 #	4.34E-02 #
Benzo(a)anthracene	3.13E-04	3.13E-04	2.24E+01	3.37E+01 *	3.37E+01 *	9.40E-03 #	9.40E-03 #	1.17E-03
Benzo(a)pyrene	3.13E-05	3.13E-05	2.24E+00	1.57E+01 *	1.57E+01 *	1.62E-03 #	1.62E-03 #	2.00E-04
Benzo(b)fluoranthene	3.13E-04	3.13E-04	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.50E-03 #	1.50E-03 #	1.17E-03
Benzo(g,h,i)perylene	2.04E-01	2.04E-01	1.11E+01 *	1.11E+01 *	1.11E+01 *	7.00E-04 #	7.00E-04 #	7.00E-04 #
Benzo(k)fluoranthene	3.13E-04	3.13E-04	9.84E+00 *	9.84E+00 *	9.84E+00 *	8.00E-04 #	8.00E-04 #	8.00E-04 #
Chrysene	3.13E-02	3.13E-02	6.37E+00 *	6.37E+00 *	6.37E+00 *	1.60E-03 #	1.60E-03 #	1.60E-03 #
Fluoranthene	2.73E-01	2.73E-01	1.01E+02 *	1.01E+02 *	1.01E+02 *	2.06E-01 #	2.06E-01 #	2.06E-01 #
Fluorene	2.73E-01	2.73E-01	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.98E+00 #	1.98E+00 #	1.46E+00
Naphthalene	6.13E-03	6.13E-03	3.71E+02 *	1.27E+02	3.71E+02 *	1.42E+01	3.10E+01 #	2.00E-02
Phenanthrene	2.04E-01	2.04E-01	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.00E+00 #	1.00E+00 #	1.00E+00 #
Pyrene	2.04E-01	2.04E-01	9.18E+01 *	9.18E+01 *	9.18E+01 *	1.35E-01 #	1.35E-01 #	1.35E-01 #
METALS								
Arsenic	1.27E-05	1.27E-05	3.63E+01	NA	NA	NA	NA	5.00E-02
Barium	9.74E-04	9.74E-04	1.36E+05	NA	NA	NA	NA	2.00E+00
Cadmium	3.03E-05	3.03E-05	9.73E+02	NA	NA	NA	NA	5.00E-03
Chromium VI	4.54E-06	4.54E-06	5.83E+03	NA	NA	NA	NA	1.00E-01
Lead	NA	NA	4.0E+02 +	NA	NA	NA	NA	1.50E-02
Zinc	6.81E-02	6.81E-02	5.84E+05	NA	NA	NA	NA	2.00E+00

--: Not a chemical of concern

NA: Not Applicable

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#: Calculated RBSLs exceeded pure component water solubility and hence water solubilities are listed as RBSLs.

Soil concentrations are presented on a dry weight basis.

+ U.S. EPA, 1996 Soil Screening Guidance, page A-5

TABLE 7-2(d)

RISK-BASED SCREENING LEVELS FOR A CONSTRUCTION WORKER

CHEMICALS OF CONCERN	AIR INHALATION		SURFICIAL SOIL	SUBSURFACE SOIL		GROUNDWATER	
	Indoor [mg/m^3-air]	Outdoor [mg/m^3-air]	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/kg]	Outdoor Inhalation of Vapor Emissions [mg/kg]	Indoor Inhalation of Vapor Emissions [mg/L]	Outdoor Inhalation of Vapor Emissions [mg/L]
ORGANICS							
Benzene	1.16E-02	1.16E-02	1.99E+02	8.14E-01	7.05E+00	2.59E+00	6.27E+02
Toluene	7.49E-01	7.49E-01	7.82E+02 *	9.51E+01	7.82E+02 *	1.50E+02	5.26E+02 #
Ethylbenzene	1.98E+00	1.98E+00	3.60E+02 *	3.51E+02	3.60E+02 *	1.69E+02 #	1.69E+02 #
Xylenes (mixed)	5.86E-01	5.86E-01	4.51E+02 *	1.42E+02	4.51E+02 *	1.26E+02	1.75E+02 #
Methyl-tert-butyl-ether (MTBE)	5.86E+00	5.86E+00	3.77E+02	9.10E+02	7.88E+03	7.18E+03	4.80E+04 #
Anthracene	2.04E+00	2.04E+00	1.02E+01 *	1.02E+01 *	1.02E+01 *	4.34E-02 #	4.34E-02 #
Benzo(a)anthracene	7.82E-03	7.82E-03	3.37E+01 *	3.37E+01 *	3.37E+01 *	9.40E-03 #	9.40E-03 #
Benzo(a)pyrene	7.82E-04	7.82E-04	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.62E-03 #	1.62E-03 #
Benzo(b)fluoranthene	7.82E-03	7.82E-03	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.50E-03 #	1.50E-03 #
Benzo(g,h,i)perylene	2.04E-01	2.04E-01	1.11E+01 *	1.11E+01 *	1.11E+01 *	7.00E-04 #	7.00E-04 #
Benzo(k)fluoranthene	7.82E-03	7.82E-03	9.84E+00 *	9.84E+00 *	9.84E+00 *	8.00E-04 #	8.00E-04 #
Chrysene	7.82E-01	7.82E-01	6.37E+00 *	6.37E+00 *	6.37E+00 *	1.60E-03 #	1.60E-03 #
Fluoranthene	2.73E-01	2.73E-01	1.01E+02 *	1.01E+02 *	1.01E+02 *	2.06E-01 #	2.06E-01 #
Fluorene	2.73E-01	2.73E-01	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.98E+00 #	1.98E+00 #
Naphthalene	6.13E-03	6.13E-03	2.89E+02	1.27E+02	3.71E+02 *	1.42E+01	3.10E+01 #
Phenanthrene	2.04E-01	2.04E-01	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.00E+00 #	1.00E+00 #
Pyrene	2.04E-01	2.04E-01	9.18E+01 *	9.18E+01 *	9.18E+01 *	1.35E-01 #	1.35E-01 #
METALS							
Arsenic	3.17E-04	3.17E-04	2.99E+02	NA	NA	NA	NA
Barium	9.74E-04	9.74E-04	3.99E+03	NA	NA	NA	NA
Cadmium	7.57E-04	7.57E-04	4.99E+02	NA	NA	NA	NA
Chromium VI	1.36E-05	1.36E-05	5.81E+01	NA	NA	NA	NA
Lead	NA	NA	4.00E+02 +	NA	NA	NA	NA
Zinc	6.81E-02	6.81E-02	1.49E+05	NA	NA	NA	NA

--: Not a chemical of concern

NA: Not Applicable

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#: Calculated RBSLs exceeded pure component water solubility and hence water solubilities are listed as RBSLs.

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+ U.S. EPA, 1996 Soil Screening Guidance, page A-5

TABLE 7-3(a)

RBSLs FOR SURFACE WATER PROTECTION

Chemical of Concern	Target Levels [mg/L]	Explanation
ORGANICS		
Benzene	0.011	1
Toluene	0.175	2
Ethylbenzene	0.453	2
Xylenes (Total)	NA	3
Methyl-tert-Butyl-Ether	NA	3
Anthracene	7.241	1
Benzo(a)anthracene	0.00002	1
Benzo(a)pyrene	0.00002	1
Benzo(b)fluoranthene	0.00002	1
Benzo(g,h,i)perylene	NA	3
Benzo(k)fluoranthene	0.00002	1
Chrysene	0.00002	1
Fluoranthene	0.0398	2
Fluorene	0.966	1
Naphthalene	0.62	2
Phenanthrene	NA	3
Pyrene	0.724	1
METALS		
Arsenic, Total recoverable	0.33	4
Barium	NA	3
Cadmium, Total recoverable	0.0027	4
Chromium (VI)	0.011	4
Lead, Total recoverable	0.0028	2
Zinc, Total recoverable	0.18	4

1. The ADEM Water Quality Criteria for consumption of fish/water.
2. The EPA suggested Water Quality Criteria values for freshwater chronic.
3. Not available. Contact the ADEM for further guidance.
4. The ADEM Water Quality Criteria based on the bioavailable portion of metals (ADEM Water Division – Industrial Section).

TABLE 7-3(b)

TIER 1 RBSLs FOR SOIL CONCENTRATIONS (FOR LEACHING TO GROUNDWATER) FOR DIFFERENT DISTANCES TO THE STREAM

CHEMICALS OF CONCERN	Water Standard† [mg/l]	Leaching Factor [(mg/l)/(mg/kg)]	TIER 1 RBSLs FOR SOIL CONCENTRATION AT THE SOURCE FOR DIFFERENT DISTANCES TO THE EXPOSURE POINT											
			0 ft. [mg/kg]	50 ft. [mg/kg]	100 ft. [mg/kg]	150 ft. [mg/kg]	200 ft. [mg/kg]	250 ft. [mg/kg]	300 ft. [mg/kg]	350 ft. [mg/kg]	400 ft. [mg/kg]	450 ft. [mg/kg]	500 ft. [mg/kg]	1000 ft. [mg/kg]
ORGANICS														
Benzene	1.10E-02	5.92E-01	1.86E-02	2.43E-02	5.77E-02	1.16E-01	1.97E-01	3.02E-01	4.31E-01	5.82E-01	7.57E-01	9.56E-01	1.18E+00	4.68E+00
Toluene	1.75E-01	2.78E-01	6.29E-01	8.23E-01	1.95E+00	3.92E+00	6.68E+00	1.02E+01	1.46E+01	1.97E+01	2.56E+01	3.24E+01	3.99E+01	1.58E+02
Ethylbenzene	4.53E-01	1.94E-01	2.34E+00	3.06E+00	7.26E+00	1.46E+01	2.48E+01	3.80E+01	5.42E+01	7.32E+01	9.52E+01	1.20E+02	1.48E+02	3.60E+02 *
Xylenes (mixed)	NA	1.60E-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methyl-tert-butyl-ether	NA	2.32E+00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Anthracene	7.24E+00	1.76E-03	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *
Benzo(a)anthracene	2.00E-05	1.15E-04	1.73E-01	2.27E-01	5.38E-01	1.08E+00	1.84E+00	2.82E+00	4.02E+00	5.43E+00	7.06E+00	8.91E+00	1.10E+01	3.37E+01 *
Benzo(a)pyrene	2.00E-05	4.26E-05	4.69E-01	6.13E-01	1.46E+00	2.92E+00	4.98E+00	7.63E+00	1.09E+01	1.47E+01	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *
Benzo(b)fluoranthene	2.00E-05	3.36E-05	5.95E-01	7.79E-01	1.85E+00	3.71E+00	6.32E+00	9.69E+00	1.38E+01	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *
Benzo(g,h,i)perylene	NA	2.61E-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	2.00E-05	3.36E-05	5.95E-01	7.79E-01	1.85E+00	3.71E+00	6.32E+00	9.69E+00	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *
Chrysene	2.00E-05	1.04E-04	1.93E-01	2.52E-01	5.98E-01	1.20E+00	2.05E+00	3.13E+00	4.46E+00	6.04E+00	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *
Fluoranthene	3.98E-02	8.41E-04	4.73E+01	6.19E+01	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *
Fluorene	9.66E-01	5.35E-03	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *
Naphthalene	6.20E-01	3.45E-02	1.79E+01	2.35E+01	5.57E+01	1.12E+02	1.91E+02	2.92E+02	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *
Phenanthrene	NA	2.93E-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pyrene	7.24E-01	6.07E-04	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *
METALS														
Arsenic	3.30E-01	6.44E-03	5.12E+01	6.70E+01	1.59E+02	3.19E+02	5.44E+02	8.34E+02	1.19E+03	1.61E+03	2.09E+03	2.64E+03	3.25E+03	1.29E+04
Barium	NA	1.01E-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	2.70E-03	5.50E-03	4.91E-01	6.41E-01	1.52E+00	3.05E+00	5.21E+00	7.98E+00	1.14E+01	1.54E+01	2.00E+01	2.52E+01	3.11E+01	1.23E+02
Chromium VI	1.10E-02	2.17E-02	5.07E-01	6.64E-01	1.58E+00	3.16E+00	5.39E+00	8.25E+00	1.18E+01	1.59E+01	2.07E+01	2.61E+01	3.21E+01	1.28E+02
Lead	2.80E-03	3.38E-03	8.27E-01	1.08E+00	2.57E+00	5.15E+00	8.78E+00	1.35E+01	1.92E+01	2.59E+01	3.37E+01	4.25E+01	5.24E+01	2.08E+02
Zinc	1.80E-01	6.66E-03	2.70E+01	3.54E+01	8.40E+01	1.68E+02	2.87E+02	4.40E+02	6.27E+02	8.47E+02	1.10E+03	1.39E+03	1.71E+03	6.81E+03

Note

* Calculated Tier 1 RBSLs for soil concentrations exceeded saturated soil concentration and hence saturated soil concentrations are listed Tier 1 RBSLs for soil concentrations protective of groundwater.

† Tier 1 stream RBSLs
Soil concentrations are presented on a dry weight basis.

TABLE 7-4

TIER 1 RBSLs FOR SOIL CONCENTRATIONS (FOR LEACHING TO GROUNDWATER) FOR DIFFERENT DISTANCES TO THE GROUNDWATER EXPOSURE POINT

CHEMICALS OF CONCERN	Water Standard† [mg/l]	Leaching Factor [(mg/l)/(mg/kg)]	TIER 1 RBSLs FOR SOIL CONCENTRATION AT THE SOURCE FOR DIFFERENT DISTANCES TO THE EXPOSURE POINT											
			0 ft. [mg/kg]	50 ft. [mg/kg]	100 ft. [mg/kg]	150 ft. [mg/kg]	200 ft. [mg/kg]	250 ft. [mg/kg]	300 ft. [mg/kg]	350 ft. [mg/kg]	400 ft. [mg/kg]	450 ft. [mg/kg]	500 ft. [mg/kg]	1000 ft. [mg/kg]
ORGANICS														
Benzene	5.00E-03	5.92E-01	8.45E-03	1.10E-02	2.62E-02	5.26E-02	8.97E-02	1.37E-01	1.96E-01	2.65E-01	3.44E-01	4.34E-01	5.35E-01	2.13E+00
Toluene	1.00E+00	2.78E-01	3.60E+00	4.70E+00	1.12E+01	2.24E+01	3.82E+01	5.85E+01	8.33E+01	1.13E+02	1.47E+02	1.85E+02	2.28E+02	7.82E+02 *
Ethylbenzene	7.00E-01	1.94E-01	3.61E+00	4.72E+00	1.12E+01	2.25E+01	3.83E+01	5.87E+01	8.37E+01	1.13E+02	1.47E+02	1.86E+02	2.29E+02	3.60E+02 *
Xylenes (mixed)	1.00E+01	1.60E-01	6.24E+01	8.15E+01	1.94E+02	3.88E+02	4.51E+02 *	4.51E+02 *	4.51E+02 *	4.51E+02 *	4.51E+02 *	4.51E+02 *	4.51E+02 *	4.51E+02 *
Methyl-tert-butyl-ether	2.00E-02	2.32E+00	8.62E-03	1.13E-02	2.68E-02	5.37E-02	9.15E-02	1.40E-01	2.00E-01	2.70E-01	3.51E-01	4.43E-01	5.46E-01	2.17E+00
Anthracene	4.34E-02	1.76E-03	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *
Benzo(a)anthracene	1.17E-03	1.15E-04	1.01E+01	1.32E+01	3.14E+01	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *	3.37E+01 *
Benzo(a)pyrene	2.00E-04	4.26E-05	4.69E+00	6.13E+00	1.46E+01	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *
Benzo(b)fluoranthene	1.17E-03	3.36E-05	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *
Benzo(g,h,i)perylene	7.00E-04	2.61E-05	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *	1.11E+01 *
Benzo(k)fluoranthene	8.00E-04	3.36E-05	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *
Chrysene	1.60E-03	1.04E-04	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *
Fluoranthene	2.06E-01	8.41E-04	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *
Fluorene	1.46E+00	5.35E-03	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *
Naphthalene	2.00E-02	3.45E-02	5.79E-01	7.57E-01	1.80E+00	3.60E+00	6.15E+00	9.42E+00	1.34E+01	1.81E+01	2.36E+01	2.98E+01	3.67E+01	1.46E+02
Phenanthrene	1.00E+00	2.93E-03	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *	1.41E+02 *
Pyrene	1.35E-01	6.07E-04	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *
METALS														
Arsenic	5.00E-02	6.44E-03	7.76E+00	1.02E+01	2.41E+01	4.84E+01	8.24E+01	1.26E+02	1.80E+02	2.43E+02	3.16E+02	3.99E+02	4.92E+02	1.95E+03
Barium	2.00E+00	1.01E-02	1.99E+02	2.60E+02	6.17E+02	1.24E+03	2.11E+03	3.23E+03	4.61E+03	6.23E+03	8.10E+03	1.02E+04	1.26E+04	5.00E+04
Cadmium	5.00E-03	5.50E-03	9.08E-01	1.19E+00	2.82E+00	5.66E+00	9.64E+00	1.48E+01	2.10E+01	2.85E+01	3.70E+01	4.67E+01	5.76E+01	2.29E+02
Chromium VI	1.00E-01	2.17E-02	4.61E+00	6.03E+00	1.43E+01	2.87E+01	4.90E+01	7.50E+01	1.07E+02	1.45E+02	1.88E+02	2.37E+02	2.92E+02	1.16E+03
Lead	1.50E-02	3.38E-03	4.43E+00	5.80E+00	1.38E+01	2.76E+01	4.70E+01	7.21E+01	1.03E+02	1.39E+02	1.81E+02	2.28E+02	2.81E+02	1.12E+03
Zinc	2.00E+00	6.66E-03	3.00E+02	3.93E+02	9.33E+02	1.87E+03	3.19E+03	4.89E+03	6.96E+03	9.41E+03	1.22E+04	1.55E+04	1.90E+04	7.56E+04

Note

* Calculated Tier 1 RBSLs for soil concentrations exceeded saturated soil concentration and hence saturated soil concentrations are listed Tier 1 RBSLs for soil concentrations protective of groundwater.

† MCL, Health Advisory, or Ingestion of water Tier 1 RBSL for a resident adult.

Soil concentrations are presented on a dry weight basis.

TABLE 7-5

TIER 1 DILUTION ATTENUATION FACTORS

SOURCE DIMENSIONS	UNITS	VALUE
Width of Groundwater Source Perpendicular to the Flow Direction, Y	[cm]	1500.0
Groundwater Mixing Zone Thickness, δ_{gw}	[cm]	200.0

Distance from Source [feet]	Dispersivity			Dilution Attenuation Factor With No Biodegradation [--]
	Longitudinal [feet]	Transverse [feet]	Vertical [feet]	
0	0	0.00	0.00	1.00
100	10	3.33	0.50	3.11
150	15	5.00	0.75	6.23
200	20	6.67	1.00	10.62
250	25	8.33	1.25	16.27
300	30	10.00	1.50	23.17
350	35	11.67	1.75	31.33
400	40	13.33	2.00	40.75
450	45	15.00	2.25	51.43
500	50	16.67	2.50	63.36
1000	100	33.33	5.00	251.76

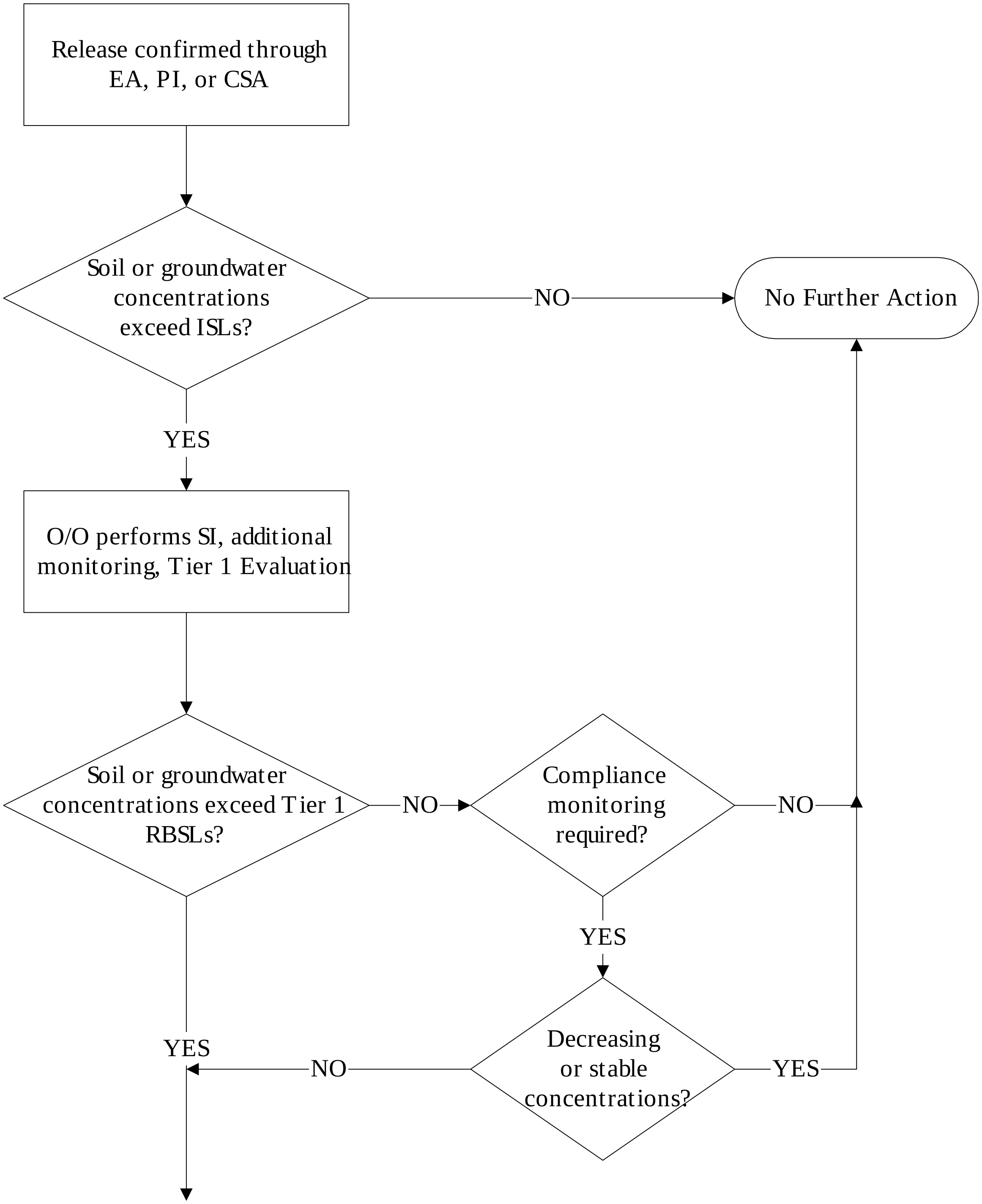


FIGURE 3-1 GENERALIZED ARBCA PROCESS (Page 1 of 2)

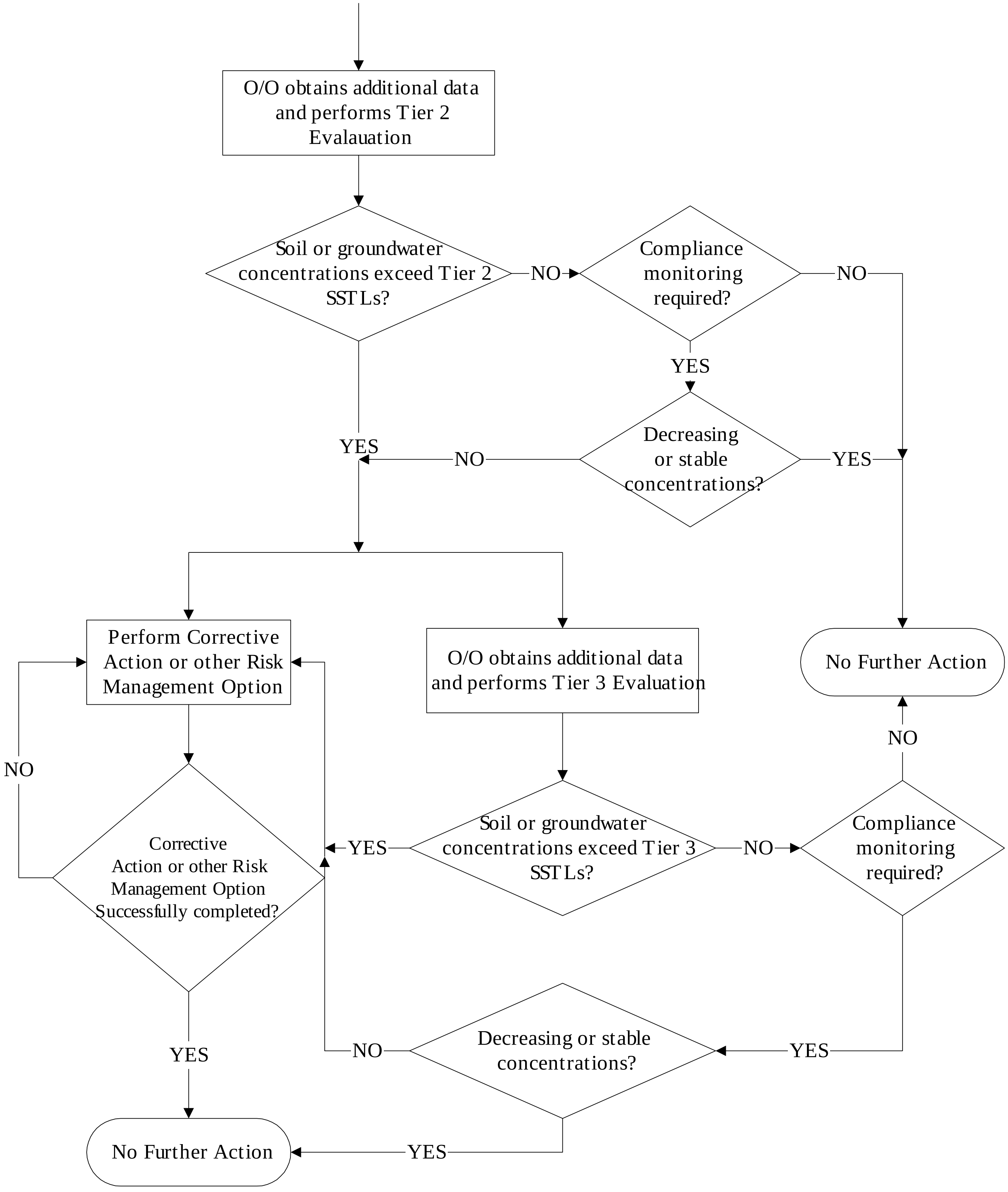
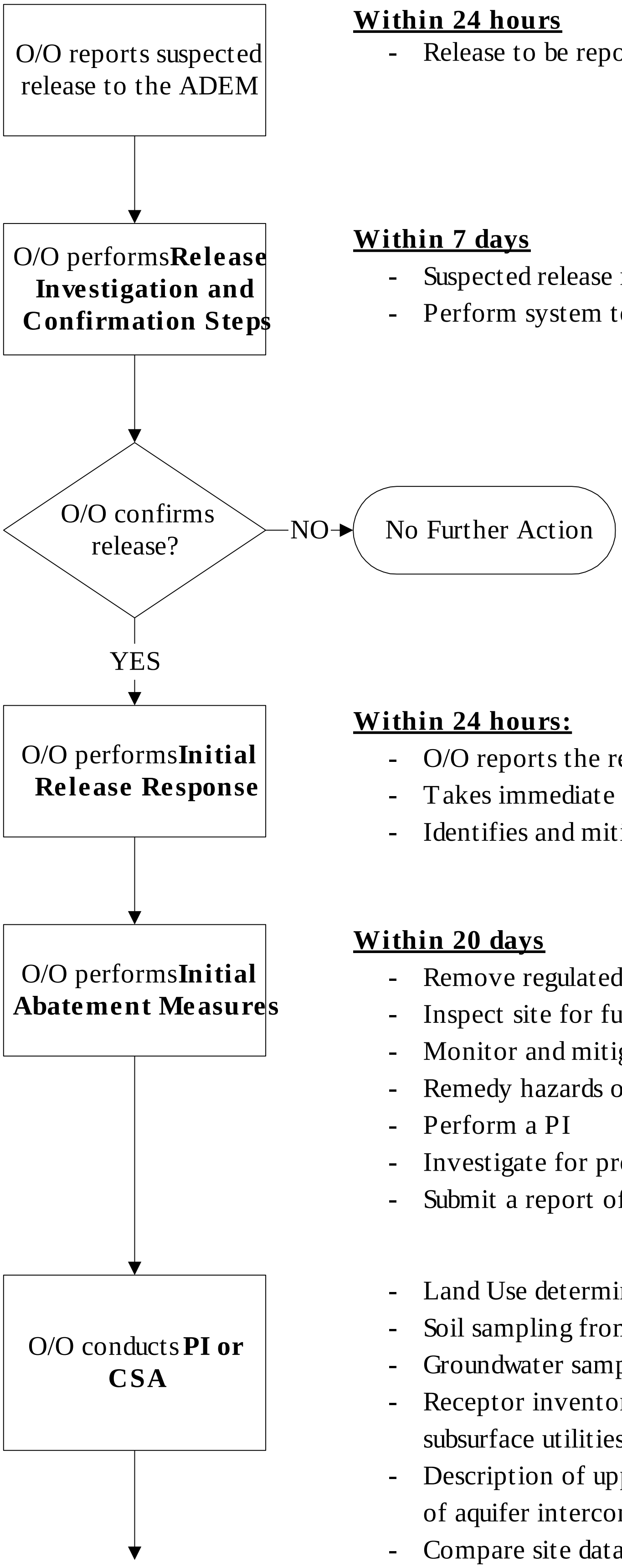


FIGURE 3-1 GENERALIZED ARBCA PROCESS (Page 2 of 2)



Within 24 hours

- Release to be reported

Within 7 days

- Suspected release must be confirmed
- Perform system tests and/or PI

Within 24 hours:

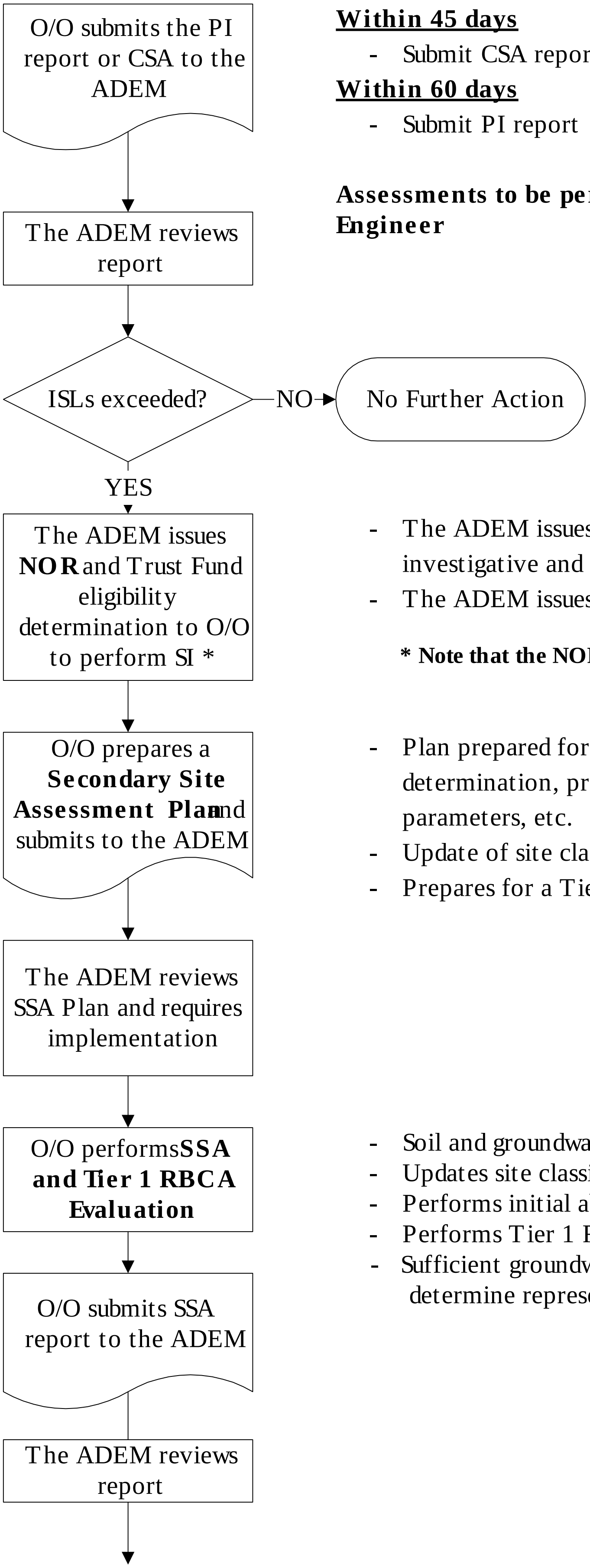
- O/O reports the release to the ADEM
- Takes immediate action to prevent further release
- Identifies and mitigates fire, explosion, and vapor hazards

Within 20 days

- Remove regulated substance from tank system
- Inspect site for further migration of substances
- Monitor and mitigate fire and safety hazards
- Remedy hazards of excavated or exposed soils
- Perform a PI
- Investigate for presence of free product
- Submit a report of findings to the ADEM

- Land Use determination
- Soil sampling from area affected by release
- Groundwater sampling from area affected by release
- Receptor inventory: wells, streams, use of land, subsurface utilities, or other conduits
- Description of uppermost aquifer, initial evaluation of aquifer interconnection
- Compare site data with ISLs
- Classificiation of site is determined

FIGURE 3-2 DETAILED ARBCA PROCESS (Page 1 of 5)



<u>Within 45 days</u>

- Submit CSA report

<u>Within 60 days</u>

- Submit PI report

Assessments to be performed by Geologist or Registered Professi Engineer

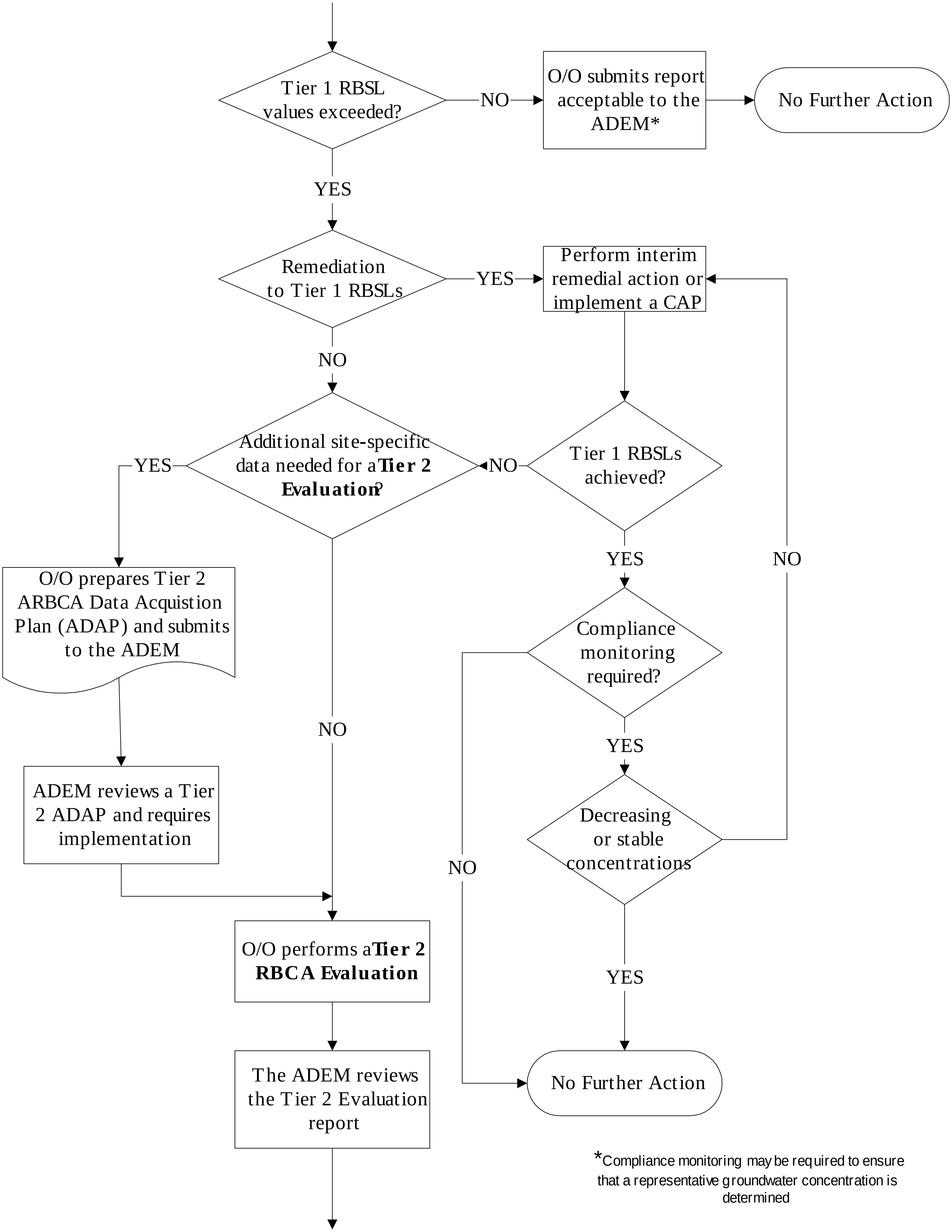
- The ADEM issues Notification of Requirement to conduct investigative and corrective actions to O/O
- The ADEM issues letter of eligibility or ineligibility to O/O

*** Note that the NOR may require a Preliminary Investigation or a Secondary Investigation**

- Plan prepared for soil and groundwater data collection, land use determination, preparation of a SCEM, receptor inventory, soil parameters, etc.
- Update of site classification
- Prepares for a Tier 1 RBCA Evaluation

- Soil and groundwater data collection
- Updates site classification
- Performs initial abatement measures as needed
- Performs Tier 1 RBCA Evaluation
- Sufficient groundwater monitoirng data must be obtained to determine representative groundwater concentrations

FIGURE 3-2 DETAILED ARBCA PROCESS (Page 2 of 5)



*Compliance monitoring may be required to ensure that a representative groundwater concentration is determined

FIGURE 3-2 DETAILED ARBCA PROCESS (Page 3 of 5)

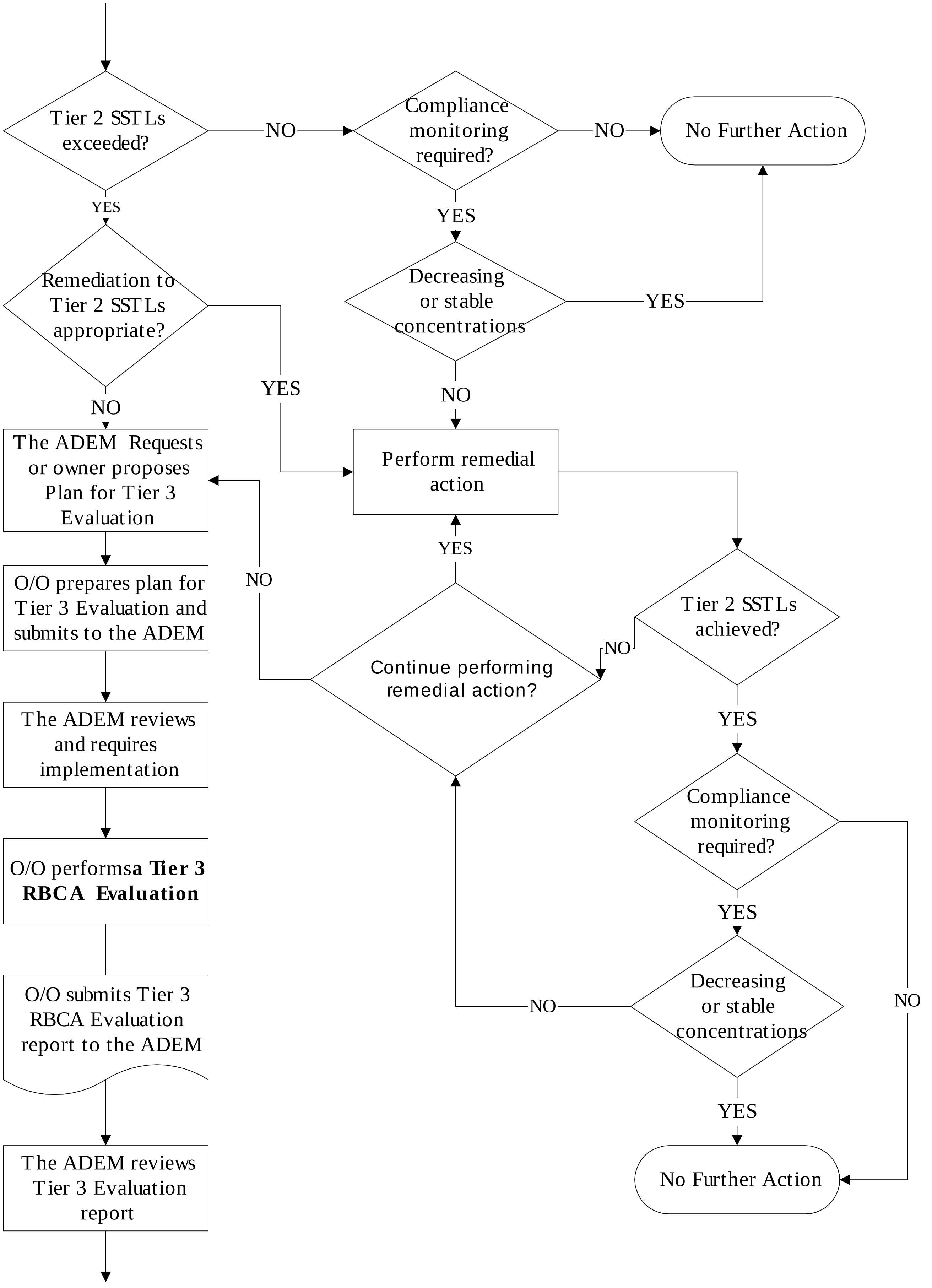


FIGURE 3-2 DETAILED ARBCA PROCESS (Page 4 of 5)

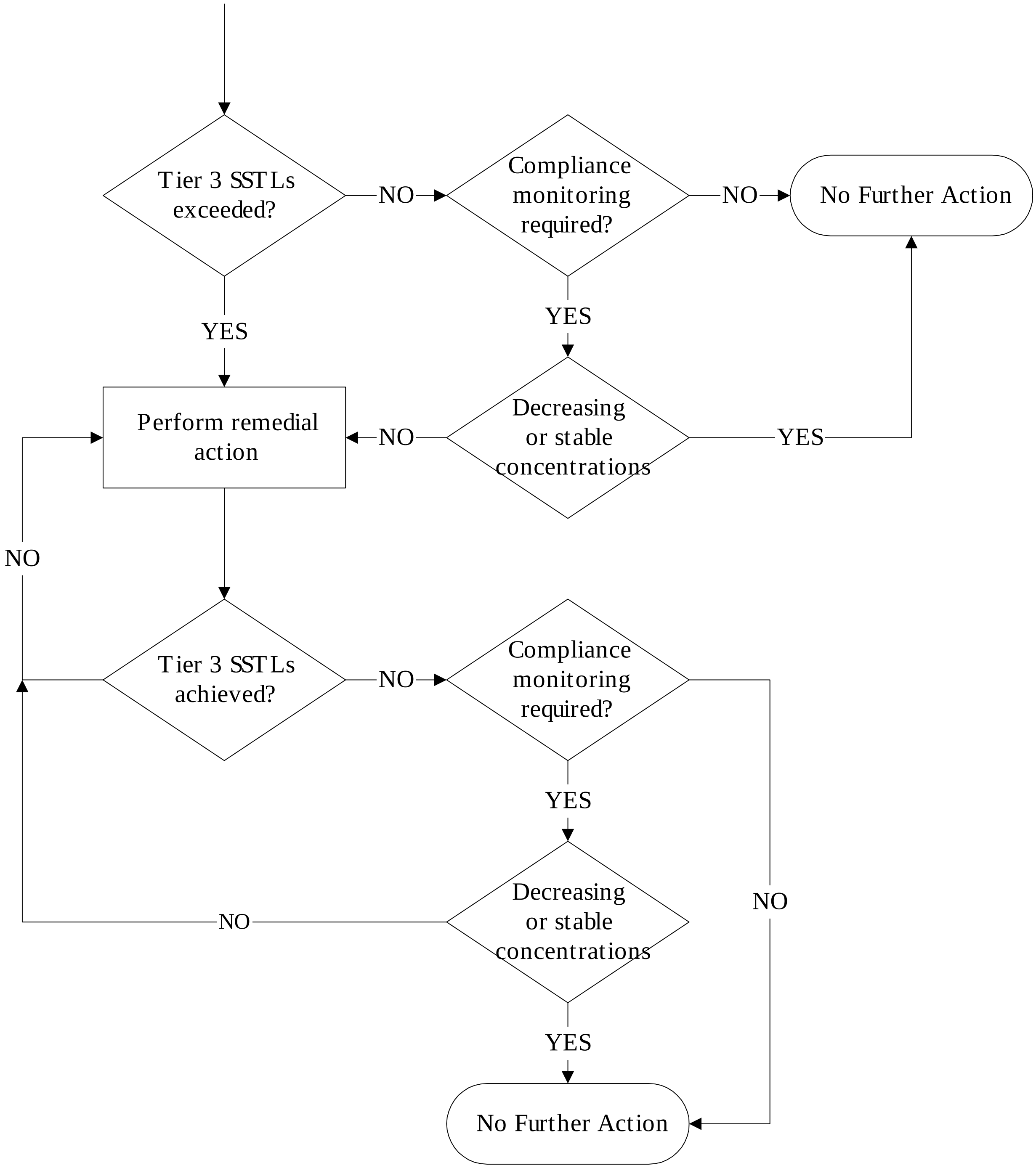
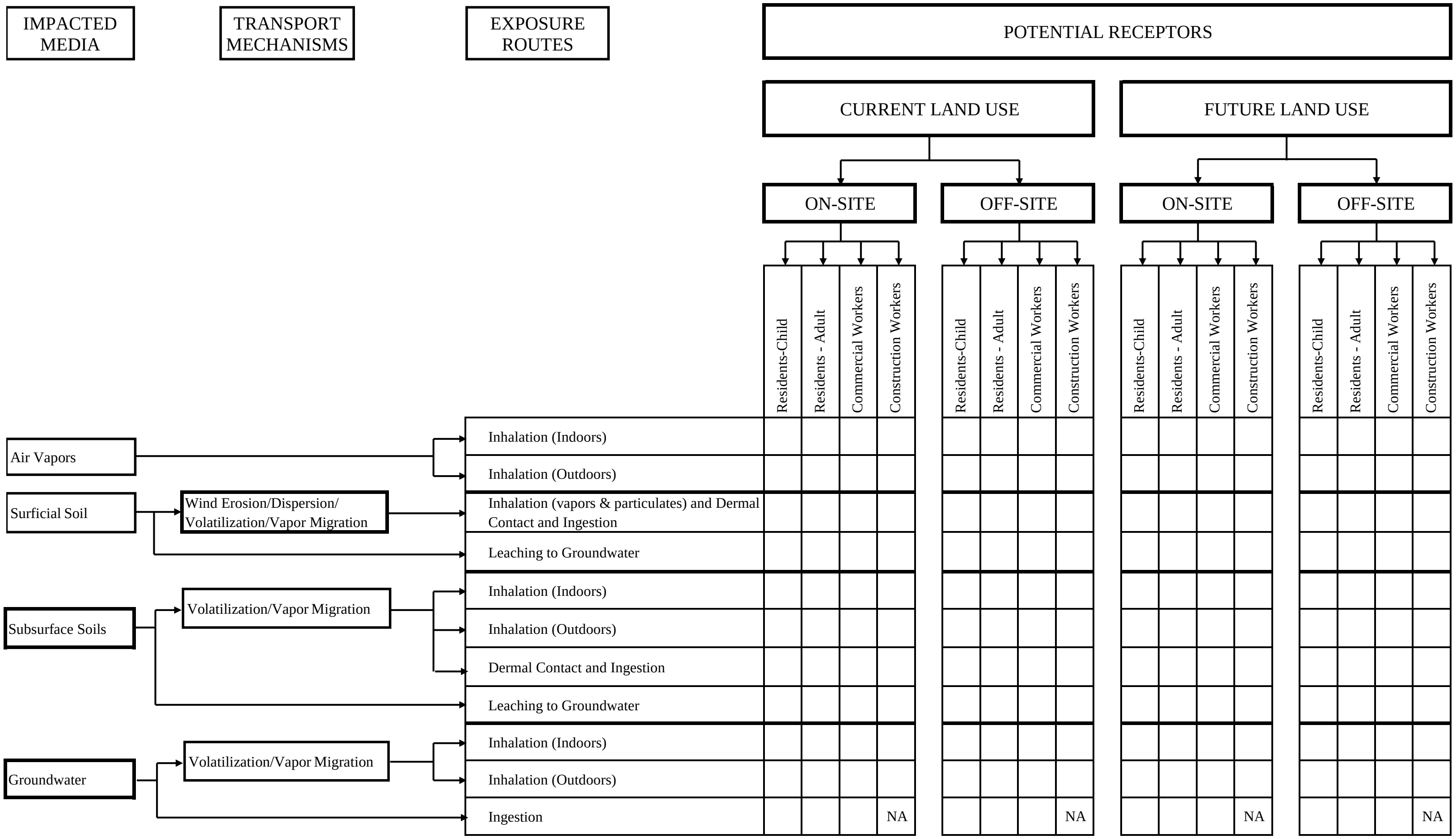


FIGURE 3-2 DETAILED ARBCA PROCESS (Page 5 of 5)



	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

APPENDIX A
LIST OF ACRONYMS USED IN THIS GUIDANCE MANUAL

ACRONYM	DEFINITION
ACAL(s)	Alternate Corrective Action Limit(s)
ADAP	ARBCA Data Acquisition Plan
ADEM	Alabama Department of Environmental Management
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
BTEX	Benzene, Toluene, Ethylbenzene and Xylenes
CALs	Corrective Action Limits
CAP	Corrective Action Plan
COC(s)	Chemicals of Concern
CRF	Concentration Reduction Factor
CSA	Closure Site Assessment
CW	Compliance Well
DAF	Dilution Attenuation Factor
EPA	Environmental Protection Agency
EA	Environmental Assessment
FID	Flame-Ionization Detector
FP	Free Product
GRP	Groundwater Resource Protection
HEAST	Health Effects Assessment Summary Tables
HQ	Hazard Quotient
HI	Hazard Index
IELCR	Individual Excess Lifetime Cancer Risk
IRIS	Integrated Risk Information System
ISL(s)	Initial Screening Levels

ACRONYM	**DEFINITION**
LEL	Lower Explosive Limit
MCL(s)	Maximum Concentration Level(s)
MLE	Most Likely Exposure
MTBE	Methyl Tertiary Butyl Ether
NAF	Natural Attenuation Factor
NFA	No Further Action
NOR	Notification of Requirements to Conduct Investigative and Corrective Action
NAPL	Non-Aqueous Phase Liquids
O/O	Owner or Operator
OSHA	Occupational Safety and Health Administration
PAH(s)	Polynuclear Aromatic Hydrocarbons
PEL(s)	Permissible Exposure Limits
PI	Preliminary Investigation
PID	Photo-Ionization Detector
POC	Point of Compliance
POE	Point of Exposure
PPM	Parts per Million
PSH	Phase Separated Hydrocarbons (Free Product)
RBCA	Risk-Based Corrective Action
RBSL(s)	Risk-Based Screening Level
RfC	Reference Concentration
RfD	Reference Dose
RME	Reasonable Maximum Exposure
RNA	Remediation by Natural Attenuation
SCEM	Site Conceptual Exposure Model
SF	Slope Factor
SI	Secondary Investigation
SSTL(s)	Site-Specific Target Level(s)
TPH	Total Petroleum Hydrocarbons

ACRONYM	**DEFINITION**
TT	Treatment Technique
U. S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
UST	Underground Storage Tanks
WHPA	WellHead 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 i.e., on an average the low flow occurs once every ten years.

APPENDIX B
ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

B.1 BACKGROUND

The site-specific application of the ARBCA process for Tier 1 and Tier 2 (in the backward mode) results in the calculation of target levels for each complete pathway identified in the site conceptual exposure model (SCEM) and each chemical of concern (COC). For site-specific risk management decisions, these target concentrations have to be compared with appropriate representative concentrations. If the ARBCA process is performed in the forward mode (option under Tier 3), 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 complete route of exposure (identified in the SCEM) and each COC. In this case, site-specific risk management decisions are based on a comparison of the estimated risk with the regulatory specified target risk levels. <u>Thus, the outcome of an ARBCA Tier 1, 2 or 3 evaluation critically depends on the representative concentrations.</u>

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 area-weighted average values should be used in the ARBCA evaluations. Arithmetic averages will be acceptable if equally spaced site data 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 of and the methodology that should be used to estimate the representative concentrations within the ARBCA process.

In an effort to reduce evaluation time, the effort necessary to calculate the representative concentrations using area-weighted averaging or the last 1-2 year maximum values may be avoided by initially comparing the historical maximum media-specific concentrations relevant for each pathway with the target levels. If the historical maximum concentrations do not exceed the target levels, it would not be necessary to compute area-weighted concentrations or to determine the recent maximums.

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) that represents the site concentration for a particular exposure pathway. It is used to compare to an Initial Screening Level (ISL), Tier 1 Risk-Based Screening Level (RBSL) or Tier 2/3 Site-Specific Target Level (SSTL) to determine if an unacceptable risk is present for that receptor of concern.

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 exposure domain for a particular pathway and the choice of the appropriate representative concentration (maximum or area-weighted average). Prior to performing the ARBCA evaluation where representative concentrations are compared to RBSLs or SSTLs, the appropriate representative concentration should be selected for the exposure domain for the medium and pathway of concern.

B.2.1 Types of Representative Concentration Values

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

Maximum Values – 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. Limited amounts of site data will need to use historical maximums in many cases. When more site data, such as groundwater monitoring data, is available, the use of a recent maximum value would be appropriate. Where an exceedance may occur, then the evaluator should utilize another type of representative concentration such as one calculated by the area-weighted average method.

The historical maximum is the highest detection ever recorded for each COC. The historical maximum should be used for the initial screening evaluation performed for a site to see if there is an exceedance for a particular pathway. Historical maximum data for groundwater is to be listed on Form 16 of the Tier 1 Forms. 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 onsite and offsite ingestion of groundwater pathway in Tier 1 and Tier 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 onsite scenario and the offsite 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. Both onsite and offsite soil values are determined and should be listed on Forms 13 and 14. 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 obtained during the Secondary Investigation, it will be necessary to look at both these data sets to choose the appropriate representative data. The soil data is entered on Forms 13 and 14. When using a maximum value in the ARBCA evaluation, the maximum values can be obtained from Forms 13 and 14 and used for the comparisons with target levels on Forms 18 and 26.

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 onsite scenario and the offsite scenario. Recent maximum values are to be entered on Form 16 in the “Recent Max” cells.

Area-Weighted Averages – An area-weighted average is a calculated value for COCs, which considers the areal distribution of concentrations. An exposure domain must be determined and those data points within the domain will be utilized in the calculation of the area-weighted averages. Separate area-weighted averages should be determined for both onsite and offsite. Area-weighted averages for COCs may be determined for both soil and groundwater for the inhalation pathways and for the soil source concentration. A discussion on how to determine the area-weighted average concentrations is found in Section B.5.

Where maximum values result in an exceedance when compared to a target level, the area-weighted average for each COC for the proper onsite or offsite property should be calculated. Area-weighted averages are appropriate for the surficial soil representative concentration, the soil and groundwater concentrations for the inhalation pathways, and for the soil source calculation. For calculating the representative groundwater concentrations for the groundwater ingestion pathway, the groundwater resource protection evaluation and the surface water evaluation pathways, a well to well comparison is used and not an area-weighted average procedure.

Area-weighted average concentrations, after calculation, are manually entered onto Forms 18. The Area-Weighted Average checkbox should be marked when the area-weighted average calculation process is used for a representative concentration.

Arithmetic Averages – In determining an arithmetic average, the onsite data is considered separately from the offsite data. This procedure should only be used when limited data is available and when data is obtained at a site from locations that are approximately equal distant apart. The use of this procedure utilizes all data entered onto Forms 13 and 14. The use of arithmetic averages is not commonly used in the ARBCA evaluations.

The arithmetic averages for soil are derived from the data entered onto Form 13 and 14. If the ARBCA evaluator deems that the arithmetic average is an appropriate representative concentration, then the value is selected for use on Forms 18 and 26 and the value is entered onto these forms and the checkbox for arithmetic averages is marked.

Volume-Weighted Averages – The volume-weighted average considers the volumetric distribution of concentrations. This method is reserved for use in a Tier 3 evaluation. The use of volume-weighted averages must first be approved by the ADEM in a Tier 3 workplan.

B.2.2 Determination of the Exposure Domain

The first and most critical step in the selection of an appropriate representative concentration is to identify the size and location of the domain over which the representative concentration will be calculated. The exposure domain is the area over which the receptor may be exposed to the contaminated medium (surficial soil, subsurface soil, groundwater). The exposure domain must be established for the onsite scenario as well as any offsite impacted or potentially impacted properties. Separate domains may also exist for current scenarios versus future scenarios.

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

In the case where there is an offsite commercial property as well as an onsite commercial property, the exposure domains would be different due to the onsite/offsite situation, but there would likely be the same RBSLs and SSTLs calculated since there is the same human receptor, the commercial worker present on both properties. Separate representative concentrations would be established – one for the onsite commercial worker and one for the offsite commercial worker.

In addition to the onsite/offsite situation, an evaluation for current and future exposure should be conducted. This evaluation requires significant professional judgement to determine the exposure domain for the current and future exposure scenarios. The determination of the exposure domain 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 exposure domain 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 onsite building), (2) place this estimated building footprint over the area that yields the highest representative concentration using the maximum, arithmetic average or area-weighted average procedure as appropriate. 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 must be supplied in the attachments. However, maps are not required for those exposure domains that are obviously not yielding the highest representative concentrations.

For the outdoor inhalation evaluation, the exposure domain would be that area available for a human receptor to walk over a contaminated area. Steep hillsides, ravines or other rough terrain may be eliminated as part of the outdoor exposure domain if access by human activity is prohibited. In some cases, the future footprint for outdoor exposure may not be known, therefore, the area of the site defined by the limits of the soil and/or groundwater contamination would be considered in the estimation of the representative concentration for future exposure for the outdoor domain.

Because a site may have varying exposure domains for a current scenario versus a future scenario, separate area-weighted averages need to be calculated which represent these two scenarios. However, the report forms only allow for one area-weighted average to be entered on Forms 18 and 26. Therefore, the ARBCA evaluator must choose the higher of the two area-weighted averages and use that in the evaluation. The backup data used to calculate the two different values should be presented in an attachment for regulatory review and documentation of the selection decision.

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 attachment section of the report forms. Attachments should include:

- Maps indicating the exposure domains selected for the various media and complete exposure pathways for both onsite and offsite, and current and future scenarios should be included.
- Tables listing the soil boring and monitoring well data used in determining the representative concentration for each boring or well should be included as an attachment in the report. All data should be listed and the data utilized in the determination of the representative concentration clearly noted.
- Tables listing the areas calculated for each polygonal element.
- Tables including the calculated representative concentration for each pathway and medium.
- Maps illustrating area discretization into polygonal elements.

B.2.4 Entering Appropriate Representative Concentrations on Tier 1/2 Forms

The ARBCA Summary Report Forms require that the domain-specific representative concentration for a specific chemical for a specific medium (surficial soil, subsurface soil, groundwater,) and for a specific receptor be entered on Forms 18, 19, 20, 26, 27 and 28. For Forms 18 and 26, the type of domain-specific representative concentration used in a particular evaluation, whether maximums, arithmetic averages, or area-weighted averages, should be marked on the checkboxes. As shown on the forms, different types of representative concentrations can be used for the different pathways. However, within a pathway, the types of representative concentrations used should not be mixed together. In order to prepare a clear evaluation report, different evaluations may need to be performed which indicate the type of representative concentration used for comparison to the RBSLs or SSTLs. A discussion of the procedure to use is presented in the following paragraphs.

For Tier 1, the first evaluation should use domain-specific maximums (either historical or recent, as appropriate) for the representative concentration for each chemical and for each complete receptor and pathway. The checkboxes for maximum should be marked. This evaluation, using maximums as the representative concentrations, should be printed out with Forms 21a and 21b. The ARBCA evaluator should then note the exceedances that occurred using the maximum values. A second evaluation should occur, and only those chemicals with exceedances ("E") should be included in another Tier 1 evaluation which uses the appropriate domain-specific arithmetic averages or area-weighted averages. Before the second Tier 1 evaluation is performed, the representative concentration cells should all be cleared with the "clear contents" function except for the chemicals with exceedances. Then, new area-weighted averages or arithmetic averages are entered in the remaining cells on Form 18. This new set of Form 18(s) should be printed out and included with the previously completed Tier 1 forms using maximums as the representative concentrations. These should be placed behind the Tier 1 Form 18(s), which used the maximum values for the representative concentrations. If an exceedance for a chemical occurs after the Tier 1 evaluation with area-weighted averages, then a decision to either remediate to Tier 1 levels or proceed to a Tier 2 evaluation should occur.

For a Tier 2 evaluation, the same hierarchical procedure should be utilized for the representative concentrations. All chemicals, even those that did not show an exceedance under Tier 1 should be evaluated in the Tier 2 evaluation. After the evaluator calculates the SSTLs, these should be entered onto Form 26. The first evaluation should include the use of the same appropriate maximum concentrations as used in the Tier 1 evaluation. The checkboxes for maximum should be marked. This evaluation, using maximums as the representative concentrations, should be printed out with Forms 29a and 29b. The ARBCA evaluator should then note the exceedances that occurred using the maximum values. A second evaluation should occur, and only those chemicals with exceedances ("E") should have another Tier 2 evaluation, which uses the same appropriate arithmetic averages or area-weighted averages as used in Tier 1. These are entered in the appropriate cells on Form 26(s). This new set of Form 26(s) should be printed out and included with the previously completed Tier 2 forms using maximums as the representative concentrations. These should be placed behind the Tier 2 Form 26(s) that used the maximum values for the representative concentrations. If an exceedance for a chemical occurs after the Tier 2 evaluation with area-weighted averages, then a decision to either remediate to Tier 2 levels or proceed to a Tier 3 evaluation should occur.

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 protection of groundwater or surface water pathway.

Surficial 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 soil source travels vertically downward to the water table without any lateral or transverse spreading. Thus, the horizontal dimensions of the surficial soil source and the groundwater source are assumed to be identical. For this pathway, the target surficial soil source concentration protective of groundwater has to be compared with the representative surficial soil source concentration that can be calculated as discussed below.

The representative surficial soil source concentration should be estimated using the surficial 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 soil data available within the source area. The representative concentration can then be estimated as the area-weighted average concentration within this source area. Since at typical LUST sites, the soil source area is small, the arithmetic average may be used as an approximation for the area-weighted average where spatial distribution of the data allows for the application of an arithmetic average. The maximum value in the source area may also be utilized, if appropriate.

The surficial soil source representative concentration should be compared with the subsurface soil source representative concentrations. The higher value should be entered in the appropriate cell on Forms 19, 20, 27 and 28. This value is then used in the groundwater resource protection and stream protection evaluations.

B.3.1.2 Representative surficial soil concentrations for dermal contact, ingestion, and inhalation of vapors and particulates.

For this pathway, the representative surficial soil concentration needs to be based on the receptor's domain, i.e., the area over which the receptor may be exposed to the surficial soil. The exact domain of the receptor is very difficult to estimate especially since the domain has to be representative of a period of time equal to the receptor's exposure duration. Under current conditions, in the absence of specific information about the receptor's activities, the unpaved portion of the site may be approximately considered as the receptor's domain. For potential future exposures, assuming the pavement is removed and exposure to surficial soil is possible, the entire site may be considered as the receptor's domain.

To estimate the representative concentration for this pathway, it would be necessary to (i) estimate the receptor's domain(s), and (ii) determine the number of soil samples available within this domain. This information should be used to estimate the area-weighted average concentration using the procedure discussed in Section B.5. The maximum value for each chemical within the domain may also be utilized, if appropriate. The appropriate value should be determined and entered into Form 18 and 26. The appropriate checkbox should be marked indicating the type of representative concentration selected.

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 protection of groundwater or surface water.

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 would be the area-weighted average subsurface soil concentration within the source area. Since at typical LUST sites, the soil source area is small, the arithmetic average may be used as an approximation for the area-weighted average where spatial distribution of the data allows for the application of an arithmetic average. 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 entered in the appropriate cell on Forms 19, 20, 27 and 28. This value is then 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 using the Johnson and Ettinger (1991) model. This model assumes that the chemicals volatilize from the subsurface soil source, and travel vertically upward without any lateral or transverse spreading, and enter a building through cracks in the floor. Thus, to be consistent with the model, the representative concentration for this pathway should be based on the soil concentrations measured in the soil within the exposure domain of indoor inhalation directly below or adjacent to the enclosed space. To evaluate the potential future indoor inhalation, i.e., in the event that an enclosed structure is constructed on top of contaminated soil, it is necessary to estimate the size (footprint) and location of the structure. In the absence of site-specific information, subjective judgement has to be used regarding the potential future location and size of the structure. This should include the area located over the most highly contaminated soil unless that area is in a location that would not allow for the building of a structure (i.e. roadway, right-of-way areas, etc). Note, if the footprint of the current and future enclosed space is different, two different representative concentrations, one for current conditions and one for future conditions, may be necessary. Also, onsite and offsite representative concentrations may need to be developed where soil contamination extends offsite.

To estimate the representative subsurface soil concentration for this pathway, it will be necessary to (i) identify the footprint of the structure within which the receptor is located, (ii) identify the footprint of the potential future location of the enclosed structure, and (iii) identify the soil concentration data available within these two footprints. The representative concentration would be the area-weighted concentration within the footprint. The maximum value for each chemical within the footprint may also be utilized, if appropriate. If data are not available within the footprint, data adjacent to the footprint should be used.

Refer to Section B.5 for the estimation of the area-weighted average concentration.

Since the 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 area-weighted average for the indoor inhalation pathway for subsurface soil. Calculations and the documentation of the selection of the proper values should be included in an attachment to the ARBCA report.

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 (1991) 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 domain. The domain 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 domain of the outdoor breathing zone for the current receptor, (ii) identify the domain of the outdoor breathing zone for the potential future receptor, and (iii) identify the soil concentration data available within each of these two domains. The representative concentration would be the area-weighted average concentration within each domain. The maximum value for each chemical within the domain may also be utilized, if appropriate. If data are not available within the domain, data adjacent to the domain may be used. If the domain 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. Refer to Section B.5 for the estimation of the area-weighted average concentration.

Where subsurface soil concentrations are located onsite and offsite, separate representative concentrations must be established to compare to receptor-specific target levels. For example, where a tank pit is located on the property line, subsurface contamination may be present both onsite and offsite. Where this occurs, separate representative concentrations need to be determined to reflect two different exposure domains for two different receptors. Offsite data should be obtained. Where it is not readily available, the nearest onsite data could be used as "mirror" data and assumed to be representative of adjacent offsite conditions.

Since the 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 area-weighted average for the outdoor inhalation pathway for subsurface soil.

Calculations and the documentation of the selection of the proper values should be included in an attachment to the ARBCA report.

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 offsite 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 onsite and offsite ingestion of groundwater.

For the current onsite and offsite 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 compliance wells) can provide for an evaluation of a potential future impact to that existing well(s).

Data from the actual water supply well either located onsite or offsite is compared against the established MCLs or groundwater target levels. Historical maximum data is used as the representative concentration and is entered on Forms 18 and 26. Note that there is an evaluation for an onsite well as well as for an offsite well.

After identifying the available groundwater monitoring data from the site, a compliance well(s) at the source area and at least one compliance well 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 Groundwater Resource Protection software to determine allowable chemical concentrations for the compliance wells based on the proximity of these wells to the water supply well. The evaluation is performed using Forms 19 and 27.

Since this is a direct exposure pathway, care should be taken in ensuring protection of the water supply well. Since most sites are small, the presence of an onsite well will likely require a corrective action plan to be developed and implemented or a risk management action be taken to remove the well from active use. Removal of the well by abandonment would then eliminate the current ingestion of groundwater pathway. However, a new future POE well (either onsite or offsite) should be selected. The groundwater resource protection evaluation must still 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, Tier 1, Tier 2 and/or Tier 3. This evaluation is performed to determine acceptable soil and groundwater concentrations protective of a current or future offsite drinking water well. For this pathway, MCLs or equivalent concentrations have to be met at the POE well (current or hypothetical future). Often the POE is a hypothetical well and data may not be available from an actual well. In this case, a well is presumed to be located at a particular distance from the site. See Section 6.9 of the ARBCA Guidance Manual for further discussion of the proper location of the POE. The groundwater resource protection evaluation is performed with data entered on Forms 19 and 27.

An important aspect of the groundwater resource protection evaluation is the selection of existing monitoring wells as Compliance Wells (CW) or Points of Compliance (POC). In addition to determining the POE for the groundwater resource protection evaluation, at least two point of compliance wells have to be located and target compliance well concentrations have to be calculated at these wells. This includes a compliance monitoring well(s) located at or very near the soil source (a source well), and at least one compliance monitoring well located between the source well and the POE. For most sites, more than two point of compliance wells located between the source and the POE should be included in the evaluation to allow for varying distances to the POE and for fluctuating or unclear groundwater flow directions. Therefore, representative concentrations for several compliance wells may need to be established.

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

- For compliance 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 compliance 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 compliance 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 an attachment to the ARBCA Report. 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 ADEM's review of the Tier 1 or Tier 2 report.

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 that assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe, the unsaturated zone, and into the enclosed space. Thus, to be consistent with the model, the representative concentration for this pathway should be based on the groundwater concentrations measured directly below or adjacent to the enclosed space. To evaluate the potential future indoor inhalation, i.e., in the event that an enclosed structure is constructed on top of contaminated groundwater, it is necessary to estimate the size (footprint) and location of the structure. In the absence of site-specific information, subjective judgement has to be used regarding the potential future location and size of the structure. This should include the area located over the most highly contaminated groundwater unless that area is in a location that would not allow for the building of a structure (i.e. roadway, right-of-way areas, etc). Note, if the footprint of the current and future enclosed space is different, two different representative concentrations, one for current conditions and one for future conditions, may be necessary. Also, onsite and offsite representative concentrations may need to be developed where groundwater contamination extends offsite.

After identifying the location of the building footprint(s), and the available groundwater monitoring data within each footprint, the area-weighted average concentration within each footprint has to be estimated as discussed in Section B.5. The maximum value for each chemical within the domain may also be utilized, if appropriate. Both the current and future locations of buildings should be considered. Therefore, several different representative concentrations may have to be estimated.

Since the 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 area-weighted average for the indoor inhalation pathway for groundwater. Calculations and the documentation of the selection of the proper values should be included in an attachment to the ARBCA report. The evaluator enters the appropriate representative concentrations on Forms 18 and 26 and indicates the type of representative concentration used (maximum, arithmetic average, or area-weighted average) by marking the correct checkbox.

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 has to 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 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 area-weighted average for the outdoor inhalation pathway for groundwater. Calculations and the documentation of the selection of the proper values should be included in an attachment to the ARBCA report. The evaluator enters the appropriate representative concentrations on Forms 18 and 26 and indicates the type of representative concentration used (maximum, arithmetic average, or area-weighted average) by marking the correct checkbox.

B.3.3.6 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 protective of the groundwater resource protection. The surface water body is the "point of exposure". Target levels for the stream must be calculated. Both source compliance monitoring well(s) and compliance monitoring well(s) must be established. The source compliance well is located in or near the soil source area. One or more compliance 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.

The representative concentrations are entered manually onto Forms 20 and 28. In the event more than one surface water body is identified as a receptor, then Forms 20 and 28 would need to be duplicated and completed for each surface water body.

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 identified in Section B.5, 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 Tier 1 RBSLs, or a new spill is suspected, 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 density of soil samples and if sampling locations are equally spaced, the arithmetic average may be used instead of the area-weighted average because the area-weighted average and arithmetic average concentrations should be about the same.

- Non-detect soil samples located at the periphery of the selected exposure domain should not be used.
- Non-detect samples within the exposure domain may be replaced by half their detection limits if detection limits are less than the appropriate ISL. If detection limits are greater than ISLs, 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, these may be averaged to estimate the concentrations representative of the area elements. 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 arithmetic average of the recent two years or recent eight measurements, whichever represents the longer time duration. Consecutive quarterly monitoring is considered optimum.

  B. For a well 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.

  C. For a well 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 longer duration. Note that for wells with increasing concentration trends, continued monitoring, at a minimum, will be required until the trend stabilizes.

  D. While calculating the average for (A), (B), and (C), non-detect samples may be replaced by half their detection limits if detection limits are less than the appropriate ISL. If detection limits are greater than ISLs, 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 exposure domain should not be used.

- For a well which contained free product during a sampling event, the concentration representative 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 Table B-1 for effective solubilities.

B.5 ESTIMATING THE AREA-WEIGHTED AVERAGE CONCENTRATION

The area-weighted average concentration can be estimated using the Thiessen Polygon method. This method is described in Fetter (1994). Software may also be utilized for estimating the area-weighted concentrations provided the software performs the calculations as described in this section. This procedure can be utilized to determine area-weighted average concentrations for both soil and groundwater.

Step 1: Identify the Domain

The first and most critical step in this method is to identify the size and location of the domain over which the area-weighted concentration is to be estimated. The location and size of this domain will vary depending on the pathway being evaluated. Specific guidance on the location of the receptor's domain has been discussed in Section B.2.2. Area-weighted average concentrations can only be estimated if multiple samples have been collected within the domain. If several samples are available just outside the domain, it may be reasonable to extend the size of the domain to include this data. Where an inadequate amount of samples exist within a particular domain, then the domain maximum value should be used and there is no need to develop an area-weighted average.

If there is a sufficient density of samples and if sampling locations are equally spaced, the arithmetic average may be used instead of the area-weighted average because the area-weighted average and arithmetic average concentrations should be about the same. In such cases, the following three steps would not be necessary.

As part of this step, the various domains for which area-weighted average concentrations are being developed should be clearly drawn on a site map and the location of data points (soil borings, monitoring wells) should be clearly identified on the map. Remember that various pathways, land uses, and current vs. future scenarios may require that different domains are defined and therefore, different representative concentrations are calculated.

Step 2: Discretize the Domain

The domain, identified in Step 1, is discretized into polygonal elements by (i) first connecting the sampling points within each domain identified in Step 1, and (ii) drawing perpendicular bisectors to these lines to form polygons. Estimate the area of each polygon.

Step 3: Estimate Representative Concentration for Each Polygon

The concentration measured at the sampling location (boring or well) within each polygon is considered representative of the area of each polygon. As previously discussed, if multiple data are available from a location, compute the arithmetic average concentration of each COC measured at that location. The arithmetic concentration is then considered representative of the polygon.

The data utilized from each boring and/or well should be presented in a tabular format and included as an attachment in the ARBCA report.

Step 4: Estimate Area-Weighted Average Concentration for the Domain

The area-weighted average concentration for the site is estimated using:

$$C_{area} = \frac{\sum_{i=1}^{i=n} (A_i * C_{avg,i})}{A_{Total}}$$

Where,

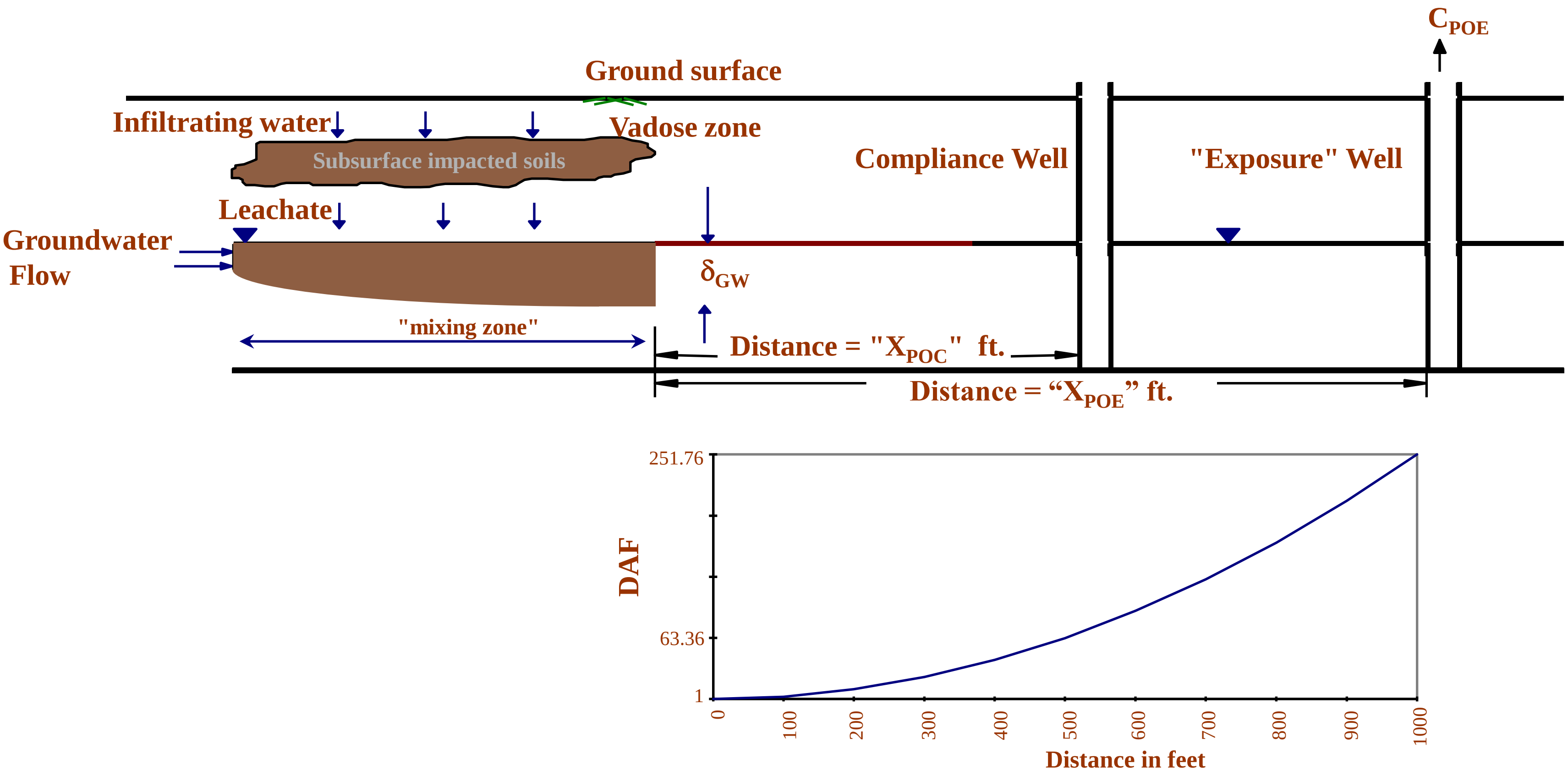
C_{area} = area-weighted average concentration over the domain [mg/kg or mg/l]

A_i = area of each polygon [m^2]

A_{Total} = total area of the polygons (i.e. area of the domain) [m^2]

$C_{avg,i}$ = mean of soil or groundwater concentrations measured within the polygonal element i [mg/kg or mg/l]

An example application of the Thiessen Polygon method is schematically shown in Figure B-2.

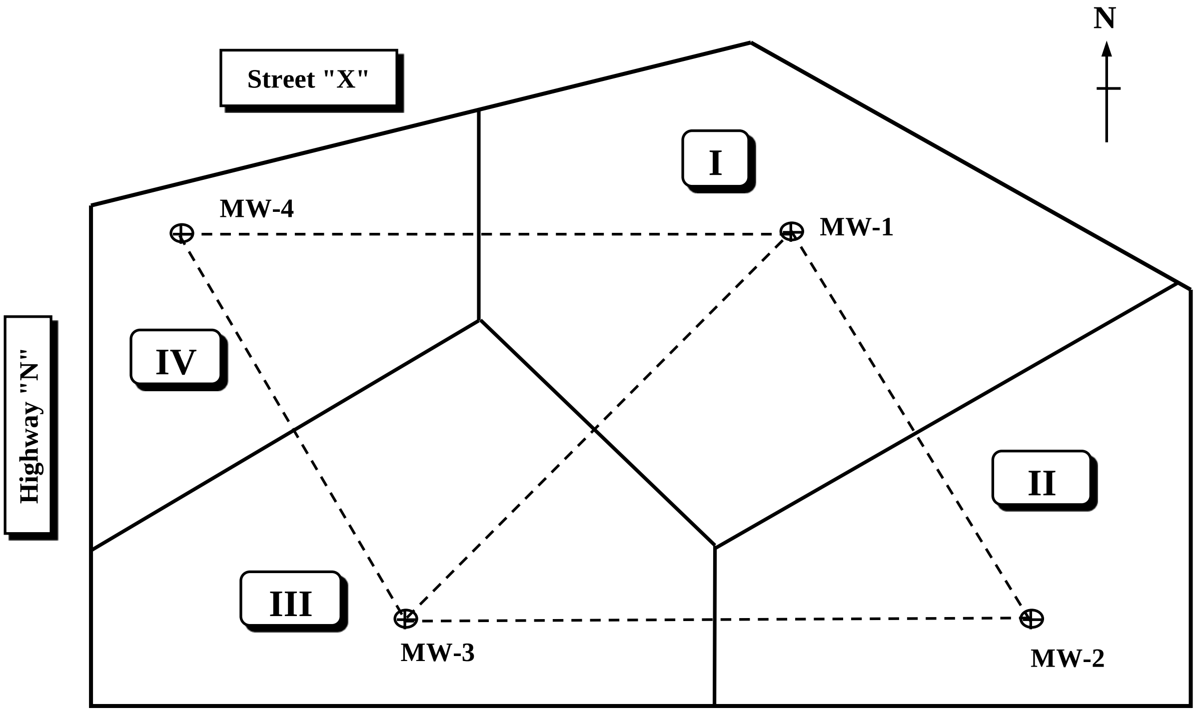


Allowable groundwater concentration at the source protective of a POE located at a distance X_{POE} from the source = C_{POE} x DAF_{POE}

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

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



Polygonal Element	Mean Soil Concentration $C_{avg,i}$ mg/kg	Area of the Element A_i m^2	$A_i * C_{avg,i}$ m^2 - mg/kg	Area Weighted Average Concentration mg/kg
I	2	604	1208	
II	1.8	398	716.4	
III	1.2	578	693.6	
IV	1	234	234	
	TOTAL	**1814**	**2852**	
Area Weighted Average Concentration = $C_{area} = \frac{\sum_{i=1}^{i=n}(A_i * C_{avg,i})}{A_{Total}}$				**1.57**

Note: None of the polygon concentrations should exceed ten times the final area-weighted average concentration.

FIGURE B-2. THIESSEN POLYGON METHOD

TABLE B-1

EFFECTIVE SOLUBILITY OF CHEMICALS OF CONCERN IN GASOLINE AND DIESEL

Chemical of Concern (COC)	**Gasoline**		**Diesel**		**Solubility Mg/l** (3)	**Effective Solubility** (1)	
	Range wt.% (2)	**Average (midpoint) wt.%**	**Range wt.%** (2)	**Average (midpoint) wt.%**		**Gasoline Mg/l**	**Diesel Mg/l**
Benzene	0.12 – 3.5	1.81	0.003 – 0.1	0.05150	1.75E+3	31.7	9.01E-1
Toluene	2.73 – 21.8	12.27	0.007 – 0.7	.035350	5.26E+2	64.5	1.86
Ethylbenzene	0.36 – 2.86	1.61	0.007 – 0.2	0.10350	1.69E+2	2.72	1.75E-1
Xylenes (Total)	3.22 – 8.31	5.77	0.037 – 1.109	0.573	1.75E+2	10.1	1.00
Methy-Tert-Butyl-Ether (MTBE)	0.25 – 2.02 (4)	1.14	*	*	4.80E+4	547	*
Anthracene	*	*	3.0E-6 – 2.0E-2	1.00E-2	4.34E-2	*	4.34E-6
Benzo(a)anthracene	*	*	2.1E-6 – 6.7E-4	3.36E-4	9.40E-3	*	3.20E-8
Benzo(a)pyrene	*	*	5.0E-6 – 8.4E-4	4.23E-4	1.62E-3	*	6.85E-9
Benzo(b)fluoranthene	*	*	3.0E-7 – 1.94E-4	9.72E-5	1.50E-3	*	1.46E-9
Benzo(g,h,i)perylene	*	*	9.0E-7 – 4.0E-5	2.05E-5	7.00E-4	*	1.44E-10
Benzo(k)fluoranthene	*	*	3.0E-7 – 1.95E-4	9.77E-5	8.00E-4	*	7.82E-10
Chrysene	*	*	4.5E-5	4.50E-5	1.60E-3	*	7.20E-10
Fluoranthene	*	*	7.0E-7 – 2.0E-2	0.0100004	2.06E-1	*	2.06E-5
Fluorene	*	*	3.4E-2 – 1.5E-1	9.20E-2	1.98	*	1.82E-3
Naphthalene	*	*	1.0E-2 – 8.0E-1	4.05E-1	3.10E+1	*	1.26E-1
Phenanthrene	*	*	2.7E-5 – 3.0E-1	1.50E-1	1.00	*	1.50E-3
Pyrene	*	*	1.8E-5 – 1.5E-2	7.50E-3	1.35E-1	*	1.01E-5

* Not a COC for the ARBCA program

(1) Effective Solubility = Average mole fraction x Pure Product Solubility in water

(2) Gustafson, John B., Joan G. Tell, and Doug Orem, 1997, Appendix A IN: Selection of Representative TPH Fractions Based on Fate and Transport Considerations, Volume 3 of *Total Petroleum Hydrocarbon Criteria Working Group Series*, July 1997, Amherst Scientific Publishers, 150 Fearing St., Amherst, MA 01002, 102 pages.

(3) See Table 6-5, this document.

(4) American Petroleum Institute, September 1994, *Transport and Fate of Non-BTEX Petroleum Chemicals in Soils and Groundwater*, API Publication #4593, Table A-9.

APPENDIX C
CONCENTRATIONS PROTECTIVE OF A STREAM

APPENDIX C
CONCENTRATIONS PROTECTIVE OF A STREAM

C.1 BACKGROUND

While performing an Alabama Risk-Based Corrective Action (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 impacted 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 compliance 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 Tier 1 and Tier 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 a Tier 1 evaluation, surface water standards listed in Table C-1, have to be met at the point of discharge, i.e. mixing within the stream is not considered in Tier 1.

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

Step 1: Identify streams potentially impacted by COCs at the site

The objective of this step is to identify surface water bodies located near the site that may be impacted by the COCs at the site. Surface water bodies include intermittent streams, drainage ditches, creeks, ponds, perennial streams, wetlands, and lakes. Since petroleum hydrocarbon plumes from leaking UST sites typically do not exceed 500 feet in length, surface water bodies located within 500 feet of the downgradient edge of the site should be identified, unless otherwise required by the ADEM. These surface water bodies should be located on a site map as well as a topographic map. The water use should also be identified. Surface water intakes for public water supply, located within 1 mile downstream of the site, should 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_{sw})

Target surface water concentrations are presented in Table 7-3(a) and Table C-1. These allowable stream concentrations represent the minimum of the suggested surface water criteria values being utilized by the ADEM for (i) freshwater acute exposure, (ii) freshwater chronic exposure, and (iii) human consumption of fish and water. In Figure C-1, these concentrations are represented as C_{sw}.

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

For a Tier 1 evaluation, groundwater concentrations at the point of discharge, C_{gw}, are set equal to the allowable stream concentration, C_{sw}. Thus, for a Tier 1 evaluation, mixing within the stream is neglected. For higher tier evaluations, mixing within the stream is used, i.e., the allowable stream concentrations, C_{sw}, 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:

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

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_{sw} = Allowable downstream concentration at the downstream edge of the stream's mixing zone (mg/L)
C_{su} = The COCs' concentration upstream of the groundwater plume discharge (mg/L)

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

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

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

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:

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

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 a Tier 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]
δ_{gw} = Groundwater mixing zone thickness [cm]
X_s = Distance from the downgradient edge of the groundwater source to the stream [ft]
α_y = Lateral dispersivity [ft]
α_z = Vertical dispersivity [ft]
30.48 = Conversion factor [cm/ft]

In Equation C-5 and C-6, α_y and α_z can be estimated as:

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

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

For a Tier 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 ADEM. The method proposed should be included in a written plan submitted to the ADEM.

For a Tier 2 evaluation, the ADEM requires that the $7Q10$ flow be used to estimate the upstream flow, Q_{sw}, in Equation C-1. For streams that are gauged, the $7Q10$ can be obtained directly from Atkins and Pearman (1994) or by calling a local USGS office. 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.

The specific regression equation takes the form:

$$7Q10 = 0.15 \times 10^{-5} \times (G - 30)^{1.35} (A)^{1.05} (P - 30)^{1.64} \qquad \text{(C-9)}$$

Where:

$7Q10$ = Estimated stream flow [ft^3/s]
G = Stream flow recession index (determined from Bingham, 1982)
A = Contributing drainage area [square miles]
P = Mean annual precipitation [inches]

The mean annual precipitation can be obtained from Bingham, 1982. See section 6.7.4.2 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

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

7*Q*10 = 1.6 cfs

Drainage using second index

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

7*Q*10 = 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-7 can be converted to Q_{sw} using the following equation:

$$Q_{sw} = 7Q10 \times 86400 \tag{C-10}$$

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 compliance 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:

$$C_{gws} = C_{gw} \times DAF_{stream} \tag{C-11}$$

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 [--]
C_{gw} = Allowable groundwater concentration at the point of discharge to the stream, estimated using Equation C-1 in Tier 2 [mg/L]. In Tier 1, $C_{gw} = C_{sw}$

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

$$C_{cw} = \frac{DAF_{stream}}{DAF_{cw}} \times C_{gw} \tag{C-12}$$

Where:

C_{cw} = Allowable concentration at the compliance well [mg/L]

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

DAF_{cw} = Dilution attenuation factor in the saturated zone between the source and the compliance well [--]

Note that the concept quantified by Equation C-12 is also used to develop the compliance well concentrations for the protection of the groundwater resource, refer to Section 6.11 of the ARBCA guidance manual.

For Tier 1 and Tier 2 evaluations, the DAF_{stream} and DAF_{cw} can be calculated using the simplified version of Domenico's model, as discussed in Section 6.11 of the ARBCA guidance manual. For the specific form of the Domenico's model, refer to Appendix E of the ARBCA guidance document.

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:

$$C_{soil} = \frac{C_{gw} \times DAF_{stream}}{LF_{sw}} \tag{C-13}$$

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 Tier 1, the user must determine (i) the distance from the source to the downgradient stream, (ii) the location of the compliance wells, and (iii) distance from the source to the compliance wells. Tables C-2 and 7-3(b) list the Tier 1 allowable soil source concentrations for different distances to the stream.

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 Tier 1 target groundwater concentrations in the compliance wells can be calculated using Equation C-12. The DAFs for various distances from the source are included in Table 7-5 of the ARBCA guidance manual.

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

The user can use the ARBCA program to calculate the allowable soil and groundwater source concentrations and the compliance 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_{sw})	- Table 7-3(a) of ARBCA guidance manual

Compliance Well Data

Distance from the downgradient edge of the groundwater source to the compliance well (X_{spoc})	- to calculate DAF_{cw}

Chemical Data

Henry's Law constant (H)	- Table 6-5 of ARBCA guidance manual
Half-life (days), when using decay	- to calculate DAF_{cw} and DAF_{stream}
Organic carbon partition coefficient (Koc)	- Table 6-5 of ARBCA guidance manual

Aquifer Properties

Hydraulic conductivity (K)	- to calculate Darcy velocity
Hydraulic gradient (i)	- to calculate Darcy velocity
Groundwater mixing zone thickness (δ_{gw})	- to calculate LF_{sw}, DAF_{cw}, and DAF_{stream}
Infiltration rate (I)	- to calculate LF_{sw}
Organic carbon content in the saturated zone (foc_s)	- to calculate retardation factor in the saturated zone
Saturated zone porosity (θ_{TS})	- to calculate retardation factor in the saturated zone
Saturated zone dry bulk density (ρ_{ss})	- to calculate retardation factor in the saturated zone

Vadose Zone Soil Properties

Total porosity (θ_T)	- to calculate LF_{sw}
Organic carbon content (foc)	- to calculate LF_{sw}
Water content (θ_{ws})	- to calculate LF_{sw}
Dry bulk density (ρ_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 (δ_{gw})	- to calculate thickness of plume at the point of discharge
Width of groundwater source perpendicular to the groundwater flow (Y)	- to calculate DAF_{cw}, DAF_{stream}, and width of plume at the point of discharge

These values are utilized by the ARBCA program 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 compliance well. Appropriate justification for using the selected values has to be provided in the ARBCA forms.

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.

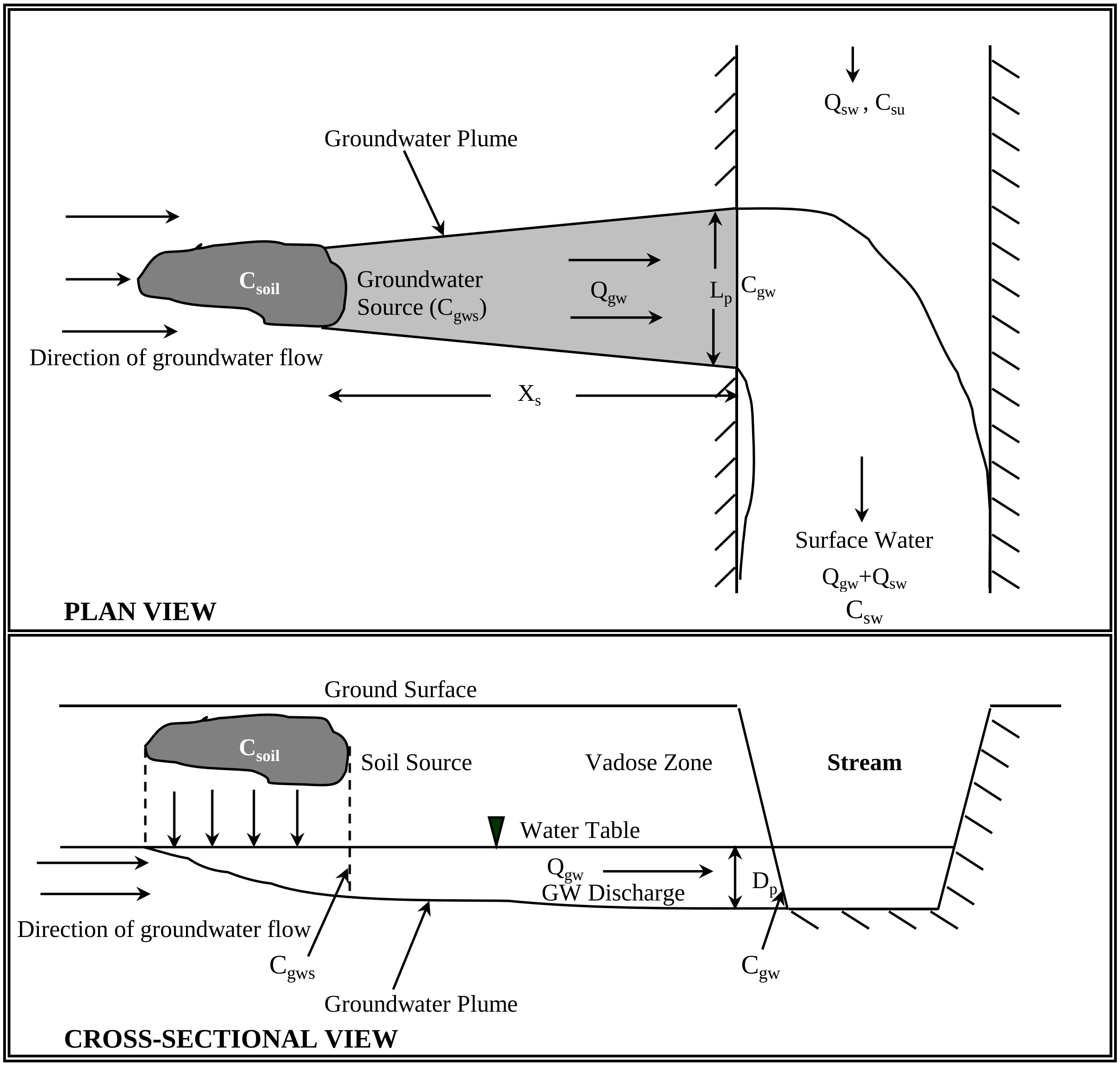


Figure C-1: Schematic of leachate migration from the soil source to the stream

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_{sw} = 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]

TABLE C-1

RBSLs FOR SURFACE WATER PROTECTION

Chemical of Concern	Target Levels [mg/L]	Explanation
ORGANICS		
Benzene	0.011	1
Toluene	0.175	2
Ethylbenzene	0.453	2
Xylenes (Total)	NA	3
Methyl-tert-Butyl-Ether	NA	3
Anthracene	7.241	1
Benzo(a)anthracene	0.00002	1
Benzo(a)pyrene	0.00002	1
Benzo(b)fluoranthene	0.00002	1
Benzo(g,h,i)perylene	NA	3
Benzo(k)fluoranthene	0.00002	1
Chrysene	0.00002	1
Fluoranthene	0.0398	2
Fluorene	0.966	1
Naphthalene	0.62	2
Phenanthrene	NA	3
Pyrene	0.724	1
METALS		
Arsenic, Total recoverable	0.33	4
Barium	NA	3
Cadmium, Total recoverable	0.0027	4
Chromium (VI)	0.011	4
Lead, Total recoverable	0.0028	2
Zinc, Total recoverable	0.18	4

1. The ADEM Water Quality Criteria for consumption of fish/water.
2. The EPA suggested Water Quality Criteria values for freshwater chronic.
3. Not available. Contact the ADEM for further guidance.
4. The ADEM Water Quality Criteria based on the bioavailable portion of metals (ADEM Water Division – Industrial Section).

Table C-2

TIER 1 RBSLs FOR SOIL CONCENTRATIONS (FOR LEACHING TO GROUNDWATER) FOR DIFFERENT DISTANCES TO THE STREAM

CHEMICALS OF CONCERN	Water Standard† [mg/l]	Leaching Factor [(mg/l)/(mg/kg)]	TIER 1 RBSLs FOR SOIL CONCENTRATION AT THE SOURCE FOR DIFFERENT DISTANCES TO THE EXPOSURE POINT											
			0 ft. [mg/kg]	50 ft. [mg/kg]	100 ft. [mg/kg]	150 ft. [mg/kg]	200 ft. [mg/kg]	250 ft. [mg/kg]	300 ft. [mg/kg]	350 ft. [mg/kg]	400 ft. [mg/kg]	450 ft. [mg/kg]	500 ft. [mg/kg]	1000 ft. [mg/kg]
ORGANICS														
Benzene	1.10E-02	5.92E-01	1.86E-02	2.43E-02	5.77E-02	1.16E-01	1.97E-01	3.02E-01	4.31E-01	5.82E-01	7.57E-01	9.56E-01	1.18E+00	4.68E+00
Toluene	1.75E-01	2.78E-01	6.29E-01	8.23E-01	1.95E+00	3.92E+00	6.68E+00	1.02E+01	1.46E+01	1.97E+01	2.56E+01	3.24E+01	3.99E+01	1.58E+02
Ethylbenzene	4.53E-01	1.94E-01	2.34E+00	3.06E+00	7.26E+00	1.46E+01	2.48E+01	3.80E+01	5.42E+01	7.32E+01	9.52E+01	1.20E+02	1.48E+02	3.60E+02 *
Xylenes (mixed)	NA	1.60E-01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methyl-tert-butyl-ether	NA	2.32E+00	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Anthracene	7.24E+00	1.76E-03	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *	1.02E+01 *
Benzo(a)anthracene	2.00E-05	1.15E-04	1.73E-01	2.27E-01	5.38E-01	1.08E+00	1.84E+00	2.82E+00	4.02E+00	5.43E+00	7.06E+00	8.91E+00	1.10E+01	3.37E+01 *
Benzo(a)pyrene	2.00E-05	4.26E-05	4.69E-01	6.13E-01	1.46E+00	2.92E+00	4.98E+00	7.63E+00	1.09E+01	1.47E+01	1.57E+01 *	1.57E+01 *	1.57E+01 *	1.57E+01 *
Benzo(b)fluoranthene	2.00E-05	3.36E-05	5.95E-01	7.79E-01	1.85E+00	3.71E+00	6.32E+00	9.69E+00	1.38E+01	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *	1.85E+01 *
Benzo(g,h,i)perylene	NA	2.61E-05	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Benzo(k)fluoranthene	2.00E-05	3.36E-05	5.95E-01	7.79E-01	1.85E+00	3.71E+00	6.32E+00	9.69E+00	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *	9.84E+00 *
Chrysene	2.00E-05	1.04E-04	1.93E-01	2.52E-01	5.98E-01	1.20E+00	2.05E+00	3.13E+00	4.46E+00	6.04E+00	6.37E+00 *	6.37E+00 *	6.37E+00 *	6.37E+00 *
Fluoranthene	3.98E-02	8.41E-04	4.73E+01	6.19E+01	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *	1.01E+02 *
Fluorene	9.66E-01	5.35E-03	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *	1.53E+02 *
Naphthalene	6.20E-01	3.45E-02	1.79E+01	2.35E+01	5.57E+01	1.12E+02	1.91E+02	2.92E+02	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *	3.71E+02 *
Phenanthrene	NA	2.93E-03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Pyrene	7.24E-01	6.07E-04	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *	9.18E+01 *
METALS														
Arsenic	3.30E-01	6.44E-03	5.12E+01	6.70E+01	1.59E+02	3.19E+02	5.44E+02	8.34E+02	1.19E+03	1.61E+03	2.09E+03	2.64E+03	3.25E+03	1.29E+04
Barium	NA	1.01E-02	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cadmium	2.70E-03	5.50E-03	4.91E-01	6.41E-01	1.52E+00	3.05E+00	5.21E+00	7.98E+00	1.14E+01	1.54E+01	2.00E+01	2.52E+01	3.11E+01	1.23E+02
Chromium VI	1.10E-02	2.17E-02	5.07E-01	6.64E-01	1.58E+00	3.16E+00	5.39E+00	8.25E+00	1.18E+01	1.59E+01	2.07E+01	2.61E+01	3.21E+01	1.28E+02
Lead	2.80E-03	3.38E-03	8.27E-01	1.08E+00	2.57E+00	5.15E+00	8.78E+00	1.35E+01	1.92E+01	2.59E+01	3.37E+01	4.25E+01	5.24E+01	2.08E+02
Zinc	1.80E-01	6.66E-03	2.70E+01	3.54E+01	8.40E+01	1.68E+02	2.87E+02	4.40E+02	6.27E+02	8.47E+02	1.10E+03	1.39E+03	1.71E+03	6.81E+03

Note

* Calculated Tier 1 RBSLs for soil concentrations exceeded saturated soil concentration and hence saturated soil concentrations are listed Tier 1 RBSLs for soil concentrations protective of groundwater.

† Tier 1 stream RBSLs

Soil concentrations are presented on a dry weight basis.

APPENDIX D
BACK--CALCULATION OF RISK-BASED TARGET LEVELS

D.1 Introduction

The back-calculation of risk-based target levels essentially provides the answer to the question, “How clean is clean?”. It helps determine if soil and/or groundwater concentrations present at a site pose an acceptable or unacceptable level of risk to a receptor. The back-calculation method 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 which can be left in the soil such that the risk due to inhalation of volatile emissions from the soil to an onsite or offsite 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.

Within the ARBCA process, the estimated or back-calculated soil concentrations are termed the risk-based screening levels (RBSLs) or the site-specific target levels (SSTLs) 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, receptor characteristics (commercial 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 RBSLs or SSTLs 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 underground storage tank sites, the ADEM currently uses values of 1.0E-5 for lifetime cancer risks. The acceptable hazard quotient is unity or 1.

The estimated target concentrations are linear with respect to these values. Thus, if the acceptable risk level were 1.0E-4 with all other factors remaining the same, the target level would increase by a factor of 10. Similarly, if the target hazard quotient is reduced to 0.5, the target levels would reduce by a factor of 2.

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

The toxicity of chemicals with carcinogenic effects is quantified using the slope factor (SF) or the potency value. For non-carcinogenic effects, the toxicity is quantified using the reference dose (RfD). For each of the chemicals of concern included in the spilled or leaked product, these toxicity values are provided in Table 6-2. These values should be utilized unless there is a strong reason to use alternative values. Any alternative value must be approved by the ADEM. The toxicity values in Table 6-2 will be updated by the ADEM as new information on the toxicity of the COCs is made available.

STEP 3: ESTIMATE THE ALLOWABLE DOSE

For carcinogenic health effects, the allowable dose for the chemical of concern is estimated by dividing the acceptable risk (refer to Step 1) with the Potency Value (refer to Step 2). For non-carcinogenic adverse health effects, the acceptable dose is equal to the hazard quotient (refer to Step 1) multiplied by the reference dose (refer to Step 2).

STEP 4: 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 default exposure factors used by the ADEM to develop the Tier 1 RBSLs are presented in Table 6-3. For Tier 2 and Tier 3 SSTL calculations, exposure factors should be the same as those used for Tier 1. For Tier 3 evaluation, the ADEM may 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 ADEM staff.

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 5: 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) - <u>Estimation of subsurface soil concentrations protective of inhalation exposures.</u>

For this exposure pathway, the concentrations estimated in Step 4 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 Tier 2 or Tier 3 evaluations.

Example (2) - <u>Estimation of soil concentrations protective of ingestion of groundwater.</u>

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 groundwater. 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 Tier 1 RBSLs and for use in the Tier 2 evaluations are shown in Appendix E.

For Tier 3 analyses the ADEM will allow other models and equations, provided the proposed equations and/or models meet the criteria established by the ADEM.

APPENDIX E

MODEL/EQUATIONS FOR ESTIMATING TIER 1 AND TIER 2 TARGET LEVELS WITHIN THE ARBCA PROCESS

The symbols used in the equations presented in this appendix follow the ASTM standard (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) appendix and may vary from other literature.

INDOOR INHALATION OF VAPOR EMISSIONS

Carcinogenic effects

$$RBTL_{ai} = \frac{TR \times BW \times AT \times 365}{IR_{ai} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT \times 365 \times RfD_i}{IR_{ai} \times ED \times EF}$$

Source: RAGS, Vol. I, 1989, p. 6-44

where:

$RBTL_{ai}$ = Risk-based target level in indoor air [mg/m^3]
TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ = Target hazard quotient for individual constituents [-]
BW = Body weight [kg]
AT = Averaging time [years]
IR_{ai} = Indoor inhalation rate [m^3/day]
ED = Exposure duration [years]
EF = Exposure frequency [days/year]
RfD_i = The chemical-specific inhalation reference dose [mg/(kg-day)]
SF_i = The chemical-specific inhalation cancer slope or potency factor [mg/(kg-day)]$^{-1}$

OUTDOOR INHALATION OF VAPOR EMISSIONS

Carcinogenic effects

$$RBTL_{ao} = \frac{TR \times BW \times AT \times 365}{IR_{ao} \times ED \times EF \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ao} = \frac{THQ \times BW \times AT \times 365 \times RfD_i}{IR_{ao} \times ED \times EF}$$

Source: RAGS, Vol. I, 1989, p. 6-44

where:

$RBTL_{ao}$ = Risk-based target level in outdoor air [mg/m^3]
TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ = Target hazard quotient for individual constituents [-]
BW = Body weight [kg]
AT = Averaging time [years]
IR_{ao} = Outdoor inhalation rate [m^3/day]
ED = Exposure duration [years]
EF = Exposure frequency [days/year]
RfD_i = The chemical-specific inhalation reference dose [mg/(kg-day)]
SF_i = The chemical-specific inhalation cancer slope or potency factor [mg/(kg-day)]$^{-1}$

DIRECT INGESTION OF GROUNDWATER
(ONLY FOR CHEMICALS WITHOUT MCLs)

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT \times 365}{IRW \times ED \times EF \times SF_o}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT \times 365 \times RfD_o}{IRW \times ED \times EF}$$

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

where:

$RBTL_w$ = Risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ = Target hazard quotient for individual constituents [-]
BW = Body weight [kg]
AT = Averaging time [years]
IRW = Water ingestion rate [L/day]
ED = Exposure duration [years]
EF = Exposure frequency [days/year]
RfD_o = The chemical-specific oral reference dose [mg/(kg-day)]
SF_o = The chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

$$RBTL_{so} = \frac{RBTL_{ao}}{VF_{samb}}$$

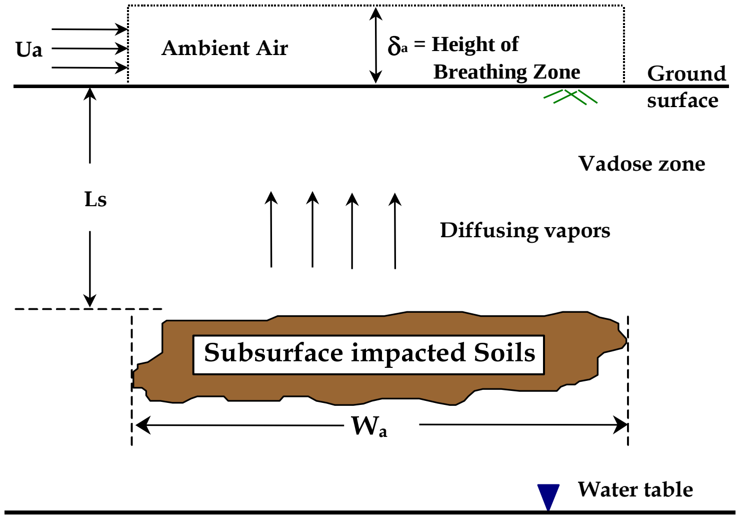
where:

$RBTL_{so}$ = Risk-based target level for outdoor inhalation of vapors from subsurface soils [mg/kg-soil]

$RBTL_{ao}$ = Risk-based target level for outdoor inhalation of air [mg/m^3-air]

VF_{samb} = Volatilization factor from subsurface soil to outdoor (ambient) air [(mg/m^3-air)/(mg/kg-soil)]

Source: ASTM E1739-95



GROUNDWATER CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

$$RBTL_{wo} = \frac{RBTL_{ao}}{VF_{wamb}}$$

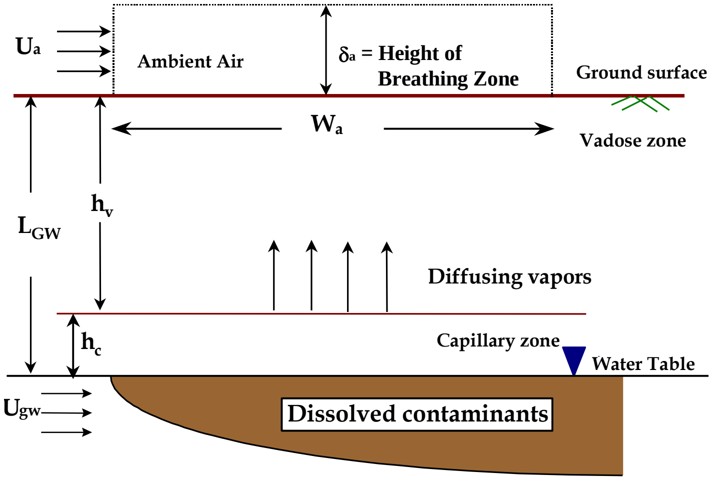
where:

$RBTL_{wo}$ = Risk-based target level for outdoor inhalation of vapors from groundwater [mg/l-H_2O]

$RBTL_{ao}$ = Risk-based target level for outdoor inhalation of air (mg/m^3-air)

VF_{wamb} = Volatilization factor from groundwater to outdoor (ambient) air [(mg/m^3-air)/(mg/l-H_2O)]

Source: ASTM E1739-95



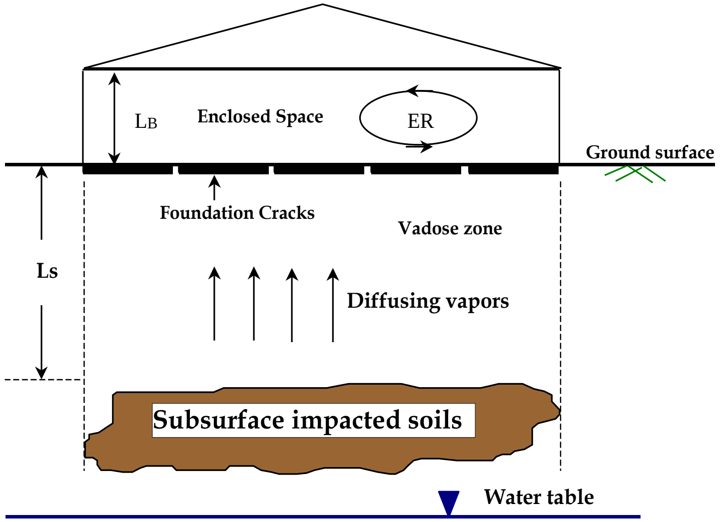
SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{si} = \frac{RBTL_{ai}}{VF_{sesp}}$$

where:

$RBTL_{si}$ = Risk-based target level for indoor inhalation of vapors from subsurface soils [mg/kg-soil]
$RBTL_{ai}$ = Risk-based target level for indoor inhalation of air [mg/m^3-air]
VF_{sesp} = Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]

Source: ASTM E1739-95



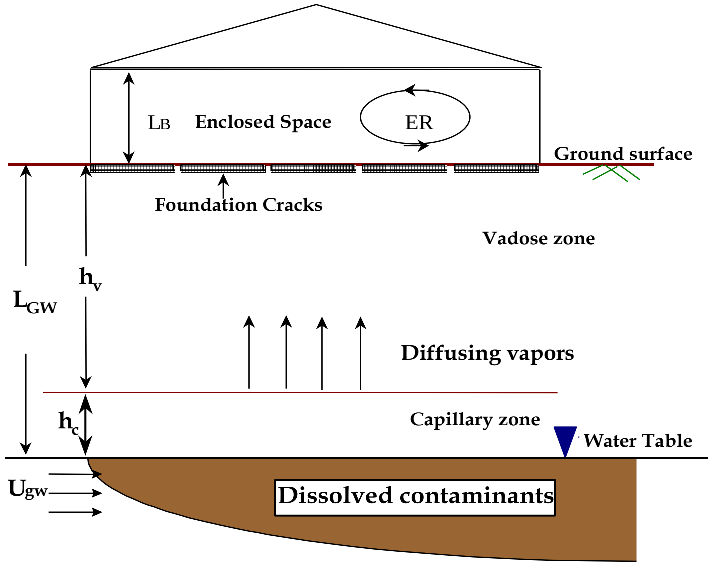
GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

$$RBTL_{wi} = \frac{RBTL_{ai}}{VF_{wesp}}$$

where:

$RBTL_{wi}$ = Risk-based target level for indoor inhalation of vapors from groundwater [mg/l-H_2O]
$RBTL_{ai}$ = Risk-based target level for indoor inhalation of air (mg/m^3-air)
VF_{wesp} = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/l-H_2O)]

Source: ASTM E1739-95



INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT AND INGESTION OF CHEMICALS IN SURFICIAL SOIL

Carcinogenic effects

$$RBTL_{SS} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times [(SF_o \times 10^{-6} \times (IRS \times RAF_o + SA \times M \times RAF_d)) + (SF_i \times IR_{ao} \times (VF_{ss} + VF_p))]}$$

Non-carcinogenic effects

$$RBTL_{SS} = \frac{THQ \times BW \times AT_{nc} \times 365}{EF \times ED \times \left[\frac{10^{-6} \times (IRS \times RAF_o + SA \times M \times RAF_d)}{RfD_o} + \frac{(IR_{ao} \times (VF_{ss} + VF_p))}{RfD_i}\right]}$$

where:

$RBTL_{ss}$ = Risk-based target level in surficial 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 individual constituents [-]

BW = Body weight [kg]

ATc = Averaging time for carcinogens [years]

$ATnc$ = Averaging time for non-carcinogens [years]

ED = Exposure duration [years]

EF = Exposure frequency [days/year]

IRS = Soil ingestion rate [mg/day]

RAF_o = Oral relative absorption factor [-]

SA = Skin surface area [cm^2/day]

M = Soil to skin adherence factor [mg/cm^2]

RAF_d = Dermal relative absorption factor [-]

IR_{ao} = Outdoor inhalation rate [m^3/day]

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

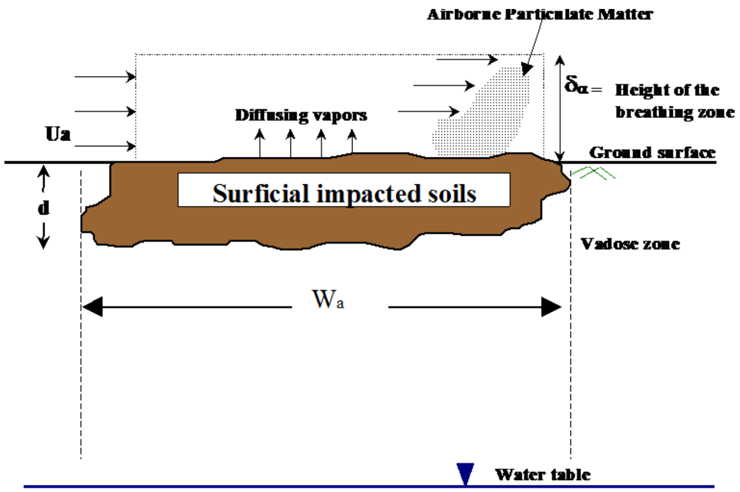
SF_i = Inhalation cancer slope factor [(mg/kg-day)$^{-1}$]

RfD_o = The chemical-specific oral reference dose [(mg/kg-day)]

RfD_i = The chemical-specific inhalation reference dose [(mg/kg-day)]

VF_p = Volatilization factor of particulates [(mg/m^3-air)/(mg/kg-soil)]

VF_{ss} = Volatilization factor from surficial soil [(mg/m^3-air)/(mg/kg-soil)]



Source: ASTM E1739-95

SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER

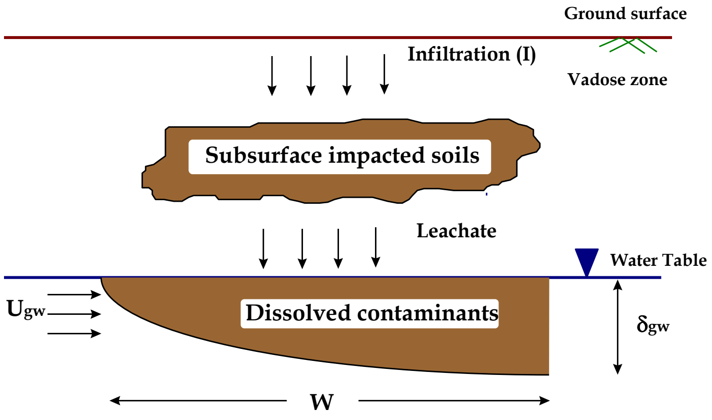
$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

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 E1739-95

VOLATILIZATION FACTORS

VF_{samb} : Volatilization factor from subsurface soil to outdoor (ambient) air [(mg/m^3-air)/(mg/kg-soil)]

$$VF_{samb} = \frac{H \times \rho_s}{\left[\theta_{ws} + \left(K_s \times \rho_s\right) + \left(H \times \theta_{as}\right)\right] \times \left(1 + \frac{U_a \times \delta_a \times L_s}{D_s^{eff} \times W_a}\right)} \times 10^3$$

where:

H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil]
K_s = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]
θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil]
W_a = Length of soil source area parallel to wind direction [cm]
U_a = Wind speed at δ_a above ground surface [cm/s]
δ_a = Breathing zone height [cm]
L_s = Depth to subsurface soil sources [cm]
D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

VF_{wamb} : Volatilization factor from groundwater to outdoor (ambient) air [(mg/m^3-air)/(mg/l-H_2O)]

$$VF_{wamb} = \frac{H}{1 + \left[\frac{U_a * \delta_a * L_{GW}}{W * D_{ws}^{eff}}\right]} * 10^3$$

where:

H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
U_a = Wind speed at δ_a above ground surface [cm/s]
δ_a = Breathing zone height [cm]
L_{GW} = Depth to groundwater [cm]
W = Length of groundwater source area parallel to groundwater flow direction [cm]
D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
10^3 = Conversion factor [l/m^3]

Note that for simplicity, the groundwater flow direction and the wind direction are assumed to be the same.

Source: ASTM E1739-95

$\boldsymbol{VF_{sesp}}$: Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m^3-air)/(mg/kg-soil)]

$$VF_{sesp} = \frac{\dfrac{H \times \rho_s}{[\theta_{ws} + (K_s \times \rho_s) + (H \times \theta_{as})]} \times \left[\dfrac{D_s^{eff} / L_s}{ER \times L_B}\right]}{1 + \left[\dfrac{D_s^{eff} / L_s}{ER \times L_B}\right] + \left[\dfrac{D_s^{eff} / L_s}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta}\right]} \times 10^3$$

Source: ASTM E1739-95

where:

H = Chemical specific Henry's Law constant [(l-H$_2$O)/(l-air)]
ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H$_2$O/cm^3-soil]
K_s = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H$_2$O/g-soil]
θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil]
L_s = Depth to subsurface soil sources [cm]
L_B = Enclosed space volume/infiltration area ratio [cm]
L_{crack} = Enclosed space foundation or wall thickness [cm]
ER = Enclosed space air exchange rate [1/s]
D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s]
η = Areal fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

VF_{wesp} : Volatilization factor from groundwater to indoor (enclosed space) air $[(mg/m^3\text{-air})/(mg/l\text{-}H_2O)]$

$$VF_{wesp} = \frac{H \times \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right]}{1 + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{ER \times L_B}\right] + \left[\dfrac{D_{ws}^{eff} / L_{GW}}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta}\right]} \times 10^3$$

where:

H = Chemical specific Henry's Law constant $[(l\text{-}H_2O)/(l\text{-air})]$

L_{GW} = Depth to groundwater [cm]

L_B = Enclosed space volume/infiltration area ratio [cm]

L_{crack} = Enclosed space foundation or wall thickness [cm]

ER = Enclosed space air exchange rate [1/s]

D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface $[cm^2/s]$

D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks $[cm^2/s]$

η = Areal fraction of cracks in foundation and/or walls $[cm^2\text{-cracks}/ cm^2\text{-total area}]$

10^3 = Conversion factor $[l/m^3]$

Source: ASTM E1739-95

VF_p : Delivery of particulate chemicals from soil to air $[(mg/m^3\text{-air})/(mg/kg\text{-soil})]$

$$VF_p = \frac{P_e \times W_a}{U_a \times \delta_a} \times 10^3$$

where:

P_e = Particulate emission rate $[g\text{-soil}/cm^2\text{-sec}]$

W_a = Length of soil source area parallel to wind direction [cm]

U_a = Wind speed at δ_a above ground surface [cm/s]

δ_a = Breathing zone height [cm]

10^3 = Conversion factor $[(cm^3\text{-kg})/(m^3\text{-g})]$

Source: ASTM E1739-95

VF_{ss} : Volatilization factor from surficial soil [(mg/m^3-air)/(mg/kg-soil)]

*** *choose the smaller of the two* ***

$$VF_{ss} = \frac{2 \times W_a \times \rho_s}{U_a \times \delta_a} \times \sqrt{\frac{D_s^{eff} \times H}{\pi \times [\theta_{ws} + \left(K_s \times \rho_s\right) + \left(H \times \theta_{as}\right)] \times \tau}} \times 10^3$$

where:

W_a = Length of soil source area parallel to wind direction [cm]
ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
U_a = Wind speed at δ_a above ground [cm/s]
δ_a = Breathing zone height [cm]
D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_s = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
τ = Averaging time for vapor flux [s]
= *ED (yr) × 365 (day/yr) × 86400 (sec/day)*
10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

$$VF_{ss} = \frac{W_a \times \rho_s \times d}{U_a \times \delta_a \times \tau} \times 10^3$$

where:

W_a = Length of soil source area parallel to wind direction [cm]
ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
d = Depth to base of surficial soil zone [cm]
U_a = Wind speed at δ_a above ground surface [cm/s]
δ_a = Breathing zone height [cm]
τ = Averaging time for vapor flux [s]
= *ED (yr) × 365 (day/yr) × 86400 (sec/day)*
10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

Source: ASTM E1739-95

EFFECTIVE DIFFUSION COEFFICIENTS

D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]

$$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a = Chemical-specific diffusion coefficient in air [cm^2/s]
D^w = Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as} = Volumetric air content in vadose zone [cm^3-air/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone [cm^3-H_2O/cm^3-soil]
θ_T = Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

D_{ws}^{eff} : effective diffusion coefficient between groundwater and surface soil [cm^2/s]

$$D_{ws}^{eff} = (h_{cap} + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$

where:

h_{cap} = Thickness of capillary fringe [cm]
h_v = Thickness of vadose zone [cm]
D_{cap}^{eff} = Effective diffusion coefficient through capillary fringe [cm^2/s]
D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
L_{GW} = Depth to groundwater ($h_{cap} + h_v$) [cm]

D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s]

$$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a = Chemical-specific diffusion coefficient in air [cm^2/s]
D^w = Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acap} = Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{wcap} = Volumetric water content in capillary fringe soils [cm^3-H_2O/cm^3-soil]
θ_T = Total soil porosity [cm^3/cm^3-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

D_{crack}^{eff} : effective diffusion coeff. through foundation cracks [cm^2/s]

$$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^{2.0}}$$

where:

D^a = Chemical-specific diffusion coefficient in air [cm^2/s]
D^w = Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acrack} = Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume]
θ_{wcrack} = Volumetric water content in foundation/wall cracks [cm^3-H_2O/cm^3-total volume]
θ_T = Total soil porosity [cm^3/cm^3-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

Source: ASTM 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 = seepage velocity [cm/year]

λ = first order decay rate [1/year]

α_x = longitudinal dispersivity [cm]

α_y = lateral dispersivity [cm]

α_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]

δ_{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:

$$\frac{C(x)}{C_o} = erf\left[\frac{Y}{4\sqrt{\alpha_y\,x}}\right]\times erf\left[\frac{\delta_{gw}}{2\sqrt{\alpha_z\,x}}\right] \qquad (2)$$

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 [--]

θ_{TS} = Total porosity in the saturated zone [cm^3/cm^3-soil]

R_s = Retardation factor in the saturated zone [--]

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

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

where:

ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil]
K_s = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]
f_{oc} = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw} = Groundwater Darcy Velocity [cm/year]
δ_{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]

Source: ASTM E1739-95

C_s^{SAT} : Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]

$$C_s^{sat} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_s\,\rho_s]$$

where:

S = Pure component solubility in water [mg/L-H_2O]
ρ_s = Dry soil bulk density [g-soil/cm^3-soil]
H = Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_s = $f_{oc} \times K_{oc}$
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm^3-H_2O/g-soil]

Source: ASTM E1739-95

ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Allowable soil concentration at the source} = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{LF_{SW}}$$

$$\text{Allowable groundwater concentration at the source} = \textit{Target groundwater concentration at the POE} \times DAF_{POE}$$

$$\text{Allowable groundwater concentration at the POC} = \textit{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{DAF_{POC}}$$

where:

POE = Point of exposure
POC = Point of compliance
DAF_{POE} = Dilution Attenuation Factor between the point of exposure and the source
DAF_{POC} = Dilution Attenuation Factor between the point of compliance and the source
LF_{SW} = Dry soil leaching factor

Additional relationships used in the calculation of allowable soil and groundwater concentration with chemical degradation:

$$\text{First order decay rate} = \frac{0.693}{\textit{Half Life}}$$

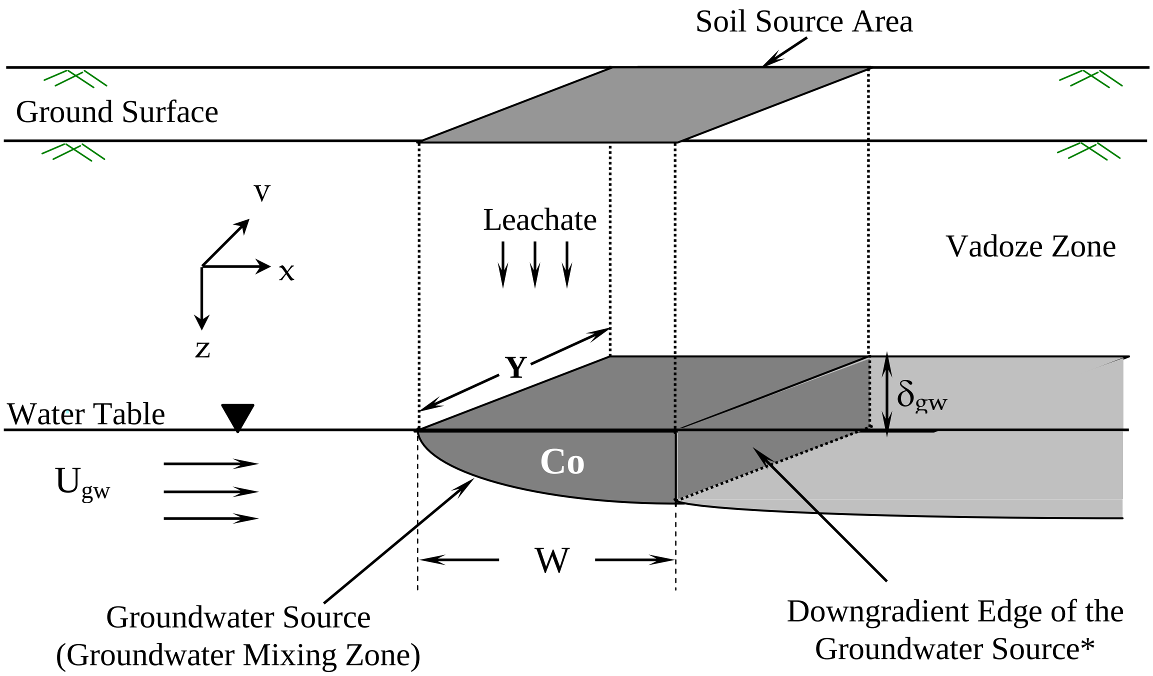
$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}} \right) \qquad K_{ss} = foc_s \times K_{oc}$$

$$\text{Retardation Factor for Metals in the saturated zone } (R_s) = 1 + \left(\frac{\rho_{ss} \times K_d}{\theta_{TS}} \right)$$

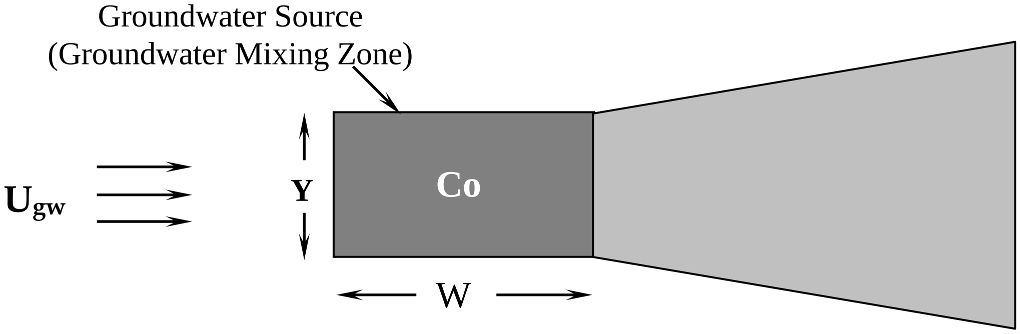
where:

ρ_{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]
θ_{TS} = Total porosity in the saturated zone [cm^3/cm^3-soil]
foc_s = 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.)

APPENDIX F
ARBCA REPORT FORMS

This Appendix contains a paper copy of the ARBCA report forms. If you have downloaded this from the ADEM website, you will need to print out a blank copy of the forms from the ARBCA report forms and software disks or CD-ROM.

APPENDIX G
USER'S GUIDE FOR ARBCA REPORT FORMS AND COMPUTATIONAL SOFTWARE

This appendix applies to both the ARBCA Report Forms and the Computational Software.

INTRODUCTION

The ARBCA Report Forms are distributed on one CD. The CD contains 4 files (one Microsoft Word and three Microsoft Excel files):

1. T1Forms.doc (contains Forms 1 to 12)
2. T1Forms.xls (contains Forms 13 to 23)
3. T2Forms.xls (contains Forms 24 to 30)
4. T3Forms.xls (contains Forms 31 to 36)

The MS Word file (T1Forms.doc) as the name implies contain forms for one of the three different tiers within the ARBCA program. The MS Excel files (T1Forms.xls, T2Forms.xls, and T3Forms.xls) contain forms for Tier 1, Tier 2, and Tier 3 analyses.

HARDWARE AND SOFTWARE REQUIREMENTS

To use the ARBCA Forms, you need:

- An 80386-based computer or better.
- A monitor with VGA capabilities or better. An 800x600 resolution is highly recommended.
- A mouse.
- A CD-ROM drive.
- Microsoft (MS) Windows 3.1 or later version.
- Microsoft (MS) Excel 5.0 or later version.
- 8 megabytes of random access memory (RAM).
- 1 megabytes of disk space per worksheet module beyond the installation of MS Windows and MS Excel or MS Word.

PREREQUISITES

Operating knowledge and intermediate level of experience of both MS Word and MS Excel.

INSTALLATION

- Insert the CD into the CD-ROM drive.
- Create directory in your harddrive,

e.g. *MD C:\Alabama if using MSDOS prompt. Window 3.1 users can create a directory in the File Manager and Windows 95 users in the Explorer.*

- Copy the files from the CD-ROM drive to the directory,
  e.g. *COPY D:*.* C:\Alabama*.**

USING THE FORMS

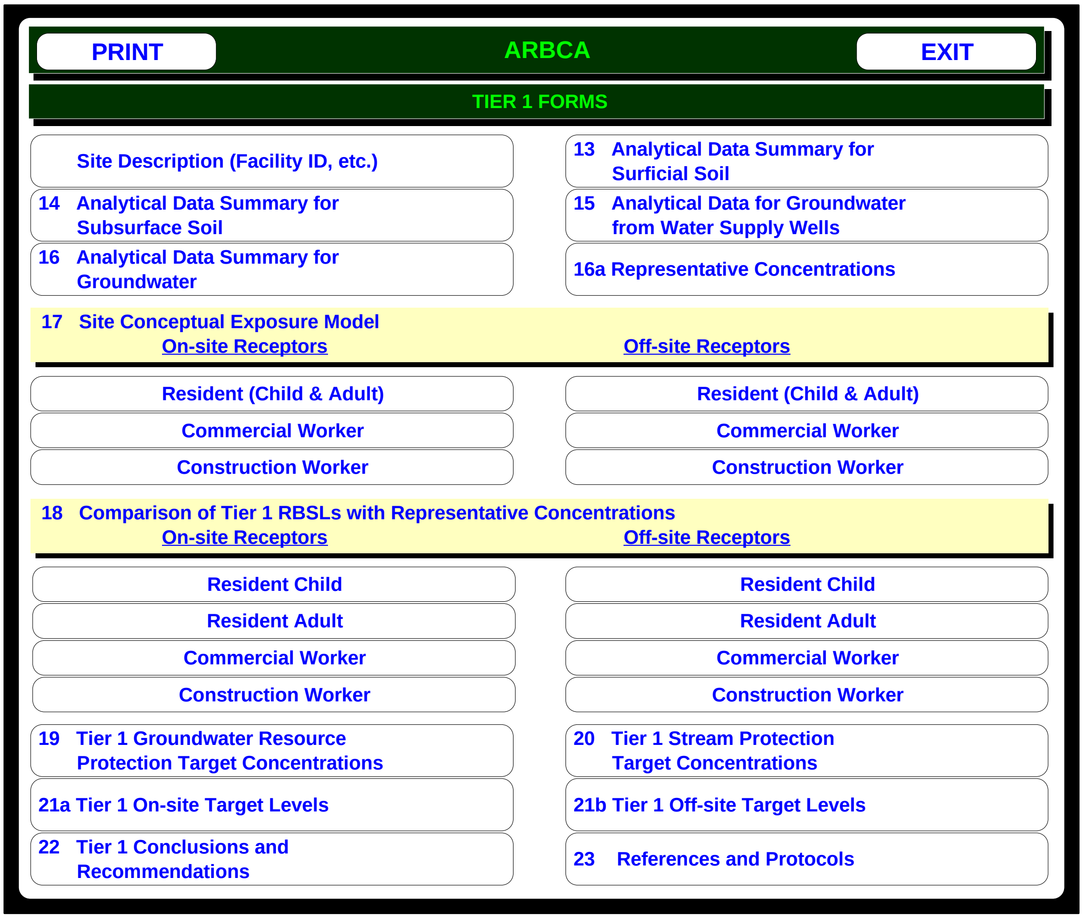
<u>Note</u>: Consult your Microsoft Word and Excel manual for the basic word processor and/or spreadsheet operations.

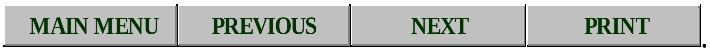
MS Word Files

- Use ***"File"*** and ***"Open"*** command from MS Word menu to open the file.
- Be sure to check the boxes besides the forms in the table of contents to indicate forms used and the maps attached.
- Each form is on a separate page. Use the vertical scroll bar to scroll through the document.
- These documents contain several checkboxes - ☒ and text boxes - **[** ▨ **]**. Text has to be entered only in these text boxes and within the parentheses. To enter text, click on the text box using the cursor, and start typing once the box is highlighted. Use the ***"Tab"*** button to select the next checkbox and/or text box. Alternatively, ***"Shift+Tab"*** allows the user to select a previous checkbox and/or text box.
- This package will not allow the user to (i) change the information originally present on the form, (ii) change the formatting, or (iii) to enter text in spaces other than the text boxes.
- To ensure that all of the bookmarks (Check boxes and Text Boxes) are highlighted, check the option for ***"Bookmarks"*** under ***"Page Layout View Options"***. To access Page Layout View Options, select ***"Tools"*** from the toolbar followed by ***"Options"*** and finally ***"View"*** within options.

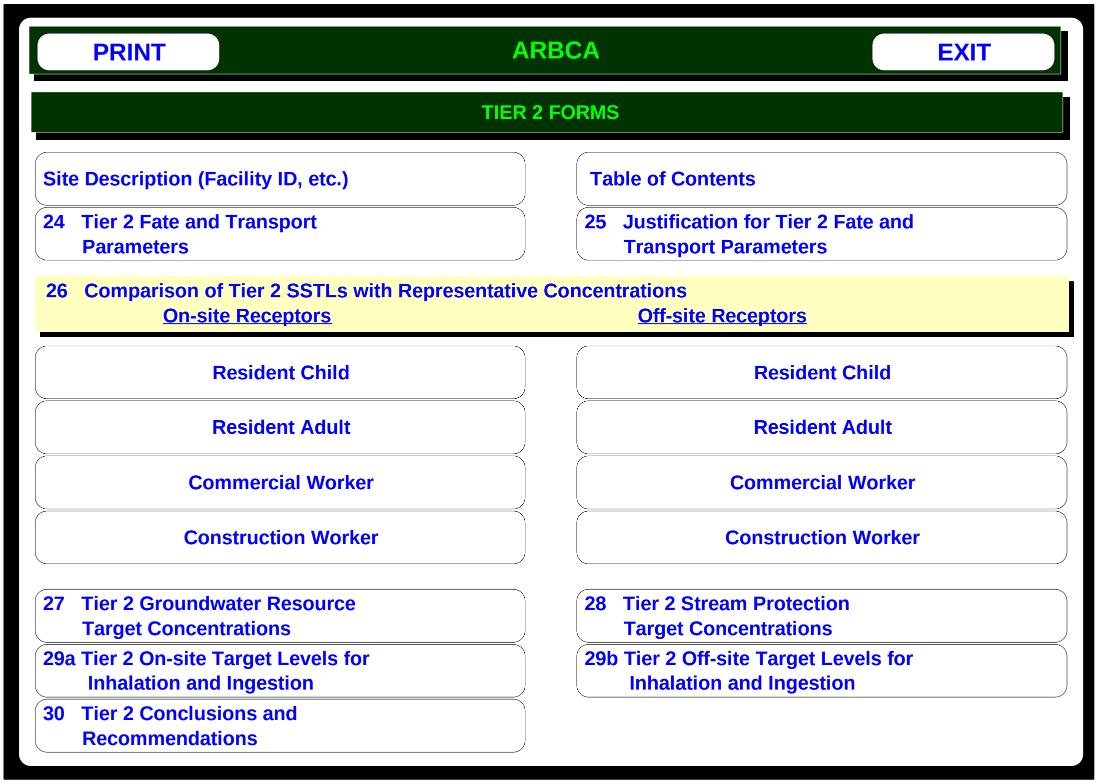
MS Excel File

- Use ***"File"*** and ***"Open"*** command from MS Excel menu to open the file.
- Use the ***"Main Menu"*** in the package to browse through the software. Once within the package, the **MAIN MENU** button, provided at the top of each form enables the user to get to the Main Menu. The relationship of the button to the ARBCA Forms is shown in the picture below.



- Enter your data in red-underlined spaces only. The package will not allow the user to (i) change the information originally present on the form, (ii) change the formatting, or (iii) enter data in spaces without red-underlined spaces.
- Each form has four options, . The first button takes you to the Main Menu, the second takes you to the previous form, the third takes you to the next form, and the fourth button prints the worksheet (other options for printing these forms are provided in the next section).

- **Hint:** Save the file under a different name. Use the "***File***" and "***Save As***" command from MS Excel menu.
- Worksheet should be viewed at 100% to see all labels and columns.



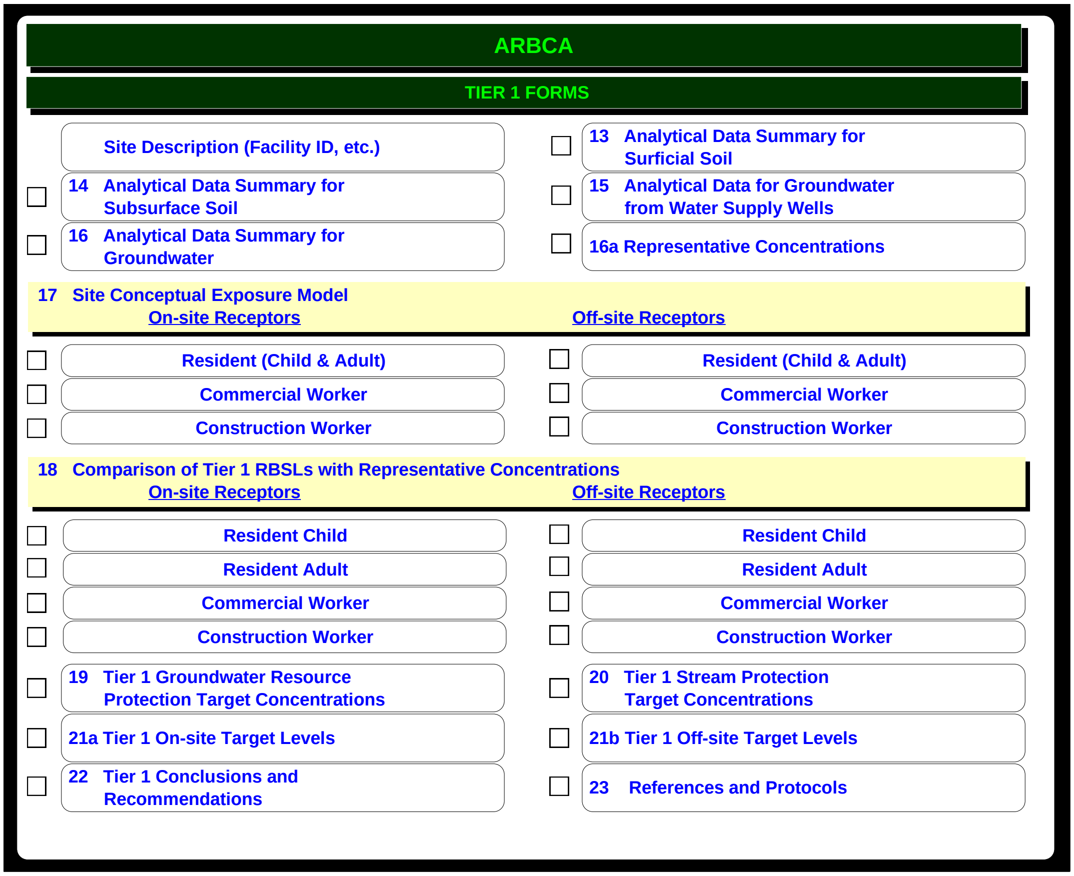
PRINTING THE FORMS

MS Word Files

- Use the ***PRINT*** icon to print the whole document in the file.
- If you desire to print only one Form, place the cursor on that Form and use the ***"Print"*** command in the ***File Menu*** (or use Ctrl+P) and then select ***"Current Page"*** before clicking the Print button.

MS Excel Files

- Click on the ***PRINT*** button on the ***MAIN MENU***.



ARBCA

TIER 1 FORMS

Site Description (Facility ID, etc.)
☐ 13 Analytical Data Summary for Surficial Soil
☐ 14 Analytical Data Summary for Subsurface Soil
☐ 15 Analytical Data for Groundwater from Water Supply Wells
☐ 16 Analytical Data Summary for Groundwater
☐ 16a Representative Concentrations

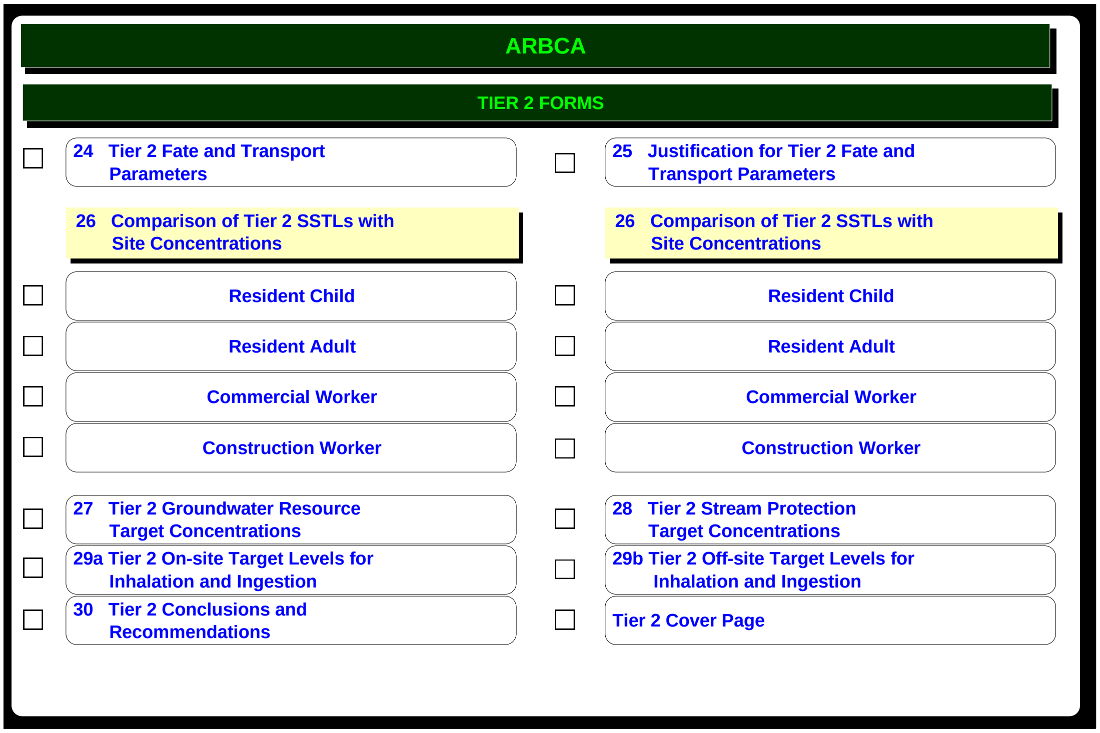
17 Site Conceptual Exposure Model

On-site Receptors	Off-site Receptors
☐ Resident (Child & Adult)	☐ Resident (Child & Adult)
☐ Commercial Worker	☐ Commercial Worker
☐ Construction Worker	☐ Construction Worker

18 Comparison of Tier 1 RBSLs with Representative Concentrations

On-site Receptors	Off-site Receptors
☐ Resident Child	☐ Resident Child
☐ Resident Adult	☐ Resident Adult
☐ Commercial Worker	☐ Commercial Worker
☐ Construction Worker	☐ Construction Worker

☐ 19 Tier 1 Groundwater Resource Protection Target Concentrations
☐ 20 Tier 1 Stream Protection Target Concentrations
☐ 21a Tier 1 On-site Target Levels
☐ 21b Tier 1 Off-site Target Levels
☐ 22 Tier 1 Conclusions and Recommendations
☐ 23 References and Protocols



ARBCA

TIER 2 FORMS

☐ 24 Tier 2 Fate and Transport Parameters
☐ 25 Justification for Tier 2 Fate and Transport Parameters

26 Comparison of Tier 2 SSTLs with Site Concentrations	26 Comparison of Tier 2 SSTLs with Site Concentrations
☐ Resident Child	☐ Resident Child
☐ Resident Adult	☐ Resident Adult
☐ Commercial Worker	☐ Commercial Worker
☐ Construction Worker	☐ Construction Worker

☐ 27 Tier 2 Groundwater Resource Target Concentrations
☐ 28 Tier 2 Stream Protection Target Concentrations
☐ 29a Tier 2 On-site Target Levels for Inhalation and Ingestion
☐ 29b Tier 2 Off-site Target Levels for Inhalation and Ingestion
☐ 30 Tier 2 Conclusions and Recommendations
☐ Tier 2 Cover Page

- Check the boxes beside the Forms you desire to print and click print.
- There are options for ***selecting*** or ***deselecting*** all the Forms simultaneously.
- The ***CANCEL*** button takes you back to the ***MAIN MENU***.
- Alternatively, the user can print each form one at a time by using the ***PRINT icon*** in the MS Excel toolbar directly.

SPECIAL INSTRUCTIONS

MS Excel Files

T1Forms.xls

Site Description

This form is provided to automate the entry of header information required on each report form and need not be included in the submitted report.

Form Nos. 13,14,15, and 16

The evaluator must note whether data entered is onsite or offsite. Checkboxes are available to identify location of the analytical data. If there are multiple offsite properties with data, the evaluator must clearly identify which offsite property the offsite data represents. In the event multiple offsite properties have been impacted, the evaluator must select which offsite data will be entered into the forms with the initial onsite evaluation. Any additional offsite data for other offsite properties can be evaluated using a separate set(s) of forms.

Form No. 17 - Site Conceptual Exposure Model

On Form No. 17, “C” represents a complete pathway whereas “NC” represents an incomplete pathway. For each receptor-route of exposure combination, you must enter either “C” or “NC”, and provide justification.

Form No. 18 - Comparison of Representative Site Concentrations with RBSLs

This form compares the representative site concentrations with RBSLs. The information that the evaluator must enter includes:

1) Selection of the appropriate type of representative concentration. Different representative concentrations can be selected for the various media and for various

receptors. The appropriate representative concentration is selected by checking either maximum, arithmetic average, or area-weighed average.

2) If the ingestion of water pathway is complete, the evaluator must enter the historical maximum concentration for the well of concern into the column entitled "Rep. Conc."

As mentioned in the footnote, "E" indicates that the representative site concentration exceeds the RBSL, and "NE" indicates that the representative site concentration does not exceed the RBSL.

Form No. 19 – Tier 1 Groundwater Resource Protection Target Concentrations

All the data must be entered onto this form. The evaluator must use the computational software to determine the allowable concentrations for soil and groundwater. The evaluator must enter the appropriate representative concentration for the soil source, the groundwater source well, and the compliance well(s).

Form No. 20 – Tier 1 Stream Protection Target Concentrations

All the data must be entered onto this form. The evaluator must use the computational software to determine the allowable concentrations for soil and groundwater. The evaluator must enter the appropriate representative concentration for the soil source, the groundwater source well, comparison for compliance well at the streambank, and the compliance well(s) between the source and the streambank.

Form No. 23 – References and Protocols

Please note that ARBCA Form No. 23 is for ***"References and Protocols"***. The location of this form along with other forms for a Tier 1 evaluation in T1Forms.xls may indicate that this form is for a Tier 1 evaluation only. On the contrary, this form is not tier specific and must be used with all ARBCA analyses.

T2Forms.xls

Form No. 24 - Fate and Transport Parameters

If a Tier 2 value is entered in this sheet, the program will automatically identify it either as the Tier 1 value, or a site-specific value. If site-specific values are used, justification must be provided on Form 25.

Form No. 26 - Comparison of Representative Site Concentrations with SSTLs

Because the Tier 2 forms are in a different excel file from the representative concentration data entered on Tier 1 forms, the evaluator must type in the representative concentrations, and the SSTLs. The evaluator must check the type of representative concentration used for each medium.

Form No. 27 - Tier 1 Groundwater Resource Protection Target Concentrations

All the data must be entered onto this form. The evaluator must use the computational software to determine the allowable concentrations for soil and groundwater. The evaluator must enter the appropriate representative concentrations for the soil source, the groundwater source well, and the compliance well(s).

Form No. 28 - Tier 1 Stream Protection Target Concentrations

All the data must be entered onto this form. The evaluator must use the computational software to determine the allowable concentrations for soil and groundwater. The evaluator must enter the appropriate representative concentrations for the soil source, the groundwater source well, comparison for compliance well at the streambank, and the compliance well(s) between the source and the streambank.

INTRODUCTION

The ARBCA spreadsheet software program (Microsoft Excel file) is distributed on one CD.

HARDWARE AND SOFTWARE REQUIREMENTS

To use the spreadsheet program, you need:

- An 80386-based computer or better.
- A monitor with VGA capabilities or better. An 800x600 resolution is highly recommended.
- A mouse.
- Microsoft (MS) Windows 3.1 or later version.
- Microsoft (MS) Excel 5.0 or later version.
- 8 megabytes of random access memory (RAM).
- 1 megabytes of disk space per worksheet module beyond the installation of MS Windows and MS Excel or MS Word.
- CD-ROM

PREREQUISITES

Operating knowledge and intermediate level of experience with MS Excel.

INSTALLATION

- Insert the CD into the CD-ROM.
- Create directory in your harddrive,

  e.g. *MD C:\Alabama if using MSDOS prompt. Window 3.1 users can create a directory in the File Manager and Windows 95 users in the Explorer.*
- Copy the files from the CD to the directory,

  e.g. *COPY D:*.* C:\Alabama*.**

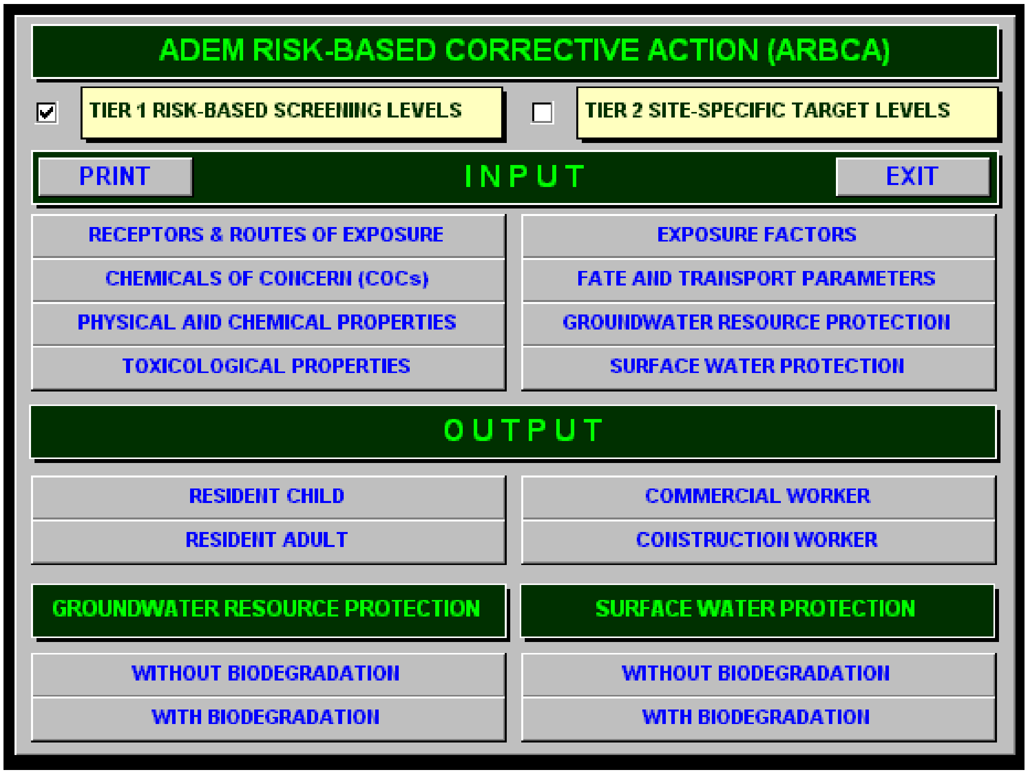
SPECIAL INSTRUCTIONS

- The ***"Analysis ToolPak"*** in MS Excel is a required add-in. Use ***"Tools"*** from the main toolbar in an open workbook and click on ***"Add-ins…"***. In the following menu, select both ***"Analysis ToolPak"*** as well as ***"Analysis ToolPak - VBA"*** (Consult your MS Excel manual for further help on "Add-ins").

OPERATING THE SPREADSHEET PROGRAM

Note: Consult your Microsoft Excel manual for the basic spreadsheet operations.

- Use ***"File"*** and ***"Open"*** command from MS Excel menu to open the file.
- Use the ***"Main Menu"*** in the package to browse through the software. Once within the package, the **MAIN MENU** button, provided on all the input/output tables enable the user to get to the Main Menu. The relationship of the buttons to the operations is shown in the picture below.



- Click on the buttons to access different input/output screen, e.g., click button *Click Here* to Select receptors and ROE.
- Each input/output screen have four options, **MAIN MENU** | **PREVIOUS** | **NEXT** | **PRINT**.
- The first button takes you to the Main Menu, the second takes you to the previous table, the third takes you to the next table, and the fourth button prints the table (other options for printing these tables are provided in the next section).

- **Hint:** Save the file under a different name. Use the "***File***" and "***Save As***" command from MS Excel menu.

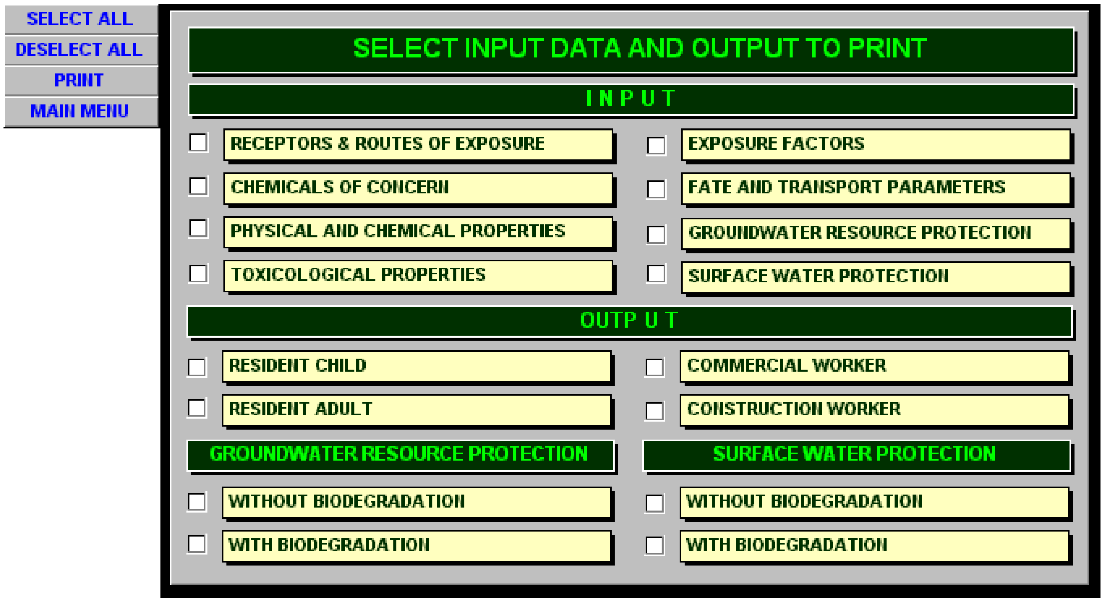
The only screens for data entry for Tier 2 evaluations will be the worksheets entitled:

- Fate and Transport Parameters
- Groundwater Resource Protection
- Surface Water Protection

The other worksheets contain the information that the models require to develop the SSTLs. Only in a Tier 3 evaluation would parameters on those worksheets not listed above be changed to use site-specific parameters.

PRINTING

- Click on the ***PRINT*** button on the ***MAIN MENU***. The following window appears:



- Selecting the checkboxes besides each input/output screen and clicking the ***PRINT*** button will enable the user to print the desired input/output screens.
- There are options for ***selecting*** (***SELECT ALL*** button) or ***deselecting*** (***DESELECT ALL*** button) all the screens simultaneously.
- The ***MAIN MENU*** button returns the user back to the ***MAIN MENU***.
- Alternatively, the user can use the ***PRINT icon*** in the MS Excel toolbar directly to print each screen individually.

STREAM PROTECTION

To calculate the Tier 1 (i) Soil Source Concentrations Protective of a Stream, (ii) Groundwater Source Concentrations Protective of a Stream, or (iii) Groundwater Concentrations at the Point of Compliance Protective of a Stream, ensure that the checkbox for "***Tier 1 Risk-Based Screening Levels***" in the "***Main Menu***" is checked. Conversely, to calculate Tier 2 SSTLs, ensure that the checkbox for "***Tier 2 Site-Specific Screening Levels***" in the "***Main Menu***" is checked.

APPENDIX H
EVALUATION OF THE INDOOR INHALATION PATHWAY

EVALUATION OF THE INDOOR INHALATION PATHWAY

H.1 BACKGROUND

A key element of the Alabama Risk-Based Corrective Action (ARBCA) process is the evaluation of risk or the determination of target levels for each current and potential future complete **route of exposure** (**ROE**). One of the ROE that is often complete at many contaminated sites is the inhalation of vapors emitted from soil or groundwater to outdoor or indoor air. Refer to Figure H-1 for a schematic of four ROE associated with the inhalation of vapors. A fifth route of exposure, outdoor inhalation of vapors and particulates from surficial soil is not shown in Figure H-1.

The quantitative evaluation of these ROE requires either the estimation of risk (forward mode of evaluation) based on known soil or groundwater concentrations or the estimation of soil or groundwater target concentrations (backward mode of evaluation) based on an acceptable level of risk. Unless site-specific indoor or outdoor air measurements are made at a site, evaluation of these ROE requires the application of two coupled models (i) a vapor emission, and (ii) a vapor dispersion model. The emission model estimates the mass of chemical emitted from soil or groundwater into the outdoor or indoor air. The dispersion model calculates concentration in the air based on the calculated emission rate.

Application of the ARBCA process at numerous underground storage tank (UST) sites has indicated that the indoor inhalation ROE often results in the lowest or most conservative target levels for soil and groundwater. This is generally attributed to the conservative assumptions inherent in the emission models. Therefore, the ADEM has developed this guidance for the evaluation of indoor inhalation ROE within the tiered ARBCA approach. The focus of this document is on indoor inhalation only since experience suggests that outdoor inhalation rarely results in unacceptable risk. However, at sites where the outdoor inhalation pathway is complete, it must also be quantitatively evaluated.

H.2 FLOWCHART TO EVALUATE INDOOR INHALATION PATHWAY

Figure H-2 shows the recommended step-by-step approach to evaluate indoor inhalation ROE. Each of the steps illustrated in the flowchart is described below:

Step 1: Evaluate whether the pathway is complete

This step is part of the development of a site conceptual exposure scenario, as discussed in Section 6.5 of this document**.** In general, it is necessary to determine which of the following five inhalation related ROE are complete:

- Outdoor inhalation of vapors and particulate from surficial soil,
- Indoor inhalation of volatile emissions from subsurface soils,
- Outdoor inhalation of volatile emissions from subsurface soils,
- Indoor inhalation of volatile emissions from groundwater,
- Outdoor inhalation of volatile emissions from groundwater.

Section H.3 of this appendix provides guidance to evaluate which of the above ROE are complete. If any one of these ROE is complete, perform Step 2.

Step 2: Perform a Tier 1 evaluation

Tier 1 evaluation requires the comparison of the pathway-specific representative soil or groundwater concentrations with the Tier 1 Risk-Based Screening Levels (RBSLs). The RBSLs are tabulated in Tables 7-2 (a) to 7-2 (d) of this document. Typically, soil vapor measurements would not be available while a Tier 1 evaluation is being performed. However, if soil vapor measurements are available, they may be compared with Tier 1 RBSLs for indoor air in the attached Table H-1, and the Tier 1 Soil and Groundwater Vapor RBSLs in Table H-2. See Section H.5 for further information on the use of Tables H-1 and H-2.

Step 3: Determine the next step: Tier 2 evaluation or corrective action plan

Based on the comparison in Step 2, the following two alternatives are possible:

> **Alternative 1:** The representative soil and groundwater concentrations or the soil vapor concentrations are below the Tier 1 target levels and the ADEM determines that the available data is sufficient. In this case the ADEM may grant a no further action/closure for the inhalation pathways. In making this decision, comparison with measured soil vapor levels may be given precedence over the comparison with soil and groundwater concentrations. Note, additional monitoring and or corrective

action may be required to achieve site no further action status based on other complete pathways such as the protection of groundwater resources.

Alternative 2: The representative soil or groundwater concentrations exceed the Tier 1 levels as found in Table H-1 or H-2. For this alternative the following two options are available:

- **Option 1:** The ARBCA evaluator may adopt Tier 1 RBSLs as the cleanup levels, develop a corrective action plan (CAP) to achieve the cleanup levels, and submit the CAP to the ADEM for approval. The CAP should be implemented in a timely manner following approval by the ADEM.

- **Option 2:** The ARBCA evaluator may choose to perform a Tier 2 evaluation. The specifics of a Tier 2 evaluation will differ depending on whether representative soil vapor data is available. If soil vapor data is available, it should be used to estimate the risk as discussed in Step 7; otherwise soil and groundwater Tier 2 Site-Specific Target Levels (SSTLs) should be developed as discussed in Step 4.

Step 4: Develop soil and groundwater Tier 2 SSTLs

A Tier 2 evaluation may require the collection of additional site-specific data including but not limited to vadose zone soil bulk density, moisture content, organic carbon content, and soil porosity. Using the procedures described in Section 8.0 of this document, Tier 2 SSTLs for soil and groundwater should be developed for each complete route of exposure. The SSTLs should be compared with representative concentrations, as discussed in Step 5.

In the event that representative soil vapor data is available, Tier 2 SSTLs for soil vapor may be developed using the equations included in Attachment 1.

Step 5: Determine the next step: no further action or soil vapor measurement

The soil and groundwater SSTLs developed in Step 4 should be compared with the representative concentrations to determine the next step. Specifically, the following two alternatives are possible:

Alternative 1: If neither the soil nor groundwater representative concentrations exceed the SSTLs, and the ADEM determines that the available data is sufficient, then the ADEM may not require any further action for the inhalation pathways. Note additional monitoring and or corrective action may be required to achieve site no further action status based on the evaluation of other complete pathways such as the protection of groundwater.

Alternative 2: The soil and or groundwater representative concentrations exceed the SSTLs. For this case, the following two options are available:

- **Option 1:** The ARBCA evaluator may adopt the Tier 2 SSTLs as the cleanup levels, develop a corrective action plan (CAP) to meet the cleanup levels, and submit the CAP to the ADEM. The CAP should be implemented in a timely manner following approval by the ADEM.

- **Option 2:** The ARBCA evaluator may choose to obtain soil vapor measurements in the subsurface.

Step 6: Soil vapor measurements

The ARBCA evaluator should develop and submit to the ADEM a work plan to perform a soil vapor survey as per the guidelines provided in Section H.4. The work plan should be implemented in a timely manner upon receiving approval from the ADEM. Upon completion of the field measurements, the data should be quantitatively evaluated as discussed in Step 7.

Step 7: Evaluate the soil vapor data

The soil vapor data collected in Step 6 should be quantitatively evaluated using the hierarchical approach discussed in Section H.5. The evaluation involves the comparison of soil vapor concentrations with soil vapor target levels and the estimation of risk if the target levels are exceeded.

Step 8: Determining the next course of action

If the estimated risk exceeds the acceptable level, the ARBCA evaluator should develop a CAP to meet the soil vapor target levels. The CAP should be implemented in a timely manner following approval by the ADEM. Upon completion of the corrective action, additional confirmatory sampling of soil vapor may be required by the ADEM.

H.3 DETERMINE WHETHER THE INHALATION PATHWAY IS COMPLETE

One of the first steps in the evaluation of indoor inhalation is to determine whether the pathway is complete. Site-specific information and professional judgement should be used to determine whether the pathway is complete. A few conditions under which the pathway may not be complete are:

1. The chemicals of concern at the site are non-volatile. If the chemicals of concern do not include any volatile chemicals, the indoor inhalation pathway for both current and future conditions would be incomplete.

2. For future conditions, site-specific land use conditions will determine whether a building may be built onsite. The pathway would be incomplete if such conditions prohibit the construction of a building onsite. Examples of such conditions include a spill over a pipeline right-of-way, the impacted area abuts a busy highway, or when the responsible party imposes an enforceable restriction (acceptable to the ADEM) that prevents the construction of a building.

3. The existing or planned future buildings have a vapor barrier or a ventilated crawl space that prevents the migration of vapors into a building.

H.4 PROTOCOL FOR THE MEASUREMENT OF SOIL VAPOR LEVELS

The intent of the soil gas measurements is to obtain spatial and temporal representative values that can be used to estimate the risk to the receptors. Soil vapor concentrations at a site are affected by a number of factors. These include (i) atmospheric conditions (temperature, pressure, moisture content etc.), (ii) soil stratigraphy, (iii) heterogeneity of soil, (iv) location of source, (v) age of the spill, especially for hydrocarbons, (vi) the biodegradation characteristics of the soil-chemical “system”, and (vii) the measurement location.

To the extent that the above factors exhibit spatial and temporal variations, the soil vapor concentrations can be variable. Thus, a single soil gas-sampling event or a single soil gas-sampling location is not adequate to characterize potential air exposure pathways. Multiple measurements must be made over time and at various locations and depths to estimate a representative soil vapor concentration. Note, two to four sampling events should occur at different times of the year or in two different years. These could include, for example, measurements in winter and summer. At sites where there are significant seasonal water table fluctuations, measurements should be made both when the water table is high and when it is low.

A soil vapor measurement work plan should be developed that will provide for the estimation of representative soil vapor concentrations. The ARBCA evaluator should refer to published literature including ***Standard Guide for Soil Gas Monitoring in the Vadose Zone*** (ASTM, 1994) while preparing the work plan. The work plan should be submitted to the ADEM and approved prior to collecting this data. The work plan should include:

- The location where samples will be collected.
- The depth where samples will be collected.
- The number of samples to be collected.
- The times of different collection events.
- Soil gas measurement technique and analysis.
- The QA/QC procedures.

Each of these factors is discussed below.

H.4.1 The location where samples will be collected.

The following should be considered when identifying the location of soil vapor measurement borings:

- The location of the release area,
- The location of highest groundwater concentration(s),
- The location of highest soil concentration(s),
- The location of existing onsite buildings,
- The location of potential future onsite buildings,

- The location of existing offsite buildings below which the groundwater plume may have migrated,
- The location of potential future offsite buildings below which the groundwater plume may migrate.

Samples should be collected around the footprint of an existing or potential future building. In all cases, at least one soil vapor boring should be located in the source area, i.e., the most affected soil area and above the highest groundwater concentration area. Sampling at offsite locations will only be required if the groundwater plume has migrated offsite or is likely to migrate offsite, or if contaminated soil is present offsite.

The ARBCA evaluator should clearly indicate the proposed locations of soil vapor borings on a site map and the rationale for the location.

H.4.2 The depth where samples will be collected.

The depth at which samples will be collected depends on the depth to soil contamination and the depth to groundwater, (if vapor inhalation from groundwater is of concern). The sampling system should consider the collection of soil vapor samples at various depths as appropriate. Unless the depth to contamination (soil or groundwater) is very shallow (approximately 3 feet), a minimum of two and possibly three samples at varying depths should be collected. In all cases, one sample should be collected at least as shallow as 3 feet below the foundation of the existing building or potential future building. For structures with basements, soil gas samples should be collected below and adjacent to the basement walls. Recommended sampling locations are shown in Figure H-3.

In most cases soil vapor samples should be collected within a depth of 10 feet below the foundation of the building. Further, samples should not be collected within the capillary fringe.

H.4.3 The number of samples to be collected.

The number of soil gas samples to be collected will depend on site-specific conditions. For existing buildings, with soil or groundwater contamination below them, four borings, one on each side of the building is recommended. At each boring, samples at several depths should be collected. Additionally, one or more borings should be located in the source area.

H.4.4 The times of different collection events.

Depending on site-specific variations, multiple soil vapor measurements during a year may be necessary. Site-specific factors that may affect the timing of measurements include fluctuations in soil and groundwater temperature, depth to groundwater, and soil moisture content. The intent of multiple soil vapor measurements is to obtain measurements representative of the range of site conditions. The ARBCA evaluator should propose the timing of soil vapor measurements so that they are representative of the temporal variations in the above factors.

H.4.5 Soil gas measurement technique and analysis.

As mentioned above, it will be necessary to collect soil vapor samples from the soil borings/ implants at multiple times. Hence the implants should be sturdy and their location clearly identifiable so that they can be used for repeat measurements over an extended period of time. These implants may be installed using direct push technology or using (2”diameter) hollow stem augers. Care should be taken to install these implants in a manner that minimizes disturbance to soil.

The soil vapor samples should be collected in accordance with EPA and ADEM accepted practices, in a tedlar bag or an evacuated Summa canister and analyzed for the volatile chemicals of concern. Prior to collecting the sample, the implants and tubing should be thoroughly purged to ensure that the sample sent for analysis is truly representative of the formation being sampled. For petroleum product spills, these volatile COCs include benzene, toluene, xylene, ethylbenzene, naphthalene, and perhaps MTBE. The samples may also be analyzed for intrinsic natural attenuation parameters. These measurements, although not mandatory, may be useful to demonstrate the occurrence or absence of natural attenuation.

H.5 EVALUATION OF SOIL VAPOR MEASUREMENTS

This section presents a hierarchical approach to evaluate the soil vapor concentrations measured at the site. Each measured soil vapor concentration should be compared to the target levels. The ARBCA evaluator may also use an alternate method for vapor data comparison (i.e., a data averaging method), but the results of the comparison will be subject to acceptance by the ADEM. In executing the following steps, only chemical-receptor-medium pathways that exceed target levels in a particular step need to be carried forward to the next step.

Step 1: Compare the measured vapor concentrations with the Tier 1 RBSLs for indoor air (Table H-1)

The Tier 1 indoor air RBSLs for resident child, resident adult, commercial worker, and construction worker are tabulated in Tables 7-2(a) to 7-2(d) and summarized in Table H-1 of this document. This is a conservative evaluation since it assumes that the point of exposure is within the soil. Thus, if the measured soil vapor concentrations do not exceed these levels, no further action would be required for the inhalation pathway.

Step 2: Compare the measured vapor concentrations with the Tier 1 soil and groundwater vapor RBSLs (Table H-2)

The soil vapor RBSLs were estimated by converting the Tier 1 soil and groundwater RBSLs protective of indoor inhalation using the soil-water equilibrium equation and are presented in Table H-2. These are soil vapor concentrations that allow indoor air Tier 1 RBSLs for soil and for groundwater to be met. If the measured vapor concentrations are below these levels, no further action would be necessary for the indoor inhalation pathway.

The measured soil vapor concentration may be a combination of vapors emanating from subsurface soil and groundwater. In Table H-2, the columns entitled “soil vapor” assume vapors emanate from soil only, whereas the columns entitled “groundwater vapor” assume vapors emanate from groundwater. The evaluator must decide which of these two vapor concentrations in Table H-2 is applicable. Where indoor inhalation from soils is being evaluated, comparison with “soil vapor” levels in Table H-2 would be more appropriate. Where indoor inhalation from groundwater is being evaluated, comparison with “groundwater” levels in Table H-2 would be more appropriate. Note, where indoor inhalation from both soil and groundwater (i.e. both the media below a structure are impacted) are being evaluated, comparison with “soil vapor” levels is most appropriate because it is the more conservative value. Note Table H-2 also assumes that the Tier 1 default factors (depth to groundwater, depth to contaminated soil, etc) are approximately applicable to the site. If site specific conditions vary from the Tier 1 default scenario, then go directly to Step 3.

Step 3: Compare the vapor concentrations with the Tier 2 soil and groundwater SSTLs

The ARBCA software should be used to calculate the Tier 2 soil and groundwater concentrations protective of indoor inhalation. These soil and groundwater target levels can be used to estimate soil vapor target levels using the equilibrium conversion equations included in Attachment 1 to this Appendix. These calculated vapor concentrations will be the Tier 2 equivalents to the values in Table H-2. For comparison of measured soil vapor target levels with the calculated values, refer to the discussion under Step 2. In the case where both the soil and groundwater pathways are being evaluated, the lower of the soil and groundwater vapor SSTLs for each chemical should be used in the comparison.

If the measured soil vapor concentrations do not exceed the site-specific soil vapor target levels (calculated per Attachment 1), then the ADEM may not require further evaluation of the indoor pathway. If an exceedance does occur, then Step 4 should be performed.

Step 4: Estimate the risks and hazard quotients using soil vapor measurements

The measured soil vapor levels should be used to estimate the risks and hazard quotients using the model presented in Attachment 2. The model presented in this attachment assumes an infinite source and no biodecay of the vapors as they migrate through the vadose zone. Therefore, the model is conservative. Thus, if the estimated risks and hazard quotients are below the regulatory acceptable levels, (Hazard Quotient [HQ] <1.0 and Individual Excess Lifetime Cancer Risk [IELCR] < 1×10^{-5}) no further action would be necessary for the inhalation pathways.

Step 5: Estimate the risks and hazard quotients using alternative models

As part of this step the ARBCA evaluator may recommend the use of any other publicly available model to estimate the risk but should receive prior approval from the ADEM. This type of evaluation would be considered a Tier 3 evaluation.

REFERENCES

1. American Petroleum Institute, May 1994, *Decision Support System for Exposure and Risk Assessment*, version 1.0.
2. ASTM 1994, Designation D5314-93, Standard Guide for Soil Gas Monitoring in the Vadose Zone in *ASTM Standards on Groundwater and Vadose Zone Investigations*, 2nd Ed., ASTM Committee D-18 on Soil and Rock, Philadelphia, PA, pages 333-363.
3. Hansen, K.C., Zhoo, Z., Yaws, C.L., and Aminabhavi, T.M., 1993, Determination of Henry's Law constants of organics in dilute aqueous solutions, *Journal of Chemical Engineering Data*, Vol.3, Pages 546-550.
4. Lucius, J.E., 1987, *Physical and Chemical Properties and Health Effects of Thirty-Three Toxic Organic Chemicals*, U.S. Geological Survey Open File Report 87-428, 137 pages.
5. U.S. EPA, 1996, *Soil Screening Guidance: Technical Background Document*, USEPA/540/R-95/128, May 1996, Office of Solid Waste and Emergency Response, Washington, D.C.

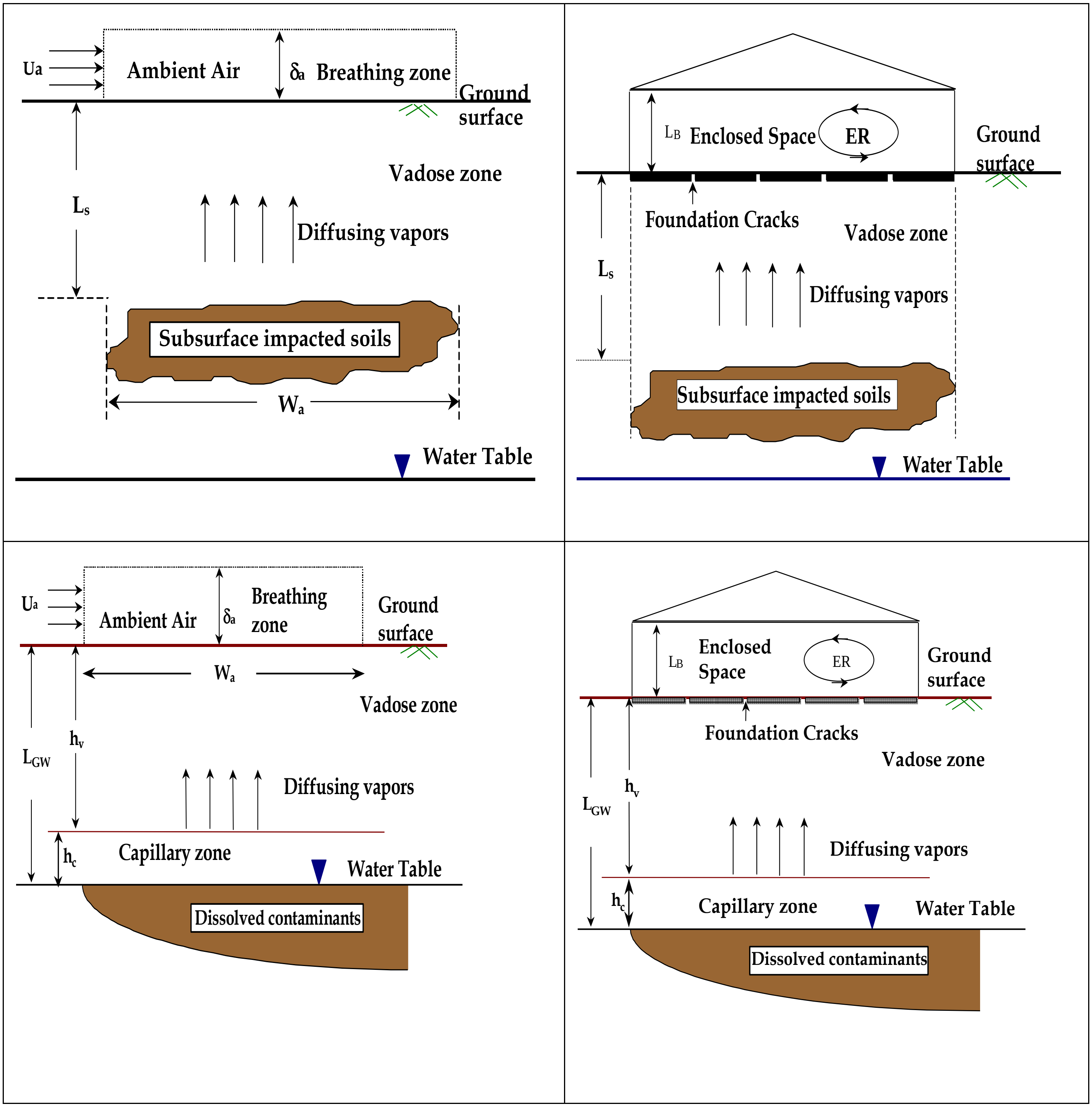


Figure H.1 Indoor and Outdoor Inhalation Pathways

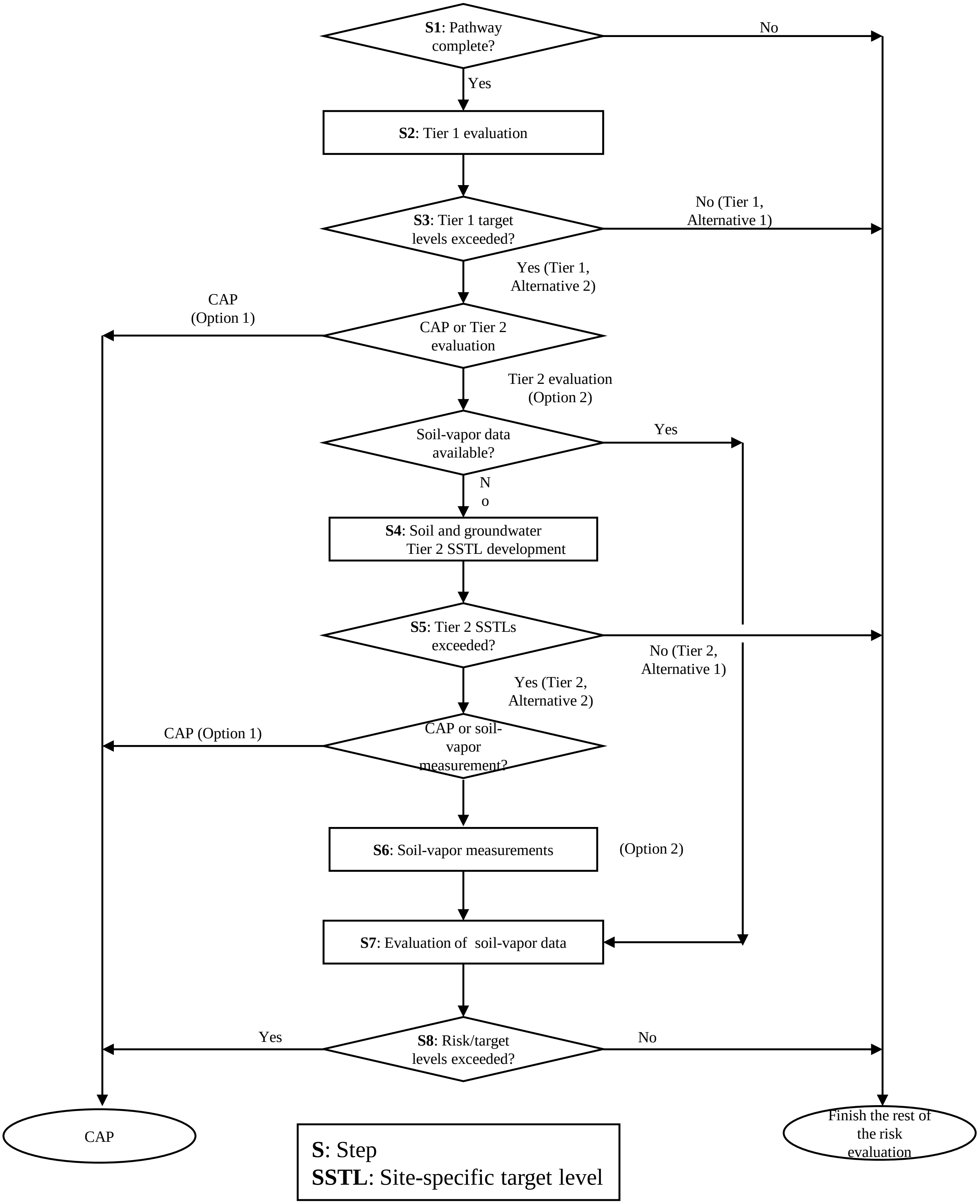


Figure H.2 Flowchart to Evaluate Indoor Inhalation Pathway

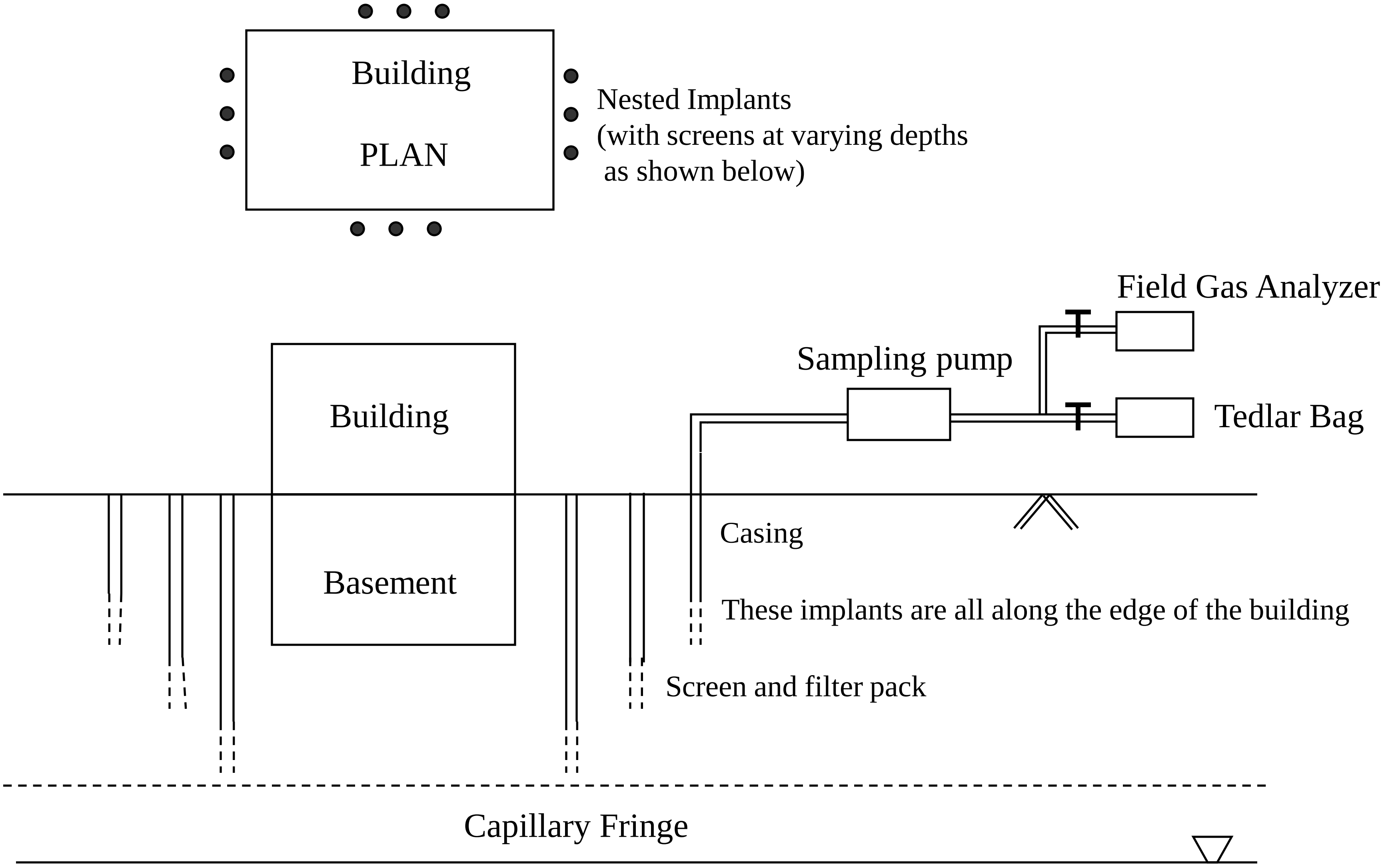


Figure H.3 Location of Nested Implants

Table H-1
Tier 1 RBSLs for Indoor Air

Chemicals of Concern	Residential		Commercial Worker	Construction Worker
	Child	Adult		
	[mg/L-air]	[mg/L-air]	[mg/L-air]	[mg/L-air]
Benzene	2.66E-06	4.15E-06	7.07E-06	1.16E-05
Toluene	1.72E-04	5.29E-04	7.49E-04	7.49E-04
Ethylbenzene	4.53E-04	1.39E-03	1.98E-03	1.98E-03
Xylenes (mixed)	1.34E-04	4.13E-04	5.86E-04	5.86E-04
MTBE	1.34E-03	4.13E-03	5.86E-03	5.86E-03
Naphthalene	1.41E-06	4.32E-06	6.13E-06	6.13E-06

Table H-2
Tier 1 Soil and Groundwater Vapor RBSLs

Chemical of Concern	SOIL VAPOR [mg/L-air]				GROUNDWATER VAPOR [mg/L-air]			
	Residential		Commercial Worker	Construction Worker	Residential		Commercial Worker	Construction Worker
	Adult	Child			Adult	Child		
Benzene	0.039	0.025	0.162	0.266	0.086	0.055	0.360	0.589
Toluene	4.982	1.621	17.407	17.407	11.673	3.797	40.785	40.785
Ethylbenzene	15.236	4.956	53.234	53.234	36.446	11.855	54.587*	54.587*
Xylene	4.344	1.413	15.179	15.179	9.974	3.245	34.851	34.851
MTBE	33.210	10.802	116.031	116.031	46.633	15.169	162.934	162.934
Naphthalene	0.060	0.020	0.210	0.210	0.081	0.026	0.282	0.282

* Values marked with asterisks are substituted values of the maximum vapor concentration over pure product.

Note: To convert mg/L to mg/m^3, multiply the above values by 1000

Often, the field soil vapor results are reported in ppbv. To convert ppbv to mg/L of gas use this formula adapted from Lucius (1987, p.16):

$$Number\,of\ \frac{mg}{L} = number\,of\ \ ppbv \times 10^{-9} \times \frac{MW\left[\frac{g}{mole}\right] \times 10^{3}}{24.45\left[\frac{L}{mole}\right]}$$

Where:

MW = Molecular Weight (g/g-mol)

24.45 = The volume that 1 g mole of a vapor occupies under conditions of 1 atmosphere pressure and 25^{0}C. This value is obtained from the Ideal Gas Law PV=nRT where P is the pressure [atm], V is the volume [liter], n is the number of moles [g mole], R is the Universal Gas Constant [(liter-atm)/(g mole-^{0}K)], and T is the temperature [^{0}K].

10^{-9} = Converts ppbv to L/L.

10^3 = Converts g to mg.

Sample Calculation:

Measured soil-vapor concentration of benzene =1000 ppbv

Benzene concentration in mg/L equivalent to 1000 ppbv =1000 x 10^{-9} x 78 x 10^3/24.45 =0.0032

ATTACHMENT 1

CONVERSION OF SOIL AND GROUNDWATER CONCENTRATIONS TO SOIL VAPOR TARGET LEVELS

Soil Concentration to Soil Vapor Concentration:

$$C_l = C_s \times \left(\frac{\rho_s}{(\rho_s K_s) + \theta_{ws} + (\theta_T - \theta_{ws})H} \right)$$

$$C_v = C_l \times H$$

(Hansen and others, 1993, eq. 5)

Groundwater to Soil Vapor Concentration:

$$C_v = C_l \times H$$

Where;

C_l = Concentration in liquid (groundwater)]mg/L]
C_s = Concentration in soil [mg/kg]
C_v = Concentration in vapor [mg/L]
ρ_s = Dry Soil Bulk Density in Vadose Zone [kg-soil/L-soil]
K_s = Soil-Water Partition Coefficient [L/kg]
θ_{ws} = Soil Volumetric Water Content in Vadose Zone [--]
θ_T = Total Soil Porosity Vadose Zone [cm^3 voids/cm^3 soil]
H = Henry's Law Constant [dimensionless]

ATTACHMENT 2

ESTIMATION OF RISK AND HAZARD QUOTIENTS BASED ON SOIL VAPOR MEASUREMENTS

The following equations are used in the estimation of risk and hazard quotient:

The measured soil vapor concentrations, if expressed in ppbv, should be converted to mg/L using the following equation:

$$Number\ of\ \frac{mg}{L} = Number\ of\ \ ppbv \times 10^{-9} \times \frac{MW\left[\frac{g}{mole}\right] \times 10^{3}}{24.45\left[\frac{L}{mole}\right]} \qquad (1)$$

Where:

MW = Molecular weight of the chemical [g/mole]
24.45 = Volume of one mole of an ideal gas [L/mole] at standard conditions of 25°C and 1 atmosphere.
10^{-9} = Converts ppbv to L/L
10^{3} = Converts g to mg

The conservative Farmer Model (API, 1994, Appendix E), as given below, may be used to estimate the indoor air concentration from the soil vapor concentration:

$$C_{air-indoor} = \frac{C_{soil-vapor}}{\left(\frac{L_B \times ER \times d}{m \times D_s^{eff}} + 1\right)} \qquad (2)$$

Where:

$C_{air\text{-}indoor}$ = Indoor air concentration [mg/L]
$C_{soil\text{-}vapor}$ = Measured soil vapor concentration [mg/L]
L_B = Enclosed space volume/infiltration area ratio (Height of the building) [cm]
ER = Air exchange rate of the enclosed space [1/sec]

d	=	Depth at which soil vapor concentrations were measured [cm]
m	=	Areal fraction of cracks in the floor [--]
D_s^{eff}	=	Effective diffusion coefficient in vadose zone soil [cm^2/s]

Effective diffusion coefficient, D^{eff}_s can be calculated using the following equation:

$$D_s^{eff} = D^a \times \frac{(\theta_T - \theta_{ws})^{3.33}}{\theta_T^{\ 2}} + \frac{D^w}{H} \times \frac{\theta_{ws}^{\ 3.33}}{\theta_T^{\ 2}} \tag{3}$$

Where:

H	=	Chemical-specific Henry's Law constant [(L-water)/(L-air)]
D^a	=	Diffusion coefficient of the chemical in air [cm^2/s]
D^w	=	Diffusion coefficient of the chemical in water [cm^2/s]
θ_T	=	Porosity of the vadose zone soil [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]

Risk is calculated using the equation:

$$Risk = \frac{C_{air-indoor} \times IR_{ai} \times ED \times EF \times SF_i}{BW \times AT_c \times 365} \tag{4}$$

Hazard Quotient is calculated using the equation:

$$HQ = \frac{C_{air-indoor} \times IR_{ai} \times ED \times EF}{BW \times AT_{nc} \times 365 \times RfD_i} \tag{5}$$

Where:

$C_{air\text{-}indoor}$	=	Indoor air concentration [mg/m^3]
IR_{ai}	=	Daily indoor inhalation rate [m^3/d] ($IR_{ai} = ET_{in} \times IR_{air\text{-}indoor}$)
ED	=	Exposure duration [years]
EF	=	Exposure frequency [days/year]
BW	=	Body weight [kg]
AT_c	=	Averaging Time for carcinogens [years]
AT_{nc}	=	Averaging Time for non-carcinogens [years]

SF_i = Inhalation slope factor [(mg/kg-day)$^{-1}$]
RfD_i = Inhalation reference dose [mg/kg-day]
365 = Conversion factor [days/year]

The values of the exposure and fate and transport parameters used in the risk and hazard quotient calculations should be selected as per guidance provided in Section 6 of this guidance document.

The above analyses involve several conservative assumptions. These include:

i. Farmer's Model assumes an infinite source, i.e., the soil concentrations do not decrease with continuing vapor emissions.
ii. The maximum measured concentrations are assumed to be the source concentrations.
iii. For chemicals with concentrations below detection limits, the detection limits are assumed as the concentrations.

REFERENCES FOR THIS ATTACHMENT

American Petroleum Institute, May 1994, *Decision Support System for Exposure and Risk Assessment*, Version 1.0.

APPENDIX I
DEVELOPMENT OF A SITE-SPECIFIC BIODECAY RATE

APPENDIX I
DEVELOPMENT OF A SITE-SPECIFIC BIODECAY RATE

I.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 site-specific target levels (SSTLs) developed for all the complete routes of exposure. At all sites, the ARBCA process requires the development of soil and groundwater target levels protective of groundwater resources. 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.

This appendix contains guidance on the development of a site-specific biodegradation rate for use in estimating soil and groundwater SSTLs protective of groundwater resources. This appendix should be used in conjunction with the latest version of the *Alabama Underground Storage Tank Release Investigation and Corrective Action Guidance Manual* and this guidance manual. The estimation of site-specific biodegradation rates is an evolving science and the user 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 the ARBCA computational software. This software includes two options to calculate these concentrations. One option, noted as “Groundwater Resource Protection – Without Biodegradation” uses a dilution attenuation factor (DAF) in the saturated zone that does not consider biodegradation of the chemical of concern. A second option, noted as “Groundwater Resource Protection – With Biodegradation”, allows for the use of a DAF that incorporates a user-specified biodegradation rate.

The choice to utilize biodecay in calculating groundwater resource protection SSTLs 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 ADEM will accept ARBCA evaluations using the biodegradation rate only if (1) adequate evidence is presented which 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 I.2 presents a discussion of the type of information that should be evaluated to demonstrate that biodegradation is occurring at the site.

- Section I.3 discusses the method used to calculate a site-specific biodecay rate for use in the ARBCA computational software.

I.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 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).

I.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.

I.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.

I.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 objective of the measurement of secondary and tertiary lines of evidence is 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.

I.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 Tier 2 Summary Form 27 to show comparison of site concentrations with SSTLs 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 ARBCA.pgm input and output.

I.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.

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 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 I.2. Note that this overall NA rate (k) should not be confused with the biodegradation rate (λ) that is an input to the Groundwater Resource Protection model used in ARBCA (see Equation 1 on page E-13).

Step 8: Estimate the biodegradation rate (λ) 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:

λ = Biodegradation rate

α_x = Longitudinal dispersivity (x/10)

x = Distance from the source to the POE

k = Attenuation Rate

v = Seepage velocity

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 λ, 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 judgment must be used to determine the most representative λ for use in the calculation of the chemical half-lives.

Step 9: Calculate a half-life for each chemical using the equation, λ = .693/half-life. λ should be written as 1/days for this calculation.

Utilize the derived site-specific half-lives in the calculation of the "Groundwater Resource Protection with Biodegradation" SSTLs (soil and groundwater). In the computational software, the half-lives for each chemical of concern should be entered on the worksheet entitled "Chemicals of Concern, Half Life and Unsaturated Zone DAF".

I. 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.