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# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

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**April 2008 – Revision 2**

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## LIST OF ACRONYMS

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ADEM	Alabama Department of Environmental Management
AEIRG	Alabama Environmental Investigation & Remediation Guidance
AOIs	Areas of Interest
ARBCA	Alabama Risk-Based Corrective Action
ASTs	Aboveground Storage Tanks
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
bgs	Below Ground Surface
BTAG	Biological Technical Assistance Group
CAP	Corrective Action Plan
CLT	Central Limit Theorem
COPCs	Chemicals of Potential Concern
COCs	Chemicals of Concern
CDI	Chronic Daily Intake
CEHT	Center for Environmental and Human Toxicology
DAF	Dilution Attenuation Factor
DNAPLs	Dense Non-Aqueous Phase Liquids
EcoSSLs	USEPA Ecological Soil Screening Levels
EMA	Emergency Management Agency
ERAGS	Ecological Risk Assessment for Superfund
GRP	Groundwater Resource Protection
GSA	Geological Society of Alabama
HEAST	Health Effects Assessment Summary Tables
HQ	Hazard Quotient
HI	Hazard Index
IELCR	Individual Excess Lifetime Cancer Risk
IRIS	Integrated Risk Information System
ISLs	Initial Screening Levels
LNAPLs	Light Non-Aqueous Phase Liquids
LUCs	Land-Use Controls
MCLs	Maximum Contaminant Levels
NFA	No Further Action



NAPLs	Non-Aqueous Phase Liquids
NCEA	National Center for Environmental Assessment
POE	Point of Exposure
PPRTV	Provisional Peer Reviewed Toxicity Value
PRGs	Preliminary Remediation Goals
PSL	Preliminary Screening Level
PSVs	Preliminary Screening Values
QA/QC	Quality Assurance/Quality Control
R4	Region 4
R9	Region 9
RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk-Based Corrective Action
RBSLs	Risk-Based Screening Levels
RBTLs	Risk-Based Target Levels
RCRA	Resource Conservation and Recovery Act
RfC	Reference Concentration
RfD	Reference Dose
RM-1	Risk Management-1 Evaluation
RM-2	Risk Management-2 Evaluation
RME	Reasonable Maximum Exposure
RMP	Risk Management Plan
RNA	Remediation by Natural Attenuation
ROE	Route of Exposure
SCEM	Site Conceptual Exposure Model
SF	Slope Factor
SQAGs	Florida Sediment Quality Assessment Guidelines
SSTLs	Site-Specific Target Levels
SW	Sentry Well
SWAA	Source Water Assessment Area
TDS	Total Dissolved Solids
TMDL	Total Maximum Daily Load
TT	Treatment Technique
USEPA	United States Environmental Protection Agency

USGS  
USTs

United States Geological Survey  
Underground Storage Tanks

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

The **Alabama Risk-Based Corrective Action (ARBCA)** document has been developed to provide the risk-based approach for the assessment of the cumulative risk at a site and the development and selection of appropriate RBTLs for contaminated sites. Site concentrations are first compared to **Preliminary Screening Values (PSVs)** and the cumulative risk at the site is calculated. If the risk exceeds acceptable levels or if the indoor air vapor inhalation pathway is complete, **Risk Management-1 (RM-1) Levels**, or **Risk Management-2 (RM-2) Levels** are then calculated. The procedure for development and comparison of site **chemicals of concern (COC)** concentrations with appropriate RBTLs is also provided. Certain cleanup programs (e.g., UST, RCRA, CERCLA) may have additional specific requirements or regulations for risk assessment and cleanup criteria. The UST Program has additional specific risk-assessment guidance that is under revision to be consistent with this guidance. This guidance may not be used as a substitute for such requirements and regulations, although it may be used in conjunction with such requirements and regulations. The most current version of the **Alabama Environmental Investigation and Remediation Guidance (AEIRG)** should be utilized for site investigation requirements. Program specific guidance is also available for certain programs (i.e. UST program). Evaluators should be aware of additional guidance in performing assessment and remediation activities.

Emergency Response actions shall be conducted in accordance with the requirements of the ADEM Emergency Response Program (contact ADEM Field Operations Division for applicable information).

The Department recognizes that as of the effective date of this guidance document, there will be a number of ongoing risk assessments using previously recognized guidance programs (e.g., the EPA RAGS approach for waste and remediation programs administered by the Water and Land Division, the UST ARBCA: Alabama Risk-Based Corrective Action for Underground Storage Tanks Guidance Manual approach for UST sites regulated by the Water Division). Those risk assessments which are requested or submitted to the Department by May 17, 2006, may continue to be processed using previous guidance. However, all risk assessments requested or submitted after May 17, 2006, shall follow the guidance contained herein and any applicable revised program-specific guidance. UST sites will continue to use existing or revised guidance, software and forms (modified as necessary to be consistent with this guidance) until new software is developed which more fully addresses the full scope of this guidance. Those sites which have corrective action limits accepted by the Department prior to May 17, 2006, may continue to utilize those corrective action limits as their cleanup goals.

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

## **1.1 APPLICABILITY**

The intent of this document is to establish a consistent procedure for evaluating the cumulative risk at a site. In the case that the risk at a site exceeds appropriate risk values this document will guide the user through the development of RBTLs that are protective of the current and future (i) human health, (ii) environment, (iii) emergency situations, and, (iv) nuisance conditions. The RBTLs are developed to be applied by the user as a guide or goal

during the remediation process to aid the site in the achievement of appropriate cumulative risk levels protective of human health and the environment. This document provides a technically defensible procedure for estimating cumulative risk and establishing risk management levels at impacted sites. This document is not intended as a detailed guide to every aspect of the risk assessment practice. It is intended for use by competent professionals with adequate knowledge of environmental risk assessment principles. Prior experience and/or training will be necessary for an individual to correctly conduct and implement the risk assessment as part of the overall site management process.

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

<http://www.osha.gov/>

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

## **1.2 COORDINATION WITH OTHER STATES**

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

The ARBCA process is applicable to a variety of sites that are regulated by ADEM under a number of different regulatory and statutory programs. These programs may impose various program-specific requirements of the responsible party. However, the identification of the nature and extent of corrective action required for remediation of sites to risk levels protective of human health, natural resources, and the environment is based on the ARBCA process. The overall decision-making process for a site where contamination is discovered and reported to ADEM is illustrated in the flowchart in Figure 2-1.

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 if representative site chemical concentrations are protective of human health and the environment. Site characterization should be conducted in accordance with the Alabama Environmental Investigation and Remediation Guidance (AEIRG) document. Each element of the site assessment and risk evaluation process is important and must be correctly applied for the adequate protection of human health and the environment.

The AEIRG document is available online at:

<http://www.adem.state.al.us/LandDivision/Guidance/guidance.htm>

## **2.1 SITE DISCOVERY**

The risk-based site management process begins with the discovery of a contaminated site. A contaminated site may be discovered and reported to ADEM under a variety of circumstances. These include, but are not limited to, citizen complaints, investigations conducted as part of real estate transactions, environmental impacts observed in surface water bodies, and notification of accidents and spills. The owner/operator has the responsibility to perform the initial notification as per the requirements of each program.

## **2.2 SITE ASSESSMENT AND INITIAL RESPONSE ACTIONS**

Upon site discovery, the responsible party should carefully evaluate the available information to determine whether the site poses any imminent or immediate threat(s) to human health or the environment. If site conditions warrant Emergency Response actions, those actions shall be conducted in accordance with the requirements of the ADEM Emergency Response Program (contact ADEM Field Operations Division for applicable information). All other (non-

Emergency Response) initial response actions, removal actions interim remediation measures, and site assessment activities should be conducted in accordance with the AEIRG document and applicable program-specific assessment guidance, such as that issued by the ADEM UST program. If an assessment of a site is determined to be necessary, the facility shall develop a **Site Conceptual Exposure Model (SCEM)** (see Section 2.4).

### **2.3 TIERED APPROACH AND RISK-BASED TARGET LEVELS**

The ARBCA process utilizes a tiered approach, with each subsequent tier being more site-specific. Table 2-1 contains a comparison of the different tiers used in the ARBCA process. A brief discussion of the types of RBTLs utilized in this process is presented below.

The **Maximum Contaminant Level (MCL)** is the highest level of a contaminant that is allowed in drinking water. With respect to groundwater, certain chemicals have established MCLs; therefore, preliminary screening level evaluations should be made against the established MCLs. In the absence of an MCL, the user has the following options:

1. Calculate a *Direct Ingestion of Groundwater* value in accordance with the equation located on page B-1 or another appropriate model (see the description in Section 3.7.1).
2. Utilize Table 2-2 of this guidance

If neither an MCL nor the necessary information needed to calculate a *Direct Ingestion of Groundwater* value as contained within Tables 3-3 and 3-4 of this guidance exists for a chemical, an approved **Lifetime Health Advisory (Lifetime HA)** value may be utilized to compare against the representative concentrations at the **point of exposure (POE)**.

**Preliminary Remediation Goals (PRGs)** are risk-based concentrations developed by USEPA R9. The PRGs have been modified as necessary and used for preliminary screening level evaluations as described in Section 3.7.1 and Section 5.0. The PRGs are calculated generic values derived without site-specific data. These levels may be applied during the early phase of site assessment and at environmental site assessments where the representative site concentrations (see Appendix A) and the source area(s) have been adequately identified and characterized. Site characterization should be conducted in accordance with the AEIRG document.

**Risk Management-1 (RM-1) levels** are media-, receptor- and pathway-specific concentrations that are based on default assumptions and parameter values that are cited in Tables 3-1, 3-2, 3-3,

and 3-4. The RM-1 levels are calculated using the models located in Appendix B. It is only necessary to calculate RM-1 levels after it has been determined that cumulative risk levels (see Section 3.7.1) at the site have been exceeded for one or more receptors. RM-1 levels may vary from site to site. These levels may be applied at sites where the source area(s) has been characterized and the site data indicates the site is appropriate for application of the default values used to develop the RM-1 levels. The RM-1 evaluation is further discussed in Section 6.0.

**Risk Management-2 (RM-2) levels** are site-specific levels that are based on site-specific data. RM-2 levels require the collection of additional site data as discussed in Section 4.0 of this document. Adequate soil and groundwater data is also necessary for the RM-2 evaluation as discussed in Appendix A. The RM-2 levels are calculated using the models located in Appendix B unless alternate models have been approved through submittal of a RM-2 workplan. It is only necessary to calculate RM-2 levels after it has been determined that cumulative risk levels (see Section 3.7.1) at the site have been exceeded for one or more receptors. A RM-2 workplan should be developed and approved as discussed in Section 7.0.

The ARBCA evaluation uses specific contaminant concentrations to evaluate the risk at a site. Use of total petroleum hydrocarbons (TPH) or diesel range organics (DRO) may be useful during the preliminary stages of site characterization, but neither DRO nor TPH data should be used to determine the risk present at a site.

## **2.4 DEVELOPMENT OF SITE CONCEPTUAL EXPOSURE MODEL**

A SCEM is developed prior to beginning the **Preliminary Screening Level (PSL)** evaluation. When the site concentrations exceed the PSVs (see Table 2-2) a more site-specific evaluation is necessary. A SCEM provides the framework for the overall risk evaluation and management of the site. The SCEM must identify (i) the land use in the site area, (ii) release sources, (iii) current and future receptors, (iv) complete routes of exposure and pathways, (v) site hydrogeology, (vi) applicable **Chemicals Of Potential Concern (COPCs)** (vii) applicable **Chemicals Of Concern (COCs)**, and (viii) any other environmental issues that require risk evaluation. COPCs are a list of chemicals that are developed during the scoping of a site. A COPC list is developed based on, but not limited to, research of the current and historical activities at a site. The SCEM should be updated as site conditions change or as new data become available. For additional details refer to Sections 3.0 and 4.0.



## 2.5 PRELIMINARY SCREENING LEVEL EVALUATION

Media-specific (soil, surface water, groundwater, etc.) data should be collected to identify the representative soil and groundwater concentrations (See Appendix A). Land use should be characterized as residential or commercial for the site and all adjacent property. If a commercial land use is applied, the facility may be required to implement and maintain **Land-Use Controls (LUCs)**, as appropriate (see Section 2.9). Based on this initial data, a **Preliminary Screening Level (PSL)** evaluation may be performed. Site-specific contaminant concentrations are compared to the **Preliminary Screening Values (PSVs)**. The list of COCs is developed from those COCs that have representative concentrations at or above the PSVs. The COCs that do not exceed the PSVs are dropped out of the calculation of the cumulative risk within an exposure domain. However, the list of COCs are carried through and all COCs must be accounted for in the cumulative risk calculation. Additional assessment activities may be necessary to ensure that human health, the environment, and natural resources are protected over the long term.

Table 2-2 contains a listing of the current (as of the revision date of this document) PSVs for many of the COCs. Table 2-2 does not include values for all COCs. Source references for the PSVs are included and should be consulted for COCs not listed. The Department should be contacted for other COCs for which information is not readily available. The PSVs are subject to change and should be verified when the evaluation is conducted.

If it is determined by the Department and/or the ARBCA evaluator that the indoor inhalation pathway is potentially complete, the facility may need to collect and analyze (sub-slab or other appropriate) soil vapor samples. The models located in Appendix B should be used to determine if the collected soil vapor concentrations exceed the acceptable risk within the exposure domain.

If the risk has been exceeded, it is appropriate to develop RBTLs using the models located in Appendix B.

An ecological screening evaluation should occur if it is determined by the Department and/or the ARBCA evaluator that potential ecological exposures exist at a site (see Section 3.14).

The most current MCLs and health advisories may be located online at:

<http://www.epa.gov/waterscience/criteria/drinking/>

Note: for the non-carcinogens, the value listed by USEPA R9 corresponds to a hazard quotient (HQ) of 1. Therefore, to be consistent with this document, all non-carcinogens have been divided by a factor of 10 to utilize a HQ of 0.1 (see Table 2-2 and Section 3.7.1 of this document for more information).

A PSL evaluation will initially involve the comparison of known site information and the maximum site concentrations with PSVs. If an acceptable level of site investigation has been performed as determined by ADEM, and the maximum media-specific concentrations at a site do not exceed the PSVs, then ADEM may grant the site a **No Further Action (NFA)** at this time. [Note: an NFA determination is a point in time determination, and may be granted with or without restrictions. For example, if the risk evaluation is based on commercial land use, then the NFA will include the restriction that commercial land use be maintained. If new information which impacts the NFA determination becomes available then the NFA may be reconsidered]. If the maximum site concentrations exceed the PSVs, then all COPCs that exceed PSVs should be evaluated under either the RM-1 or RM-2 process. Since a site may be granted NFA under a PSL evaluation, it is very important that the site evaluation identify the representative media-specific concentrations. For additional details refer to Section 4.0.

## 2.6 RISK MANAGEMENT-1 EVALUATION

An RM-1 evaluation first requires the determination of whether the cumulative risk at a site exceeds appropriate risk levels (i.e. Hazard Index = sum of HQs = 1.0 and Individual Excess Lifetime Cancer Risk = 1E-05). This determination should be made using the RM-1 default values located in Tables 3-1, 3-2, 3-3, and 3-4 of this manual. If it is determined that the cumulative risks do not exceed acceptable risk levels, there are no groundwater resource protection-related exceedances and no surface water protection-related exceedances an NFA (with or without restrictions) may be granted by the Department. Certain requirements for land-use controls and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site. If it is determined that the cumulative risks at the site exceed appropriate levels, the user may either follow the steps as described in Section 2.7 or develop RM-1 RBTLs for each COC, complete pathway and receptor as identified in the SCEM. The RM-1 RBTLs are then compared with representative site concentrations (See Appendix A) and adopted as cleanup levels during the development and implementation of a **Corrective Action Plan (CAP)** or **Risk Management Plan (RMP)**. The calculated RM-1 levels are used as clean-up goals and the representative site concentrations do not necessarily have to meet all of the cleanup goals as long as the target cumulative risks at the site are met and there are no groundwater resource protection or surface water protection-related exceedances.

Upon completion of the corrective action and/or risk management activities, the user should re-evaluate the cumulative risks at the site. If it is determined that the cumulative risks do not exceed acceptable risk levels, there are no groundwater resource protection-related exceedances and no surface water protection-related exceedances, an NFA (with or without restrictions) may

be granted by the Department. Certain requirements for LUCs and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site. If it is determined that the cumulative risks at the site exceed appropriate levels, the user should follow the steps as described in Section 2.7.

## **2.7 RISK MANAGEMENT-2 EVALUATION**

The RM-2 evaluation is the most site-specific evaluation. An RM-2 evaluation may require the collection of additional site-specific data, use of alternate fate and transport models, or other risk assessment approaches. Other approaches may include strategies such as the procedure of segregation by target organ of noncarcinogenic effects in accordance with Chapter 8 of USEPA's *Risk Assessment Guidance for Superfund (Part A)*.

In preparation of an RM-2 evaluation, the SCEM should be revised as appropriate and additional data collected as necessary. The specific data to be collected may vary from site to site. This data will be used to determine the cumulative risk at the site and to develop RM-2 RBTLs if necessary. Prior to collection of this data, a work plan should be developed outlining the specific additional data needs and the overall approach for the RM-2 evaluation. The plan should be approved by ADEM prior to proceeding with the RM-2 evaluation.

Cumulative risks should be calculated for all of the complete pathways and chemicals identified in the SCEM. Site-specific data must be used in the specified models/equations to determine the cumulative risk at the site. The acceptable models/equations are located in Appendix B of this document. Other, more appropriate models may need to be used in some cases (see Section 3.7.1 for a more detailed discussion) If it is determined that the cumulative risks do not exceed acceptable risk levels, there are no groundwater resource protection-related exceedances and no surface water protection-related exceedances an NFA (with or without restrictions) may be granted by the Department. Certain requirements for LUCs and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site. If it is determined that the cumulative risks at the site exceed appropriate levels, the user should develop RM-2 RBTLs for each COC, complete pathway and receptor as identified in the SCEM. The RM-2 RBTLs are then compared with representative site concentrations (See Appendix A) and adopted as cleanup levels during the development and implementation of a CAP and/or RMP.

Upon completion of the corrective action and/or risk management activities, the user should re-evaluate the cumulative risks at the site. If it is determined that the cumulative risks do not exceed acceptable risk levels, there are no groundwater resource protection-related exceedances

and no surface water protection-related exceedances an NFA (with or without restrictions) may be granted by the Department. Certain requirements for LUCs and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site. If it is determined that the cumulative risks at the site exceed appropriate levels, the user should complete additional corrective action and/or risk management activities.

## **2.8 DEVELOPMENT AND IMPLEMENTATION OF THE RISK MANAGEMENT PLAN**

A Risk Management Plan (RMP) is developed to achieve the RBTLs as approved by ADEM. The RMP may include a combination of active and passive remedial options and owner-imposed land-use restrictions. A CAP may be required to indicate the methods and data that will be utilized to achieve the established cleanup levels. During the implementation of the CAP and/or RMP, sufficient data should be collected and analyzed to evaluate the performance of the plan. If the data indicates that cleanup is not progressing at the rate that was anticipated, modification to the RMP may be necessary. The specific modification(s) will vary from site to site. The site may be granted an NFA (with or without restrictions) by the Department after the responsible party demonstrates that the appropriate cumulative risks levels have been achieved and the risk management plan has been successful. Certain requirements for LUCs and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site. Refer to Section 8.0 for additional details.

## **2.9 LAND-USE CONTROLS**

If land use other than unrestricted residential use is applied, the Department may require that the facility be required to implement and maintain land-use controls in perpetuity. LUCs may include, but are not limited to:

- Engineering controls
- Institutional controls
- Water use restrictions
- Deed restrictions
- Restrictive covenants
- Access controls
- Usage restrictions
- Protective cover maintenance
- The listing of sites (e.g. State Cleanup Inventory List)

Acceptable LUCs will be determined on a site-by-site basis, and in accordance with particular program regulations and guidelines. Individual regulatory programs may have additional requirements for the types of LUCs that may be acceptable for a facility.

## **2.10 NO FURTHER ACTION UNDER THE ARBCA PROGRAM**

The overall objective of all characterization and risk management activities at a site is to ensure the long-term protection of public health, the environment, and natural resources under the current and reasonable future conditions. ADEM may grant an NFA status (with or without restrictions) to the site when the responsible party has demonstrated the following:

- The site has been adequately characterized.
- Target cumulative risk levels have been achieved.
- The groundwater plume is stable or decreasing.
- There are no groundwater resource protection-related exceedances.
- There are no surface water protection-related exceedances.
- The site concentrations have met the risk-based target levels.

The issuance of an NFA status implies that based on the data submitted and the information available to ADEM, no further action is necessary at that time. However, if additional information becomes available in the future that indicates the existence of previously unknown conditions (leading to the likelihood of unacceptable risk, or if the land use, etc. changes), the site may have to be re-evaluated. Furthermore, it should be noted that certain requirements for LUCs and/or site listing (e.g. State Cleanup Inventory List) may apply depending on the regulatory program applicable to the site.

Please note that while no further investigative or remedial actions may be required for a site, LUCs may be necessary. LUCs may include engineering controls, institutional controls, water use restrictions, a restrictive covenant, access controls, usage restrictions, protective cover maintenance, the listing of sites (e.g. State Cleanup Inventory List) and/or other appropriate measures. This will be determined on a site-by-site basis, and in accordance with particular program regulations and guidelines.

## **2.11 REMEDIATION PROGRAM**

If after following an appropriate risk evaluation, a determination is made that the risk at a site is greater than that appropriate for an unrestricted (i.e., no remedies, including LUCs are required) residential land-use scenario, then the responsible party must implement a remediation program.

The remediation program must address all contamination (on-site and off-site) which exceeds the unrestricted residential land use levels, and shall include appropriate monitoring programs combined with active and/or passive remediation technologies, LUCs, and/or other components as necessary to remediate and prevent unacceptable exposures to the contamination. The remediation program should be developed and implemented in a manner consistent with the guidelines set forth in the AEIRG and the applicable state regulations located in the ADEM Administrative Code.

## **2.12 Overarching Cleanup Goal**

The overarching cleanup goal of all ADEM remediation programs is the attainment of chemical concentrations found in the soil, groundwater, and all other media to levels appropriate for an unrestricted residential land-use scenario. The Department may require LUCs until the ultimate goal of unrestricted residential land-use has been attained. The “overarching cleanup goal” shall not be waived due to difficulty in attaining the clean-up standard within a set period of time.

## RISK-BASED EVALUATION: GENERAL CONSIDERATIONS

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The objective of a risk assessment is to quantify the adverse effects to the current and most likely future receptors. An ARBCA evaluation requires the consideration of several factors common to the PSL, RM-1 and RM-2 evaluations. These factors are discussed within this section.

### 3.1 LAND USE

The characterization of the population and the activities on and adjacent to the release site is a critical component of the ARBCA process. The cumulative risk and target levels vary depending on whether the land use is commercial or residential. Some properties may have multiple land uses. For such properties, the land use that yields the most conservative risk evaluation should be utilized. Residential land use is the most conservative evaluation.

Within the ARBCA process, land use is categorized as either residential or commercial. Of these, residential land use results in lower target levels. Thus, cleanup to residential standards will allow unrestricted land use. Land use as utilized in the ARBCA evaluations is defined as:

- **Residential:** Includes but is not limited to schools, dwellings, homes, hospitals, childcare centers, nursing homes, playgrounds, recreation centers, and any other areas or structures with sensitive human activity.
- **Commercial:** Includes former 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 ten (10) hours a day, five (5) days a week. Hotels, motels, and other transient activities are included in the commercial definition.

The land use status should be clearly illustrated on maps submitted to ADEM identifying the current land use of the site and adjacent properties. A land use map with a radius of 500 to 1000 feet depending on the size of the site and the source should be prepared.

### **3.1.1 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, and should be determined by a site visit.

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, maps (zoning, insurance, topographic, land use, housing, etc.), state or local zoning boards, county property tax records, the U.S. Bureau of the Census, and aerial photographs can provide information for determining land use.

Undeveloped land should be characterized by the most likely future use of that property. If the undeveloped parcel is located in an area which is predominantly commercial, then the commercial classification may be appropriate (this will require the appropriate LUCs to be in place). However, if the setting is more rural or the land use is mixed, the undeveloped land should be considered residential unless the owner is willing to install LUCs to protect the land use classification.

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

Careful consideration of future land and groundwater usage will reduce the possibility that the selected remedy will have to be re-evaluated due to changing usage assumptions/realities. As a caveat, it should be noted that if cleanup is not based on an unrestricted usage scenario (i.e. residential), the future use of the property or groundwater will be limited to the usage



scenario utilized for the calculation of the risk determination and/or cleanup values and protected with LUCs.

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

### 3.2 ONSITE AND OFFSITE

All ARBCA evaluations must consider the impact of the chemicals to both the onsite receptors and offsite receptors. The SCEM must clearly identify all complete pathways, routes of exposure, and receptors that may be impacted by COCs located onsite and offsite. Chemicals released at a site may impact multiple land uses and multiple receptors. For example, a contaminated groundwater plume could migrate below an offsite 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 contiguous property under the control of the facility. This includes the soil, groundwater, surface water, and air within the legal site boundaries.
- **Offsite:** The property(s) of concern located outside the contiguous legal property boundaries of the facility. This includes the soil, groundwater, surface water, and air located offsite.

Site characterization will include a determination of the onsite and offsite **areas of interest (AOIs)**. These areas are considered in determining the pathway-specific **exposure domain(s)** (areas over which receptors will have equal and random contact) of the receptor(s). The exposure domain is the area over which the receptor may be exposed to the contaminated media. Determination of the exposure domain is critical in developing representative concentrations separately for groundwater and soil for onsite and offsite properties. An impacted site may have multiple AOIs and exposure domains, one for each receptor and each complete **route of exposure (ROE)**. Where there are multiple offsite properties, which have been impacted, the user must evaluate each property separately.

Future changes in exposure domains also need to be considered. If exposure domain decisions are based on anything other than an unrestricted land-use scenario (i.e., residential scenario),

then those decisions should be supported with the installation of LUCs (see Section 2.9). For residential land use involving single-family dwellings, the exposure domain is the residential lot.

### **3.3 RECEPTORS**

For an ARBCA evaluation, human receptors to be considered should include persons who live or work within at least a 500-foot radius of the site boundary (and at times more depending on the source and hydrogeologic conditions). The actual radius of delineation should be discussed with the ADEM project manager.

Human receptors include children (age  $\leq 6$  years), trespassers (age 7-17 years) and adults (age  $\geq 18$  years). Adults and children should both be evaluated as residential receptors. Adults working at a commercial location and adult construction workers will be considered in the ARBCA evaluation. The trespasser scenario may not need to be evaluated if a site has a security fence surrounding all of the contaminated property in addition to security personnel onsite on a daily basis. Additionally, the exposure frequency for a trespasser should consider site-specific factors such as distance from the site to residences and the attractiveness of the site to the receptor. During the RM-1 evaluation, if recreational opportunities are present at a site, the recreational scenario may be evaluated using the trespasser default values. Typically if either the recreational or the trespasser are considered significant receptors at a site an RM-2 evaluation should be performed. The need to develop site-specific data is due in part to the wide variations of potential opportunities provided to either the trespasser or the recreational receptor. Generally, exposure is expected to be higher at inactive sites versus operating facilities. The most likely exposed human receptors that should be included in the ARBCA evaluation are listed below:

- **Residential – Child**
- **Residential – Adult**
- **Trespasser (and/or Recreational) – Adolescent**
- **Commercial Worker – Adult**
- **Construction Worker – Adult**

Other human receptors such as visitors or maintenance workers will generally have less exposure and therefore may not be considered, as long as the site is evaluated as either residential or commercial.

Surface water bodies such as creeks, rivers, springs, ponds, lakes, bays, etc., should be

identified within a minimum 500-foot radius of the site. Surface water bodies should be evaluated to determine the impacts of discharging groundwater or surface runoff from the release site. At a minimum, information 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 should be evaluated to determine whether they can serve as conduits for COCs to migrate. Adverse impacts may include vapors in storm and sanitary sewers, degradation of water and sewer lines, or property damage to outer coatings of gas lines, buried phone or electrical lines.

Non-human receptors such as endangered species or other ecological receptors live in many types of areas that may be impacted by contamination. Some of these areas include surface waters, wetlands, conservation areas, sensitive resource areas, agricultural areas, livestock, etc. and should all be evaluated for potential ecological impacts. **Source Water Assessment Areas (SWAAs) I or II** should be identified and evaluated as necessary. A definition and a table describing SWAAs I and II can be located in the ADEM Admin Code R. 335-7-15. These types of areas should be thoroughly evaluated under a RM-2 evaluation. The potential risk to the receptors living in these areas will be evaluated on a case-by-case basis. The following is a list of media specific values that should be used to evaluate ecological impacts at sites:

➤ Surface Water

- Surface water data collected during the assessment phase should be compared to the USEPA Region 4 Ecological Screening Values with respect to surface water
- In the absence of a Region 4 Ecological Screening Value for surface water, the representative surface water concentrations should be compared to the Water Quality Criteria located in ADEM Admin. Code 335-6-10 (the “Aquatic Life Criteria” should be used)
  - If the surface water is a “water of the state” as defined in ADEM Admin. Code R. 335-6-10-.02(10), the representative surface water concentrations should be compared to the Water Quality Criteria regardless of whether a Region 4 Value exists and the ADEM Water Division should be contacted
- In the absence of a USEPA Region 4 Ecological Screening Value or an ADEM Water Quality Criteria Value, surface water should be compared to the appropriate Region 3 Biological Technical Assistance Group (BTAG) screening value
- In the absence of an ecological screening value for surface water in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department

should be consulted.

➤ Sediments

- Sediment data collected during the assessment phase should be compared to the USEPA Region 4 Ecological Screening Values with respect to sediment
- In the absence of a Region 4 Ecological Screening Value for sediment, the sediment concentrations should be compared to the Florida Sediment Quality Assessment Guidelines (SQAGs). These guidelines contain values for marine, estuarine and freshwater sediments. These values were developed utilizing data from not only Florida but throughout the Southeast Region
- In the absence of a USEPA Region 4 Ecological Screening Value or a Florida SQAGs, sediment should be compared to a Region 3 Biological Technical Assistance Group (BTAG) screening value
- In the absence of an ecological screening value for sediment in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be consulted.
- Sediment that is not saturated year round should be evaluated as surficial soil as well as sediment

➤ Soils

- Soil data collected during the assessment phase should be compared to the USEPA Ecological Soil Screening Levels (EcoSSLs).
- In the absence of a USEPA EcoSSL, the soil concentrations should be compared to the USEPA Region 4 Ecological Screening Values with respect to soils.
- In the absence of an ecological screening value for soils in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be consulted.

USEPA Region 4 Ecological Screening Values are available online at:

<http://www.epa.gov/region4/waste/ots/ecolbul.htm>

ADEM Water Quality Criteria Regulations can be accessed online at:

<http://www.adem.state.al.us/Regulations/regulations.htm>

Region 3 BTAG Screening Values can be accessed online at:

<http://www.epa.gov/reg3hwmd/risk/eco/index.htm>

Florida Sediment Quality Assessment Guidelines can be accessed online at:

[http://www.dep.state.fl.us/waste/quick\\_topics/publications/pages/default.htm](http://www.dep.state.fl.us/waste/quick_topics/publications/pages/default.htm)

USEPA Ecological Soil Screening Levels can be accessed online at:

<http://www.epa.gov/ecotox/ecossl/>

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

### **3.4 EXPOSURE PATHWAYS**

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. The source of a chemical depends on the nature of the site activities, the release and the release area. Release mechanisms may cause chemicals to be released either in the air, on the ground surface or in the subsurface. Potentially impacted media include surficial and subsurface soil, air, surface water and groundwater. ROEs include ingestion of groundwater and soil particulates, indoor (and possibly outdoor, see Section 3.4.1) inhalation of vapors in the air, indoor (and possibly outdoor, see Section 3.4.1) inhalation of vapors from soil and groundwater, inhalation of soil particulates, dermal contact with soil, and, leaching to groundwater from surficial and subsurface soils. Figure 3-1 is an example SCEM that illustrates the relationships between the impacted media, transport mechanisms, exposure pathways and potential receptors that comprise complete exposure pathways.

The most commonly encountered exposure pathways for which an ARBCA evaluation must be conducted to determine whether a complete exposure pathway exists at the release site are discussed below.

#### **3.4.1 Pathways for Inhalation**

For the inhalation pathway, the chemical intake occurs by the indoor inhalation of vapors or the outdoor inhalation of vapors and/or soil particulates at a site. In most cases, the outdoor

inhalation of vapors pathway is not evaluated due to the extreme dilution of outside air and the fact that the sunlight degrades most solvents. However, the outdoor inhalation of soil particulates should be evaluated at sites. The Department may require evaluation of the outdoor inhalation of vapors pathway on a site-specific basis.

Depending on the toxicity of the chemical, unacceptable exposures may occur at concentrations below the odor threshold levels. In most cases, the source for these vapors is the presence of volatile chemicals in soil and/or groundwater. Chemicals that have migrated through subsurface soil to groundwater volatilize from the soil and/or groundwater. The volatiles diffuse upward 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 the vapor inhalation pathway, mathematical models are used to relate the allowable air concentrations with the soil or groundwater concentrations. Soil and groundwater target levels protective of indoor (and outdoor as necessary) vapor inhalation are developed for RM-1 and RM-2 evaluations. An evaluation should be performed to determine the necessity of taking air samples at a site for comparison to the indoor/outdoor vapor inhalation target levels. Indoor air measurements should not be performed at many sites due to technical difficulties associated with accurately measuring the indoor air concentration contributed by soil and/or groundwater impacts. Rather, either models used to estimate indoor air concentrations or the use of an empirical relation/attenuation factor to estimate indoor air concentrations based on soil, groundwater, and soil vapor should be used.

The outdoor inhalation of soil particulates pathway is addressed at the PSL stage with the PSVs associated with the “Direct Contact Exposure Pathway” for *Residential Soil* and *Commercial Soil*. For the RM-1 and RM-2 evaluations the mathematical equations located in Appendix B should be used to quantitatively determine either the risk or the RBTLs associated the outdoor inhalation of soil particulates.

Plans for the collection and analysis of air, soil, or soil vapor measurements should be submitted to ADEM for approval prior to implementation of the sampling activities. Refer to Appendix A for guidance on the methods for estimation of representative concentrations.

### **3.4.2 Pathways for Surficial Soils (0 - 1 foot below ground surface)**

Surficial soils are defined as soils extending from the ground surface to one foot **below ground surface (bgs)**. Dry sediment, as described in Section 3.3, should be evaluated as surficial soil. The thickness and type of site cover must be considered when determining the exact depth of the surficial zone that contributes to the surficial soil exposure pathways. The

exposure pathways associated with impacted surficial soil include:

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

A representative number of surficial soil samples should be obtained from the impacted area to evaluate these pathways. These measured concentrations are used to determine the representative concentration(s) that are used to determine if the cumulative risk is acceptable. Refer to Appendix A for guidance on the methods for estimation of representative surficial soil concentrations.

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

### **3.4.3 Pathways for Subsurface Soils (1 foot bgs to the water table)**

Subsurface soils are defined as soils located at one foot bgs and extending to the water table (if a site wishes to define subsurface soils as anything other than the above definition, LUCs may be necessary). When evaluating potential future direct contact exposure pathways of a construction and/or commercial worker, subsurface soils may be defined as from one foot bgs extending to 10 ft. bgs. 10 ft. bgs is a common nominal maximum depth for construction activities. However, if it is anticipated that future excavation depths could exceed the 10 ft. bgs, the anticipated depth of excavation should be used to evaluate the risk to construction and/or commercial workers. The exposure pathways associated with subsurface soils include:

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

- Future potential ingestion, inhalation, and/or dermal contact of soil particulates during excavation activities

A representative number of subsurface soil samples should be collected in the exposure domain(s) in order to evaluate these pathways. Representative subsurface soil concentrations are then used to determine if the cumulative risk is acceptable. Refer to Appendix A for guidance on the methods for estimation of representative subsurface soil concentrations.

#### **3.4.4 Pathways for Groundwater**

Exposure pathways for impacted groundwater include:

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

Representative groundwater samples should be obtained onsite and offsite to evaluate these pathways. Refer to Appendix A for requirements concerning sufficient data necessary to develop representative groundwater concentrations. The representative groundwater concentrations are then used to determine if the cumulative risk is acceptable.

#### **3.4.5 Other Pathways**

Other significant pathways of exposure, such as ingestion of food crops for human consumption grown in impacted media, ingestion of fish and shellfish, or use of groundwater for irrigation purposes should be evaluated if these pathways are complete. Refer to the USEPA (1989) Risk Assessment Guidance for Superfund, Volume I, for detailed guidance on evaluation of risk due to food intake.

The USEPA Superfund Risk Assessment regulations and documents are available online at:

<http://www.epa.gov/oswer/riskassessment/ragsa/index.htm>

Additional references are available on the USEPA Region 9 PRG website located at:

<http://www.epa.gov/region09/waste/sfund/prg/otherlinks.htm>



### 3.5 SITE CONCEPTUAL EXPOSURE MODEL

The information obtained during the site assessment phase is used to develop a 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 COCs 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 a risk. The exposure domain of all receptors must be considered. 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.

A SCEM is required for the PSL, RM-1 and RM-2 evaluations. The SCEM should be updated and become more detailed as the assessment of the site progresses from the PSL phase into the RM-1 phase and finally into the RM-2 phase. At some sites, where there are numerous impacted offsite properties, multiple SCEMs may have to be developed. Throughout the ARBCA evaluation process, the SCEM should be evaluated and revised to reflect accurate site conditions. Figure 3-1 is a graphical presentation that may be used as a worksheet to develop a SCEM. The user must clearly document all the source-pathway-receptor-route combinations and present clear justification for complete and non-complete pathways. There may be multiple SCEMs if there are multiple impacted offsite properties.

### 3.6 POINT OF EXPOSURE

The 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 ROE identified in the SCEM. For direct pathways of exposure, the POE is located at the source of

the COCs. For example, for the ingestion of surficial soil, the POE is at the same location as the soil source. For indirect pathways of exposure, the POE and the source of COCs are physically separate. For example, the POE for indoor inhalation of vapors from soil is the breathing space inside the building, whereas the source is the soil below the building. Thus, for each complete ROE, the user must identify the source and the POE.

For the GRP evaluation, 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 (Some programs may require that the POE be established at a location no further than the property boundary). For the PSL evaluation, the POE is assumed to be located directly below the source. For the RM-1 and RM-2 evaluations, the POE will be at the closest downgradient residential property boundary where a well could be installed or at another location or distance such as the site's property boundary. The evaluation of the likely installation of a well and resulting POE will depend on considerations such as availability of public water supply, potability and use of shallow water (quality and yield), history of aquifer use, existence of municipal restrictions to install wells, and the most likely future land use setting. Justification of an alternate POE location must be based on site-specific characteristics such as the current and likely future land and water use, the types of COCs (including their impact, mobility and persistence), and their potential for biodegradation.

A **sentry well (SW)** is a monitoring well(s) that must be located between the COC source area and the POE. The SW serves as a sentry or guard well(s) for the protection of the POE. For RM-1 and RM-2 evaluations, SW target levels will be developed that are compared to the source soil and groundwater representative concentrations for that location. For most sites, several SWs should be selected for the groundwater resource evaluation. For sites with variable or radial flow, multiple POEs and SWs may have to be evaluated.

### **3.7 CALCULATION OF RISK-BASED TARGET LEVELS**

RBTLs are the allowable concentrations using the back-calculation mode. Cumulative risk is calculated utilizing the forward-calculation mode. Appendix D of this document provides example calculations of RBTLs and calculation of the cumulative risk. This procedure requires quantitative values of (i) target risk levels, (ii) chemical-specific quantitative toxicity 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.

The risk evaluator will calculate the target levels using technical data and pathway-specific models. RM-1 target levels should be developed utilizing the models/equations provided in

Appendix B and the default input parameters listed in Tables 3-1 and 3-2 as well as chemical specific parameters as listed in Tables 3-3 and 3-4. For RM-2 evaluations, the provided models, the chemical specific parameters as listed in Tables 3-3 and 3-4, and appropriate site-specific data should be used for developing the RM-2 levels unless alternate models are approved by ADEM.

### 3.7.1 Target Risk Level

A risk-based decision making process requires the specification of a target or acceptable risk level for both **carcinogenic (ca)** and **non-carcinogenic (nc)** adverse health effects. For carcinogenic effects, risk is quantified using the **Individual Excess Lifetime Cancer Risk (IELCR)** that represents an increase in the probability of an individual developing cancer due to exposure to a chemical of concern through a complete **Route of Exposure (ROE)**. Since a receptor may be exposed to multiple COCs and ROEs, the acceptable risk level should account for the effect of simultaneous exposure to multiple COCs and ROEs. The IELCR level used to calculate PSVs (see Table 2-2) was 1E-06, while the IELCR level used in the calculation of the RM-1 and RM-2 levels is 1E-05.

For non-carcinogenic effects, risk is quantified using a **Hazard Quotient (HQ)** that represents the ratio of the estimated dose for a chemical and a route of exposure to the reference dose. When a receptor is exposed to multiple COCs and multiple ROEs, individual HQs may be added together to estimate the **Hazard Index (HI)**. The HI is the sum of individual HQs. An HQ of 0.1 was used to calculate the PSVs (see Table 2-2) while an HI of 1.0 should be used in the RM-1 and RM-2 calculations.

The target risk levels IELCR and the HQ/HI may be used in one of two ways. First, the representative concentrations may be used to calculate the site-specific risk that is then compared with the target risk. If the cumulative risk (sum of risk for each COC and each complete ROE) exceeds the target risk, risk management and/or remediation may be necessary. Groundwater contaminants must be included within the cumulative calculation even if the established MCL is not exceeded. Following a cumulative evaluation where it is determined that the acceptable risk has been exceeded, target risk may be used to back-calculate the target concentrations for each chemical, each ROE, each medium, and each receptor. The target concentration levels are then used as a guide during risk management and/or remediation activities and compared with the representative concentration(s) (see Appendix A). Once it appears that the target concentrations have been met, the cumulative risk at the site should be re-evaluated to ensure that the target risk goals have been met.

For non-carcinogenic effects for the Preliminary Screening Values, a HQ of 0.1 was used

(see Table 2-2). It should be noted that Table 2-2 uses the USEPA R9 PRG Table as a primary reference. In the case of non-carcinogens (nc), the values presented on the USEPA R9 PRG table have been divided by a factor of 10 in order to utilize an HQ of 0.1 (see Table 2-2). Since the additive effects of multiple chemicals and multiple routes of exposure must be considered for RM-1 and RM-2 evaluations, a hazard index (HI) (sum of HQs for each COC and each complete ROE) of less than or equal to 1.0 must be used. When determining the additive effects of multiple chemicals and multiple routes of exposure, ingestion of groundwater must be considered and all COCs having an MCL must be included within the cumulative risk evaluation.

During the screening process, if a constituent had both carcinogenic and non-carcinogenic health effects, the most conservative value of the two was used.

For the RM-1 and the RM-2 evaluation, the use of a site-wide IELCR (the sum of the IELCR for each COC and each complete ROE) of  $1 \times 10^{-5}$ , and a site-wide HI (the sum of HQs for each COC and each ROE) less than or equal to 1.0 is required. A cumulative risk evaluation should be calculated using representative concentrations for each COC as described in Appendix A. To calculate the cumulative risk for an area of contamination, the “forward-calculation” method must be used as opposed to the “back-calculation” method. The back-calculation method is described in Appendix D and solved for in the models located in Appendix B. In the back-calculation method, the user specifies target risks and then calculates RBTLs. Conversely, in the forward-calculation method, risk is calculated from a receptor point’s representative concentrations and receptor input parameters. An example of this process is provided in Appendix D.

For the ingestion of groundwater pathway, the chemical-specific concentrations at the POE should not exceed the MCLs. In the absence of an MCL, the following options are available:

1. Calculate a *Direct Ingestion of Groundwater* value in accordance with the equation located on page B-1 or other appropriate model (see the description in the paragraph below).
2. Utilize Table 2-2 of this guidance (note that the screening values used are up to the date of this publication and the user should apply the most recent values.)

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If neither an MCL nor the necessary information needed to calculate a *Direct Ingestion of Groundwater* value as contained within Tables 3-3 and 3-4 of this guidance exists for a chemical, an approved lifetime HA value may be utilized to compare against the representative concentrations at the POE. As stated above, POE contaminant concentrations can be determined through the use of a fate and transport model. Appropriate groundwater

models (or a combination thereof) for the geological characteristics at the site should be utilized. This guidance contains the equations needed for the Domenico Model which is based on laminar flow in a homogeneous geologic environment. For sites in unique geologic environments not suited for the Domenico Model (such as karst or fractured flow regimes), another, more appropriate, model or modeling pack should be applied. Examples of models that have been accepted for use within EPA Region 4 at sites where conditions are favorable are a combination of the BIONAPL/SEAM3D/BIOREDOX models or the TRAFRAP-WD model. In many cases, it may be necessary to validate a model through the use of historical concentrations and potentiometric data to demonstrate that the model can approximate downgradient concentrations at a site. In some cases, modeled concentrations at the POE, SW, and source area locations should be verified using actual data collected from those locations. Additional monitoring (at a minimum) or corrective action may be required if the concentrations exceed the groundwater ingestion values at the POE well or values protective of the POE at the SW.

For impacts to surface waters of the state, target surface water concentrations should utilize the target risk levels determined and developed by ADEM Water Division in accordance with the Water Quality Criteria established in ADEM Admin. Code 335-6-10. The most conservative scenario should be used (i.e., consumption of water and fish). In the absence of a constituent addressed in 335-6-10, the most current version of the USEPA National Recommended Water Quality Criteria should be utilized.

USEPA National Recommended Water Quality Criteria (USEPA, 2002c)

<http://www.epa.gov/waterscience/criteria/wqcriteria.html>

For constituents not addressed in either of the above references, the Department should be contacted for guidance on the matter.

### 3.7.2 Quantitative Toxicity Factors

The toxicity of chemicals is quantified using a **slope factor (SF)** or potency value for chemicals with carcinogenic adverse health effects. For chemicals that cause non-carcinogenic adverse health effects, toxicity is typically quantified by the **reference dose (RfD)** and **reference concentration (RfC)**. The most current toxicity values recommended by the USEPA must be used for ARBCA evaluations. For COCs that may not have a preferred reference, please contact ADEM. Alternative values must be approved by ADEM. Table 3-4 of this guidance (note that the toxicological properties presented are up to the date of this publication and the user should apply the most recent values) provides the ARBCA user with acceptable toxicity values. To obtain the current toxicity values, a user should

consult the following sources in the order listed:

- Integrated Risk Information System (IRIS)  
<http://www.epa.gov/iris/index.html>
- National Center for Environmental Assessment (NCEA)  
<http://cfpub.epa.gov/ncea/>
- USEPA Region 4 Recommendations  
<http://www.epa.gov/region4/waste/ots/otsguid.htm>
- Health Effects Assessment Summary Tables (HEAST)  
<http://www.epa.gov/radiation/heast/index.html>
- Agency for Toxic Substance and Disease Registry (ATSDR)  
<http://www.atsdr.cdc.gov/>
- Center for Environmental and Human Toxicology (CEHT), University of Florida  
<http://www.dep.state.fl.us/waste/categories/wc/pages/LinksToGuidanceDocuments.htm>
- California EPA  
<http://www.oehha.ca.gov/risk/ChemicalDB/index.asp>
- USEPA Region 9  
<http://www.epa.gov/region09/waste/sfund/prg/index.html>
- Oak Ridge National Laboratory  
<http://rais.ornl.gov/index.shtml>
- State recommended values
- Review of literature by qualified professionals to develop toxicity factors

It should be noted that the Department is aware that the **Provisional Peer Reviewed Toxicity Values (PPRTVs)** developed by NCEA are not available for direct access by the general public. In order to become a “Registered User” of the PPRTVs, the Department should be contacted and a request will be made through the USEPA National Center for Environmental Assessment, Office of Research and Development for access to the PPRTVs. Prior to becoming a registered user, the Department should be contacted if a toxicity value is needed from the PPRTV list. Due to this inconvenience, the Department has included a table of toxicity values (see Table 3-4). However, for the most current and up-to-date values, the PPRTVs must be consulted.

In many cases in Table 3-4, the toxicity of a chemical had to be converted from a reference concentration (RfC) to a reference dose (RfD). The reason for structuring the equations to use the RfD term exclusively is due to children generally having a much higher ventilation rate relative to body weight than adults. Consequently, children may receive a higher dosage of a chemical from air than an adult at the same air concentration. The use of RfDs allows

this difference to be taken into consideration. For the same reason, the equation for carcinogenicity utilizes **inhalation cancer slope factors (SF<sub>i</sub>)** rather than the inhalation unit risk (IUR) values.

When an **inhalation RfC (RfC<sub>i</sub>)** was available, it was converted to an **inhalation RfD (RfD<sub>i</sub>)**. The conversion from RfC<sub>i</sub> to RfD<sub>i</sub> assumed a 70 kg individual breathing 20 m<sup>3</sup>/day. Thus, the RfC was multiplied by 20 m<sup>3</sup>/day and divided by 70 kg to obtain a value with the unit's mg/kg-day.

When a RfC<sub>i</sub> was not available, the second choice was to develop a RfD<sub>i</sub> from the oral RfD (RfD<sub>o</sub>) using route-to-route extrapolation. Such extrapolation was only done when the toxic endpoint being addressed was systemic in nature. Oral RfDs that were known or likely to be route-specific were not extrapolated.

The formula for the conversion of a RfD<sub>o</sub> to a RfD<sub>i</sub> was as follows:

$$\text{RfD}_i = \text{RfD}_o \times \text{GI absorption}$$

The Gastrointestinal (GI) absorption term represents the bioavailability of the chemical following exposure through the oral route. Current USEPA guidance (USEPA, 1989) recommends assuming 100% GI absorption for all chemicals that do not have chemical-specific GI absorption values.

Similarly to the non-carcinogens, in many cases in Table 3-4, the toxicity of a carcinogenic chemical had to be converted from an inhalation unit risk (IUR) to a SF<sub>i</sub>. The conversion assumes a 70 kg individual breathing 20 m<sup>3</sup>/day. Thus, the IUR (per µg/m<sup>3</sup>) is divided by 20 m<sup>3</sup>/day and multiplied by 70 kg and a conversion factor of 1000 µg/mg to obtain a value with the units (mg/kg-day)<sup>-1</sup>.

If an IUR was not available and the chemical was regarded as likely producing carcinogenicity via a systemic effect, a SF<sub>i</sub> was derived from the SF<sub>o</sub>, if available. The aforementioned route-to-route extrapolation was accomplished by using the following formula:

$$\text{SF}_o = \text{SF}_i / \text{GI absorption}$$

In general, route-to-route extrapolation from the SF<sub>o</sub> was not performed if the SF<sub>o</sub> was known or presumed to reflect route-specific toxicity. When a chemical exhibits route-specific toxicity, it exerts its toxic effect (i.e., cancer) only by a specific exposure route

(USEPA, 1989a, p.7-8).

### 3.7.3 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 for each route of exposure
- Exposure frequency
- Soil ingestion rate
- Hourly indoor/outdoor 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 default exposure factors that should be used to compute the RM-1 levels is presented in Table 3-1. The exposure factors are typically estimated based on literature and site-specific measurements are not obtained. For a RM-2 evaluation, site-specific exposure factors may be used provided they can be adequately justified. Site-specific human activity patterns different from those used to derive the default skin to soil adherence factor would be cause for a site to develop a more site-specific value. The recommendations in USEPA's *Risk Assessment Guidance for Superfund (Part E, Supplemental Guidance for Dermal Risk Assessment)* and/or the *USEPA Exposure Factors Handbook* should be followed when determining a soil to skin adherence factor different from the values presented in Table 3-1.

For RM-2 evaluations, acceptable sources of exposure information include:

- USEPA Exposure Factors Handbook (*August 1997*)  
<http://www.epa.gov/ncea/pdfs/efh/front.pdf>
- USEPA Region 4 Human Health Risk Assessment Bulletins – Supplement to RAGS (*May 2000*)  
<http://www.epa.gov/region4/waste/ots/otsguid.htm>



- USEPA Risk Assessment Guidance for Superfund. Volume 1: Human Health Evaluation Manual (Part E Supplemental Guidance for Dermal Risk Assessment. Final. (July 2004)

<http://www.epa.gov/oswer/riskassessment/ragse/>

Other sources of exposure factor data may be utilized with approval of ADEM.

### **3.7.4 Fate and Transport Parameters**

Fate and transport parameters are necessary to estimate the target levels for the indirect pathways of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. For calculating the RM-1 levels, ADEM has selected conservative default values that are listed in Table 3-2. For a RM-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 value) must be justified based on site-specific conditions. Where site-specific conditions are significantly different from the RM-1 assumptions, site-specific values should be used and a RM-2 evaluation performed. Section 4.0 contains additional details concerning site data needed for the ARBCA evaluation. For a RM-2 evaluation, the specific fate and transport parameters required to calculate the target levels could vary depending on the choice of models.

### **3.7.5 Physical and Chemical Properties of the COCs**

To develop the target levels, the ARBCA evaluation requires selected physical and chemical properties of the COCs. Since several of these properties are experimentally determined, their values may differ from different references. ADEM recommends the use of values as referenced by USEPA R9 or the Center for Environmental and Human Toxicology (CEHT), University of Florida. Sufficient justification must be provided to ADEM for the use of alternate values and would be allowed only under a RM-2 evaluation. The proposal to use the different values should be submitted in the RM-2 work plan prior to the use of the values in the evaluation. See Table 3-3 for a list of recommended physical and chemical properties.

### 3.7.6 Mathematical Models

Two types of models or equations, (i) the uptake equations and (ii) the fate and transport models, are required to calculate the target levels. For RM-1 and RM-2 evaluations, ADEM has selected the models and equations presented in Appendix B. Alternate models may be used for RM-1 or RM-2 evaluations with the prior approval of ADEM. In some cases, the models (e.g., Domenico Model) presented within Appendix B may not be suitable for use at a site. The ARBCA user should exercise caution to ensure that the models being applied are appropriate for the existing site conditions. If an alternate model is planned to be used at a site it will generally be necessary to submit an RM-1 or RM-2 work plan. Certain programs within ADEM may not require a work plan due to the specificity of the guidance used within the program. The user should contact ADEM to establish if a work plan is required.

## 3.8 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, for example, if the COCs are **dense non-aqueous phase liquids (DNAPLs)**. At sites where a deeper aquifer may be impacted, the evaluation has to be performed on a site-by-site basis.

## 3.9 GROUNDWATER RESOURCE PROTECTION

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. The ARBCA user must evaluate groundwater as a potential drinking water source. A determination of allowable soil and groundwater contaminant levels must be made when there are water supply wells onsite or offsite. At sites where there are no water supply wells present, the remedial measures for soil and groundwater are required to be protective of the groundwater resource for likely future use (some programs (e.g., RCRA, CERCLA, VCP) may require that the water supply well be assumed to be located at the downgradient property boundary). If the *likely future use* of a site is determined to be a use other than unrestricted land use (i.e., residential scenario), LUCs (e.g., restrictive covenant) shall be installed in perpetuity or until the Department has determined that an unrestricted land use is appropriate at the site.

A POE must be identified at all impacted sites where MCLs or equivalent RBTLs have to be met. A site-specific determination of the location of the POE should consider the current and likely future groundwater use, the types of COCs including their impact, mobility and

persistence, and the documented occurrence of biodegradation of the contaminant plume. Other site-specific features and/or programmatic requirements may influence the final location of the POE. In most cases, modeled concentrations at the POE location must be verified using actual data collected from the referenced locations. Generally it is inappropriate to use hypothetical well locations; however, some programs may allow a hypothetical POE well location to be used if certain conditions are met. The POE location is used to estimate the target soil source concentrations and target groundwater source and SW concentrations protective of the POE. The ultimate goal is to meet levels appropriate for an unrestricted residential land use scenario throughout the entire area of attainment for groundwater, soils, and all other media of concern. The evaluation requires the selection of a well(s) in the source area and SWs (located between the source and the POE) for comparison to the allowable target levels calculated at the source, SWs and POE. The COC concentrations in the source and SWs are compared to the calculated values. The soil source area COC concentrations should be determined and compared to target soil source screening levels. Target soil screening levels (for the source area) are calculated which are protective of groundwater at the POE to meet the MCL or other accepted target level. Table 2-2 lists the soil screening levels protective of groundwater for select chemicals. These soil screening levels were calculated utilizing the equations in Appendix B (pages B-11 through B-14), the toxicity value for each COC (Table 3-4), physical and chemical properties of each COC (Table 3-3), and the default fate and transport parameters (Table 3-2). If the COC is not listed, a RM-1 or RM-2 value must be calculated (See Sections 6 and 7).

### **3.10 LEACHING TO GROUNDWATER**

Potential impacts to groundwater and/or surface water bodies must be determined. There are a number of different methods that a site may use to determine if the potential for soil contaminant concentrations exist at a level that could threaten the groundwater or surface water quality. At the PSL, the representative soil concentrations (see Appendix A) should be compared to the appropriate soil screening levels protective of groundwater value located in Table 2-2. In either the RM-1 or RM-2 stages, the facility may also choose to use either EPA Method 1312, the Synthetic Precipitate Leaching Procedure (SPLP), or EPA Method 1311, the Toxicity Characteristic Leaching Procedure (TCLP), and compare the resulting “leached” material with a level protective of the ingestion of groundwater. For the RM-1 and RM-2 stages, the ARBCA evaluator may choose to use either the equation located on page B-13 to determine an acceptable soil (surface or subsurface) concentration or one of the methods described above that utilizes the SPLP method or the TCLP method.

### 3.11 SURFACE WATER AND STREAM PROTECTION

Potential impacts to streams and other surface water bodies from a release have to be determined. Sampling for COCs in surface water bodies may need to occur when COC migration is known or suspected to affect a surface water body. Target levels represent the smallest of the suggested surface water quality criteria values being utilized for (i) freshwater acute exposure, (ii) freshwater chronic exposure, and (iii) human consumption of fish and water. A surface water sample for determination of hardness should also be collected if the target surface water value for the COC is hardness or pH dependent as described in ADEM Admin. Code Rule 335-6-10-.07(1). The *Toxic Pollutant Criteria Applicable to State Waters* are based on dissolved phased surface water concentrations. When addressing ecological impacts, the target levels should be consistent with the hierarchy presented in Section 3.3. For a more detailed, site-specific determination of risks present to ecological receptors at a site, the *Ecological Risk Assessment for Superfund (ERAGS): Process for Designing and Conducting Ecological Risk Assessments* should be followed. The values determined should not be exceeded in the groundwater discharging into a stream. For a RM-1 evaluation, target levels must be met at the discharge point. Appendix D (Example D-4) contains a detailed discussion of a surface water evaluation.

ERAGS is located online at:

<http://www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm>

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.  $C_{\text{soil}}$  = Allowable soil source concentrations
- ii.  $C_{\text{gws}}$  = Allowable source groundwater concentrations
- iii.  $C_{\text{sw}}$  = Allowable SW concentrations in groundwater at different distances between the surface water and the source

Items (ii) and (iii) above are considered SW concentrations protective of the surface water. Details of this procedure are discussed in Appendix D. If the RM-1 fate and transport assumptions are not representative of the site, and, the measured soil source or the SW concentration(s) exceed the corresponding target concentrations, a RM-2 stream impact evaluation should be performed.

For a RM-2 evaluation, the surface water target levels are applicable at the downstream edge of the mixing zone formed by the mixing of the discharge of the contaminated groundwater

into the stream. Biodegradation of chemicals as they migrate from the source to the stream may be utilized in a RM-2 evaluation if adequate justification is provided.

If representative COC concentrations at the soil source, groundwater source or SW exceed the RM-1 levels for the stream, then remediation may be required at the site or a RM-2 evaluation may be performed. Under a RM-2 evaluation, alternate fate and transport models may be used. Prior approval of alternate models must be obtained through approval of a RM-2 work plan by ADEM (see Section 7.1.14 for additional information regarding target surface water concentrations).

### **3.12 ESTIMATING SENTRY WELL CONCENTRATIONS**

In the ARBCA evaluation, it is necessary to designate SWs either onsite and/or offsite to confirm that the concentrations at the POE do not exceed the target levels in the groundwater or in a surface water or stream, if applicable. Monitoring of SWs must occur, and the data obtained from the monitoring of those wells must be utilized as representative concentrations to compare with calculated RM-1 or RM-2 target levels. Monitoring of SWs will be required until the concentrations in the SWs stabilize below the calculated levels. The SW target concentrations can be estimated using the models in Appendix B and the procedure discussed in Appendix D.

### **3.13 FREE PRODUCT**

The presence of free product serves as a long-term source of contaminants which will continue to migrate to surrounding soils, groundwater, and surface water. Therefore, ADEM requires that all free product be removed to the maximum extent practicable.

### **3.14 ECOLOGICAL EXPOSURE**

Exposures to ecological receptors and habitats such as wetlands, sensitive environments, or threatened and/or endangered species should be thoroughly evaluated. Where an ecological threat may exist due to a release, an ecological evaluation should be performed. For details regarding the level of detail and the specific method to be used for ecological evaluation, contact ADEM. Note that within the ARBCA framework, protection of surface waters and streams (see Sections 3.11 and 7.1.14 for additional information) is considered independent of the ecological risk evaluation unless a sensitive population not otherwise properly addressed by the stream evaluation is present at the site. A separate ecological risk evaluation should be performed if there is a sensitive population identified which may not be protected by the typical stream evaluation. The following is a list of media-specific values

that should be used to evaluate ecological impacts at sites.

➤ Surface Water

- Surface water data collected during the assessment phase should be compared to the USEPA Region 4 Ecological Screening Values with respect to surface water
- In the absence of a Region 4 Ecological Screening Value for surface water, the surface water concentrations should be compared to the Water Quality Criteria located in ADEM Admin. Code 335-6-10 (the “Aquatic Life Criteria” should be used)
  - If the surface water is a “water of the state” as defined in ADEM Admin. Code R. 335-6-10-.02(10), the surface water concentrations should be compared to the Water Quality Criteria regardless of whether a Region 4 Value exists and the ADEM Water Division should be contacted
- In the absence of a USEPA Region 4 Ecological Screening Value or an ADEM Water Quality Criteria Value, surface water should be compared to the appropriate Region 3 Biological Technical Assistance Group (BTAG) screening value
- In the absence of an ecological screening value for surface water in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be contacted to ensure that the value chosen is appropriate for use.

➤ Sediments

- Sediment data collected during the assessment phase should be compared to the USEPA Region 4 Ecological Screening Values with respect to sediment
- In the absence of a Region 4 Ecological Screening Value for sediment, the sediment concentrations should be compared to the Florida Sediment Quality Assessment Guidelines (SQAGs). These guidelines contain values for marine, estuarine and freshwater sediments. These values were developed utilizing data from not only Florida but throughout the Southeast Region
- In the absence of a USEPA Region 4 Ecological Screening Value or a Florida SQAGs, sediment should be compared to a Region 3 Biological Technical Assistance Group (BTAG) screening value
- In the absence of an ecological screening value for sediment in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be contacted to ensure that the value chosen is appropriate for use.
- Sediment that is not saturated year round should be evaluated as surficial soil as

well as sediment

➤ Soils

- Soil data collected during the assessment phase should be compared to the USEPA Ecological Soil Screening Levels (EcoSSLs).
- In the absence of a USEPA EcoSSL, the soil concentrations should be compared to the USEPA Region 4 Ecological Screening Values with respect to soils.
- In the absence of an ecological screening value for soils in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be contacted to ensure that the value chosen is appropriate for use.

USEPA Region 4 Ecological Screening Values are available online at:

<http://www.epa.gov/region4/waste/ots/ecolbul.htm>

ADEM Water Quality Criteria Regulations can be accessed online at:

<http://www.adem.state.al.us/Regulations/regulations.htm>

Region 3 BTAG Screening Values can be accessed online at:

<http://www.epa.gov/reg3hwmd/risk/eco/index.htm>

Florida Sediment Quality Assessment Guidelines can be accessed online at:

[http://www.dep.state.fl.us/waste/quick\\_topics/publications/pages/default.htm](http://www.dep.state.fl.us/waste/quick_topics/publications/pages/default.htm)

USEPA Ecological Soil Screening Levels can be accessed online at:

<http://www.epa.gov/ecotox/ecossl/>

Please note that the benchmarks listed are subject to change. The most current data should be used. If questions arise as to which set of benchmarks should be used, please contact the Department for additional guidance. For a more detailed, site-specific determination of risks present to ecological receptors at a site, the *Ecological Risk Assessment for Superfund (ERAGS): Process for Designing and Conducting Ecological Risk Assessments* should be followed. *ERAGS* is located online at:

<http://www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm>

### 3.15 SPECIAL CASES

#### 3.15.1 Arsenic

For the evaluation of direct human contact of arsenic contaminated soil, as recommended by USEPA Region 4 and contrary to what was typical prior to 2004, both the carcinogenic and noncarcinogenic effects should be evaluated. Additionally, the migration from soil to groundwater pathway should also be evaluated. For the evaluation of the ingestion of groundwater, per USEPA Region 4 recommendation, it is also appropriate to evaluate both the carcinogenic and non-carcinogenic effects of arsenic.

Further recommendations from USEPA Region 4 allows for bioavailability measured *in vivo* using animal models or for the funding of research to find an *in vitro* method for assessing bioavailability. Similarly, the option to use a subchronic reference dose with an exposure duration of 7 years or less is scientifically justifiable and applicable to children's' exposures.

#### 3.15.2 Lead

For the evaluation of lead contaminated soil, it is not appropriate to use the models located in Appendix B of this document. The final cleanup values used for lead should be those values presented in Table 2-2 or the values should be developed using one of the following models dependent upon the exposure scenario.

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

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

Both of the aforementioned models are part of USEPA's Risk Assessment *Databases and Tools* and can be located at the following website:



<http://www.epa.gov/oswer/riskassessment/tools.htm>

### **3.15.3 2,3,7,8 TCDD (Dioxin)**

For the evaluation of 2,3,7,8 TCDD (dioxin) contaminated soil, the values cited in Table 2-2 of this guidance may be used for screening or cleanup purposes. The aforementioned values are direct contact human exposure values based on USEPA OSWER Directive 9200.4-26.

### **3.15.4 Tetrachloroethene and Trichloroethene**

As cited in the toxicity table (Table 3-4), the toxicity values used for tetrachloroethene (PCE) and trichloroethene (TCE) are consistent with Cal EPA's Toxicity Criteria Database. The Cal EPA values were used based on recommendation from USEPA Region 4 as the preferred values at this time.

## **3.16 DOCUMENTATION OF THE ARBCA EVALUATION**

The ARBCA evaluation should be clearly and concisely documented and submitted to ADEM for review. An example outline of an ARBCA evaluation is presented in Appendix C. The submitted report should include all items as outlined in Appendix C.

## DATA REQUIREMENTS FOR THE ARBCA PROCESS

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This section presents the data necessary to implement the ARBCA process and a brief discussion of the techniques used to collect the data. The AEIRG document should also be consulted to determine the procedures for performing a proper investigation.

### 4.1 DATA COLLECTION OBJECTIVES

The objective of the data collection effort is to ensure that sufficient quality and quantity of data are available to:

- Develop and validate a site conceptual exposure model
- Compare the maximum site concentrations with the screening levels
- Evaluate the cumulative risk at each exposure domain and if the target risk levels are exceeded, develop RM-1 or RM-2 target levels
- Compare the target levels with representative concentrations
- Develop a feasible corrective action or risk management plan
- Confirm the effectiveness of risk management alternatives

This data would typically be collected subsequent to the confirmation of a release as part of the site characterization activities. Ideally, all the data necessary to perform a risk-based evaluation should be collected in one mobilization, however due to a variety of reasons, it may be necessary to perform several phases of characterization. Also, although the specific data requirements are similar irrespective of the program under which the site is being evaluated, the site characterization activities are named differently. Users should be aware of the different nomenclature and requirements to ensure that appropriate site characterization is performed at the site.

To accomplish the above data objectives, the following categories of data are required:

- Nature and magnitude of the spill or release
- Site information
- Land use and receptor information
- Vadose zone soil properties
- Saturated zone properties
- Hydrogeological properties

- Distribution of the contaminants in soil
- Distribution of the contaminants in groundwater
- Distribution of the contaminants in surface water bodies and sediments
- Risk management measures

At most impacted sites, portions or all of the necessary data may have been collected over an extended period of time, perhaps over several years. As part of the ARBCA evaluation, the responsible party must carefully review all the available data and identify any data gaps. A comprehensive chronology of events related to reported releases, site characteristics, remediation, tank removal activity, etc., must be developed to understand the soil and groundwater impacts at the site. The chronology of events must be clearly and accurately documented.

#### **4.2 DEVELOPMENT OF A SITE CONCEPTUAL EXPOSURE MODEL (SCEM)**

The development of a site conceptual exposure model (SCEM) forms the basis of understanding site-specific conditions and performing the risk evaluation. The SCEM identifies and integrates the various factors that contribute to human and environmental risk at a site. A SCEM should be developed as early in the process as possible, perhaps soon after site discovery, but no later than the PSL evaluation. The SCEM should be revised as additional data is collected. Thus, a SCEM helps in collection of the right quality and quantity of data necessary in identifying the most significant risk issues at a site.

A SCEM should provide an overall understanding of the site based on the following:

- Site description and land use
- Release scenario and sources
- Current and future human receptors
- Site stratigraphy and hydrogeology
- Description of COPCs and/or COCs
- Identification of complete exposure pathways and routes of exposure

The specific data required to develop the SCEM was discussed in Section 3.0. A graphical example of a SCEM is provided as Figure 3-1 (note: Figure 3-1 is for example only. More or less information may be required when developing a SCEM).

### **4.3 RELEASE CHARACTERIZATION**

Knowledge about the nature and magnitude of the spill or release is necessary to identify the soil and/or the groundwater source at the site as well as to identify the contaminants herein referred to as the contaminants of potential concern (COPCs). The following information regarding a spill or release is necessary:

- Location and time of the spill or release
- Quantity of the spill or release
- Product spilled or released
- Interim corrective action measures already performed

The spill-related information can be obtained by (i) a review of the inventory records, (ii) interview of past employees, (iii) interviews with current onsite workers, and, (iv) any spill incident reports filed with ADEM. Additional information that can help identify the location of source and the COPCs is information related to the activities at the site as discussed in Section 4.3.1 -4.3.4.

#### **4.3.1 Location and Time of Spill or Release**

The location of the spill or release defines the soil and groundwater source area. The responsible party should review the operational history of the site to determine the location and timing of spill(s) or release(s). For most sites, the exact location and timing of the spill/source area may not be known. The site may have had multiple spills/releases at different times and at different locations. In these cases, soil and groundwater sampling should be used to identify the likely location and extent (vertical and horizontal) of the residual soil and groundwater sources. The exact number and location of samples have to be determined on a site-by-site basis using professional judgment and the concurrence of ADEM project manager.

#### **4.3.2 Quantity of Spill or Release**

The ARBCA does not necessarily require knowledge of the exact quantity of the spill or release. Often this information is not known. However, a general idea of the amount released may help evaluate the severity of the impact and the extent of contamination.

### **4.3.3 Chemicals of Potential Concern**

Identification of the specific product(s) spilled or released is important for identification of the appropriate COPCs. At sites where mixtures of chemicals or multiple chemicals may have been released, it is important to identify all of the chemicals. Where definitive information on the chemicals released is not available, it may be necessary to analyze soil and groundwater for an extended list of chemicals. The responsible party should contact ADEM to discuss the analyses required to determine what COPCs might be present at the site.

The environmental behavior (mobility, persistence, bio-degradation, 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. COPCs corresponding to all the products suspected to have been stored at the site should be analyzed. If data collected in the past did not include all the suspected COPCs at a site, additional sampling may be necessary before an ARBCA evaluation can be performed.

### **4.3.4 Interim Corrective Actions**

Typical interim corrective actions include the excavation and offsite disposal of contaminated soil, removal of free product, soil vapor extraction, pump and treat, etc. Corrective actions performed at the site may have removed all or part of the product spilled or released. Soil and groundwater data collected prior to such activities may not be representative of current conditions and should not be used in the risk evaluation. At such sites, additional soil and groundwater data should be collected after the completion of the corrective action. Data collected prior to the completion of corrective action may be useful in determining the locations where additional data is needed or where further corrective action is needed. Following the completion of interim measures, the facility should submit a report to ADEM that details all of the activities that occurred at the site in response to the release.

## **4.4 SITE INFORMATION**

The following site information is necessary to complete the ARBCA evaluation:

- Site map
- Ground surface condition
- Onsite and offsite utilities
- Existing groundwater use

- Regional hydrogeology and aquifer characteristics

Relevant site information can be obtained by (i) a site visit, (ii) review of engineering drawings showing the layout of the site, (iii) review of regional information, and (iv) review of the ADEM files related to the site or adjacent sites.

#### **4.4.1 Site Map**

All maps should be made to scale with a bar scale and a north arrow. Site maps showing the locations of various historical and current structures onsite, and the location of all data collection points should be developed. Water use wells, recovery wells, remediation system location, soil borings, soil excavation areas, land use adjacent to the site, etc. should be illustrated on a site map.

#### **4.4.2 Ground Surface Conditions**

Prior to the performance of an ARBCA evaluation, a site visit and walk through should be conducted. Areas of the site that are paved, unpaved, landscaped, or covered with buildings should be indicated on a site map. Details of the ground surface should also be provided including the type, extent of ground cover, general condition of the ground surface and the site topography.

#### **4.4.3 Onsite and Offsite Utilities**

Due to the potential for preferential flow of contaminated groundwater and vapors into underground utility lines/conduits, a thorough evaluation of potential and real impacts to underground utilities must be performed. Utilities include phone lines, water lines, sanitary sewers, storm sewers, and natural gas lines. A combination of site observations, knowledge of buried utilities, and discussions with utility representatives and site owner should reveal the locations of site utilities. At a minimum the following activities should be performed:

- Locate all underground utility lines and conduits within the area of known or likely soil and groundwater impact, both onsite and offsite where the release may have migrated, or may migrate in the future.
- Determine the direction of flow in the utilities (water, storm water, and sewage).
- Identify the utility lines/conduits on a base map that also contains a diagram showing the extent of soil and groundwater impacts.
- 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, concrete, steel, etc.).
- Determine any past impacts to utilities and any complaints that may have been previously filed with ADEM.
- As appropriate, sample the utilities and vaults using either explosimeters or by taking air samples. The local fire department and ADEM should be immediately notified if explosive conditions are encountered.
- Where a utility is threatened, or where an explosive situation exists, appropriate measures to eliminate fire, explosive, and vapor hazards must be undertaken.
- If free product is present it must be removed to the maximum extent practicable.
- Where dissolved contamination is present, an evaluation of potential impacts of dissolved contamination should be made.

#### **4.4.4 Existing Groundwater Use**

A water well survey should be conducted as appropriate to site specific conditions (i.e. size of release, geology, hydrogeology, etc). The user should consult the AEIRG document and any other applicable regulatory or program requirements. Available 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 with surrounding businesses and residents to identify existing potable and non-potable wells. The current use and status of all located wells should be noted. The current and former owners and operators should be interviewed to determine whether a water well is/was located onsite. In cases where an onsite well is identified, construction details of the well should be obtained. At a minimum, the total depth of the well, screen interval, and the use of water should be determined. Onsite wells not currently in use or not likely to be used in the future should be properly abandoned with the approval of ADEM in accordance with the most current version of the AEIRG. Also any dewatering wells on or adjacent to the facility should be identified. The anticipated future, current and past use of the groundwater should be identified.

#### **4.4.5 Regional Hydrogeology and Aquifer Characteristics**

Published literature, especially **Geological Survey of Alabama (GSA)** and **United States Geological Survey (USGS)** publications, and any investigations conducted on adjacent release sites should be reviewed to determine the regional and site hydrogeology, soil types,

and aquifer characteristics. This evaluation should be used to determine the type and depth of aquifers in the area and whether they are confined, semi-confined, or unconfined. General aquifer characteristics such as yield, **Total Dissolved Solids (TDS)**, and salinity should be documented. Regional information will help the responsible party in efficiently collecting site-specific soil and groundwater information as discussed in Sections 4.5 and 4.6.

The survey should also identify surface water bodies located within an appropriate radius of the site (ADEM should be contacted to inquire of the “appropriate radius”) that could be potentially impacted by the site release. If a surface water body is identified, information regarding the type of surface water body, type of flow (perennial vs. intermittent), flow rate, flow direction and water use should be collected. The water body must be located on an area map and included in the report.

Note that there are water quality standards that apply for all water bodies of the state. If the water body is determined to be threatened, impaired or impacted, additional information must be collected and the ADEM Water Quality Branch should be notified. Any impacts to the surface waters of the state should be submitted to ADEM for review. The **Total Maximum Daily Load (TMDL)** is a calculation of the maximum amount of a pollutant that a water body can receive and meet water quality standards and an allocation of that amount to the pollutant sources. The State of Alabama maintains a 303(d) list pursuant to the Clean Water Act that includes all segments of water bodies that are determined to be non-supportive of the water quality standards required to meet that water body’s designated uses. It should be noted that in some cases, the TMDLs calculated for a particular water body may become the driving factor for cleanup values for one or more media.

#### **4.5 LAND USE AND RECEPTOR INFORMATION**

Land use information is used to identify the location and type of receptors, and the complete routes of exposure by which the receptors may be exposed to the chemicals of concern. This information is critical in developing a site conceptual exposure scenario. The following information should be collected:

- Current Land Use
- Potential Future Land Use
- Surface Water Intakes and Potable Springs Inventory
- Surface Water and Stream Inventory
- Ecological Receptor Survey

Specific distances needing to be inventoried for this information varies and is discussed in



other portions of the guidance. At sites where there is likelihood that the extent of impacts may be much larger, a land use map covering the entire impacted and potentially impacted area is necessary.

#### **4.5.1 Current Land Use**

Land use of the site and its immediate vicinity defines the onsite and offsite receptors who may be exposed to the COCs. A walking land use survey should be conducted within a minimum 500-foot radius of the site or the extent of the area that may be impacted. The survey should clearly identify residences (apartments, single-family homes), schools, hospitals, basements, day care centers, nursing homes, and the nature of businesses. The map should also identify surface water bodies, parks, recreational areas, wildlife sanctuaries, wetlands, and agricultural areas. The results of such a survey should be documented accurately on a scaled land use map.

#### **4.5.2 Potential Future Land Use**

Future land use and receptors may not be certain. Unless the future land use is known, local zoning laws and surrounding land use patterns should be used to determine the most likely future land use. As appropriate, zoning atlas and maps, aerial photographs, local planning offices, the U.S. Bureau of the Census, community master plans, changing land use patterns, interviews with current property owners, and commercial appraisals of a site can provide information for determining land use. Proximity to wetlands, critical habitat, and other environmentally sensitive areas are additional criteria that may help determine future land uses.

When the future land use cannot be determined, it may be appropriate to assume conservative land use from an exposure consideration (i.e. residential). A risk evaluation under a less conservative land use scenario may require LUCs and/or revalidation of the risk management plan due to changing land use scenarios.

#### **4.5.3 Surface Water Intake and Potable Springs Inventory**

All surface water intakes and potable springs must be identified. A surface water intake inventory should be performed in accordance with the AEIRG document. The inventory should also fulfill any other program regulatory requirements.

#### **4.5.4 Surface Water and Stream Inventory**

Review topographic or other area maps to locate any potentially impacted surface water bodies within an appropriate radius of the site (ADEM should be contacted to inquire of the “appropriate radius”). A walking survey of the properties within 500-feet of the site should be undertaken and the results documented.

#### **4.5.5 Ecological Receptor Survey**

As appropriate, a one-mile walking survey around the site to identify any ecological receptors may be necessary. Ecological receptors include but are not limited to wetlands, surface water bodies, wildlife refuge, sensitive habitats or the presence of endangered species. Any site where ecological receptors may be impacted will require consultation with ADEM.

### **4.6 VADOSE ZONE SOIL CHARACTERISTICS**

The vadose zone soil is the medium through which the COCs migrate to intercept groundwater and through which vapors move upward to the surface or into an enclosed space. Thus, characteristics of the vadose zone soils have considerable impact on the target levels. Relevant soil characteristics include but are not limited to:

- Thickness of vadose zone
- Depth to groundwater
- Porosity
- Volumetric water content / moisture content
- Fractional organic carbon content
- Dry bulk density

For the development of RM-1 target levels, the ADEM has assigned default values for the fate and transport parameters as presented in Table 3-3. For an RM-2 evaluation, site-specific parameters should be obtained that are representative of (i) the source area, (ii) soils through which COCs migrate to reach groundwater (vadose zone), and (iii) soils through which vapors of the COCs migrate to reach the surface.

Of the parameters mentioned above, fractional organic carbon content must be determined using soil samples not impacted by the release. An undisturbed sample is necessary for measuring soil porosity and dry bulk density. An undisturbed sample can be collected using

a Shelby tube. Samples representative of vadose and saturated zones should be collected where it appears that these two zones differ at a site. Consideration must be given to collecting multiple samples if multiple lithologies are present which might affect transport of the COCs.

#### **4.6.1 Thickness of Vadose Zone**

The thickness of the vadose zone represents the distance from the ground surface to the depth at which the water table is encountered less the thickness of the capillary fringe. The capillary fringe thickness plus the vadose zone thickness equals the depth to groundwater. Soil boring logs may be used to determine the depth to groundwater. A literature value is normally utilized for the capillary fringe thickness since measurement of the capillary fringe in the field or from boring logs is usually not possible or practical.

#### **4.6.2 Depth to Groundwater**

Depth to groundwater is one of the parameters used to estimate the vapor emissions from groundwater. When the depth to groundwater is significantly less than 10 feet (the RM-1 default value), then a RM-2 evaluation should be conducted that utilizes the site-specific depth to groundwater. 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.

#### **4.6.3 Porosity (cc/cc-soil)**

Porosity 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 equation:

$$n = 1 - \rho_s / \rho_b \quad (4-1)$$

where,

$n$	=	porosity (cc/cc)
$\rho_s$	=	dry bulk density (gm/cc)
$\rho_b$	=	specific gravity or particle density (gm/cc)

The “Standard Test Method for Specific Gravity of Soil” **American Society for Testing and Materials (ASTM)** Method D854, may be used to determine specific gravity. If specific gravity is not available, then 2.65 g/cc can be assumed as the particle density. Site-specific values of porosity may be estimated from a literature source based on site lithology.

#### 4.6.4 Volumetric Water Content / Moisture Content (cc/cc)

Volumetric water content is the ratio of volume of water to the volume of soil. The ASTM Method D2216-98 (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, it may be necessary to use the following:

$$\theta_{wv} = \theta_{wg} * \frac{\rho_s}{\rho_l} \quad (4-2)$$

where,

$\theta_{wv}$	=	volumetric water content (cc water / cc soil)
$\theta_{wg}$	=	gravimetric water content, typically reported by the laboratory (gm of water / gm of soil)
$\rho_s$	=	dry bulk density (gm of dry soil/cc of soil)
$\rho_l$	=	density of water (gm/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.

#### **4.6.5 Fractional Organic Carbon Content (g-C/g-soil)**

Fractional organic carbon content is the weight of organic carbon in the soil divided by the weight of the soil and is expressed either as a ratio or as a percent. The Walkley Black Method (Page et al, 1982. Method of Soil Analysis, Part 2. *Chemical and Microbiological Properties*, pp 570-571, Second Edition) 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 content. The reported value can be converted to a fraction by dividing by 100.

If 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).

#### **4.6.6 Dry Bulk Density (g/cc)**

Dry bulk density (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 analysis.

### **4.7 SATURATED ZONE CHARACTERISTICS**

COCs that reach the water table typically migrate in the saturated zone. Some COCs prefer to move vertically, therefore, the type of chemical and its characteristics is extremely important in conducting an adequate evaluation. Characteristics of the saturated zone that determine the travel time for the COCs as well as the travel direction include:

- Horizontal hydraulic conductivity
- Horizontal and vertical hydraulic gradients (magnitude and direction)
- Saturated zone soil characteristics (fractional organic carbon content, porosity)
- Groundwater parameters
- Infiltration rate
- Indicators of biodegradation

Of the characteristics mentioned above, the most important aquifer properties are the horizontal hydraulic conductivity and vertical and horizontal hydraulic gradient. Each of these properties is discussed below.

#### **4.7.1 Horizontal Hydraulic Conductivity (cm/sec)**

Hydraulic conductivity is the discharge of water per unit area per unit hydraulic gradient in a subsurface formation. Reliable estimates of site-specific hydraulic conductivity should be obtained by pump test or slug test. However, hydraulic conductivity may also be estimated based on the grain size distribution of the porous formation if a pump test or slug test is not feasible.

#### **4.7.2 Horizontal and Vertical Hydraulic Gradient**

The magnitude and direction of the hydraulic gradient is estimated by comparing water levels measured in the monitoring wells. Water level contour maps are prepared based on the measured data using a computer program or professional interpretation. These contour maps can be used to estimate both the direction and magnitude of the hydraulic gradient. When drawing the contour maps, care should be taken to ensure that measurements in monitoring wells screened in the same interval or hydrologic unit are used. For sites that have seasonal variation in hydraulic gradient, estimate the average hydraulic gradient for each season.

Consideration should also be given to determining any vertical gradients at the site. Estimation of these will require a comparison of adjacent water levels in wells screened in different intervals. In areas where the shallow aquifer has been impacted and a deeper aquifer is used for drinking water, the vertical gradient must be determined. Care must be taken to avoid cross contamination when drilling and installing deep wells.

#### **4.7.3 Saturated Zone Soil Characteristics**

In addition to the hydraulic conductivity, the saturated zone soil characteristics include the fractional organic carbon content, porosity, and bulk density. These parameters are required to quantify the movement of the chemicals within the saturated zone. The hydraulic conductivity and the hydraulic gradient are used to determine the groundwater velocity.

#### **4.7.4 Groundwater Parameters**

The length, width, and thickness of the groundwater source are required to evaluate the potential future use of groundwater downgradient from the source. Although the source length and width can be estimated from the groundwater analytical data and soil source dimensions, groundwater source thickness is not usually measured at a site. The groundwater source area is usually assumed to equal the soil source area. In the RM-1 evaluation, the default parameters as shown on Table 3-2 assume that the source size is square by making length equal to width. A groundwater mixing zone thickness of 200 cm (6.56 feet) is usually assumed, unless vertical profiling data is available. If the plume is not delineated in all directions, location of new monitoring wells should be chosen based on the groundwater flow direction and the location of the soil source area. Wells should be installed and the groundwater evaluated until there is confidence that the groundwater plume has been delineated in all directions.

#### **4.7.5 Infiltration Rate**

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

RM-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. 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 justified.

#### **4.7.6 Indicators of Biodegradation**

Intrinsic groundwater quality indicators (chemical concentrations, geochemical indicators, electron acceptors, microorganisms, etc.) may be measured at a site to document the occurrence of biodegradation. Data collected under each line of evidence can be evaluated either qualitatively or quantitatively to demonstrate the occurrence of biodegradation. Biodegradation indicators include:

- Decreasing contaminant concentrations in monitoring wells at a site (The concentrations should be evaluated using mol/L to ensure that dilution is not occurring. Concentrations should also be presented to the Department in mg/L).

- Measured intrinsic geochemical parameters including but not limited to, (i) dissolved oxygen, (ii) dissolved nitrates, (iii) manganese, (iv) ferrous iron, (v) sulfate, and (vi) methane. Other geochemical indicators, such as carbon dioxide, oxidation-reduction potential or dissolved gases, may need to be measured depending on the COCs. These water quality parameters should be measured in at least three wells located along the centerline of the plume. Locations of these wells should include (i) a background or upgradient well, (ii) a well located within the plume near the source, and, (iii) a well located within the plume downgradient from the source.
- Results of microbiological studies such as the identification of the microorganisms (e.g., *Dehalococcoides ethenogenes*) present in the formation.

#### **4.8 DISTRIBUTION OF COPCs / COCs IN SOIL**

Adequate soil concentration data are necessary to define the soil source dimensions and develop representative concentrations for each complete pathway. The representative concentrations are then used to determine if the cumulative risk within each exposure domain is acceptable. Sufficient data should be collected to define the horizontal and vertical extent of impacts up to PSVs. If it becomes apparent during the site investigation that the PSVs will be met, then no additional information may be needed at the site. However, if the concentrations exceed the PSVs, the site investigation should be performed such that all data necessary to perform a RM-1 or RM-2 evaluation are obtained as expeditiously as possible.

The field investigation to collect the soil data should follow current industry standards, EPA guidance, and the most current version of the AEIRG document. The soil investigation(s) should focus on collection of the following data/information:

- Identification of the area impacted by COPCs appropriate to the type of product released.
- Identification of the horizontal and vertical extent of impacts to soil. Unless otherwise directed by ADEM, the extent of impact should be defined to screening levels.

The ARBCA evaluation requires that a thorough assessment of source areas be performed to ensure that representative concentrations of chemicals are detected at the site (see Appendix A). The horizontal extent of the contamination should be determined through the collection of soil data. Soil data should continue to be collected and analyzed until a point is met, in all horizontal directions, which demonstrates that the soil samples contain contaminant concentrations below the PSVs. To determine the vertical extent of the contamination, soil borings should be extended down to the water table and samples collected from surface and



subsurface soil zones as defined in Sections 4.8.1 and 4.8.2. Depending on the characteristics of the COC released at the site, the vertical extent, and the presence of vertical gradients, sampling of soils beneath the water table in multiple deep saturated zones may need to be conducted.

#### **4.8.1 Surficial Soil Sampling**

Within the ARBCA program a distinction is made between surficial soil and subsurface soil. Surficial soil is defined as the soil from ground surface to 1 foot bgs. Surficial soil data is necessary where there was a surface spill or overflow, or where it is likely that surficial soils have been impacted. The exposure pathways associated with surficial soil include:

- Direct dermal contact
- Ingestion of soil particulates
- Inhalation of vapors
- Inhalation of soil particulates
- Leaching to groundwater

Evaluation of surficial soil pathways requires representative concentrations in surficial soil. Therefore, an adequate number of surficial soil samples should be collected and analyzed for COPCs. When sampling from boreholes, collect one soil sample for laboratory analysis at a depth of one foot bgs or two inches below the impervious (concrete or asphalt) cover, whichever is shallower. Note that in some cases very permeable material may be located immediately below the pavement. Care should be taken to collect representative samples.

#### **4.8.2 Subsurface Soil Sampling**

Subsurface soil is defined as the soil existing between one foot bgs and the water table or bedrock. If another definition of subsurface soil than the one noted above is desired to be applied at a site (i.e., subsurface soil is defined as the soil existing between one foot bgs and 10 feet bgs), then LUCs may be necessary. Representative concentrations in subsurface soil depend on the pathway and the exposure unit of the receptor. The exposure pathways associated with subsurface soils include:

- Ingestion of soil particulates
- Inhalation of vapors and particulates (this may include the indoor inhalation pathway)
- Leaching to groundwater
- Direct dermal contact

The construction worker may have direct exposure to the subsurface soil when involved in excavation activities. The commercial worker may have indirect exposure through indoor and outdoor inhalation of vapors. The resident (unrestricted property use) may be exposed as noted in both of the aforementioned scenarios since they may perform any task at the site. Representative concentrations in subsurface soil depend on the pathway and the exposure unit of the receptor. To adequately evaluate these pathways, a sufficient number and density of soil samples should be collected in the impacted area(s). Therefore, the sampling plan for subsurface soil is pathway-specific as described below:

- Representative concentrations of COCs within each exposure domain are required to evaluate outdoor inhalation of vapor emissions from subsurface soil.
- For the current indoor inhalation of vapors pathway from subsurface soils, soil samples should be collected from borings adjacent to or below any existing structures. For the future scenario, soil samples should be collected within the known footprint of a planned structure or from the most contaminated boring(s), i.e. in the soil source area.
- For exposure to a construction worker, commercial worker or a resident during excavation activities, representative concentrations are necessary within a 3-dimensional exposure domain which should include the surface and subsurface soils.
- Several critical parameters are required to evaluate the leaching of COCs from soil into groundwater. These parameters include (i) thickness of the contaminated soil zone, (ii) distance from the bottom of the contaminated zone to the water table, if any, and (iii) the representative concentration of COCs within the contaminated zone.
- Soil sampling must be done in accordance with the guidelines and procedures documented in the most current version of the AEIRG.

The appropriate method for abandoning boreholes is described in the most current version of the AEIRG.

#### **4.8.3 Soil Vapor Sampling**

If it is determined by the Department and/or the ARBCA evaluator that the indoor inhalation pathway is potentially complete, the facility may need to collect and analyze (sub-slab or other appropriate) soil vapor samples. The models located in Appendix B should be used to determine if the collected soil vapor concentrations exceed the acceptable risk within the exposure domain. If the risk has been exceeded, it is appropriate to develop RBTLs using the models located in Appendix B.

#### **4.8.4 Soil Source Data**

The soil analytical data, along with the historical use of the site should help identify the soil source area. If more than one (1) source area is identified at a site, each source area should be evaluated separately. A representative number of soil samples should be collected within each source area. Soil source dimensions are estimated based on the delineation of the extent of soil contamination. These dimensions are used to estimate target levels protective of leaching to groundwater.

#### **4.8.5 Logging of Soil Boreholes**

Each soil boring must be logged by qualified personnel (see Section 1.0). Soil boring logs should indicate depths correlating with changes in lithology (with lithologic descriptions), soil vapor measurements, occurrence of groundwater, total depth, visual and olfactory observations, and any other pertinent data. When a monitoring well is installed, as-built diagrams including depth to groundwater must be submitted for each well. A continuous soil profile from each soil 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.

### **4.9 DISTRIBUTION OF COPCs / COCs IN GROUNDWATER**

Adequate groundwater samples should be collected to delineate the extent of dissolved contaminant plumes both horizontally and vertically and to provide representative concentrations based on the SCEM. Soil source delineation can serve as a guide in choosing the location of monitoring wells.

#### **4.9.1 Groundwater Sampling**

If 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 (4) for a PSL evaluation) to document COC migration and groundwater flow. The monitoring wells must be installed and sampled in accordance with ADEM guidelines and procedures as outlined in the most current version of the AEIRG.

#### **4.9.2 Surface Water and Sediment Sampling**

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 for COC analyses. A surface water sample for determination of hardness may also need to be collected if the target surface water value for the COC is hardness or pH dependent as described in ADEM Admin. Code Rule 335-6-10-.07(1). It should be noted that the *Toxic Pollutant Criteria Applicable to State Waters* are based on dissolved phase surface water concentrations. In addition, sediment samples may be collected if the site conditions warrant. Sampling should be conducted in accordance with the most current version of the AEIRG.

#### **4.10 WORK PLAN AND DOCUMENTATION OF DATA**

Prior to collecting the field data, all available site data should be compiled to identify the data gaps. A work plan should be developed clearly identifying the specific methods for data collection. The ARBCA evaluation should not be conducted until all the necessary data has been collected. Plan modifications as requested by ADEM should be implemented when performing the fieldwork. After collection of additional site data, all information should be submitted with the ARBCA evaluation to support the conclusions of the evaluation. Appendix C contains the information that should be submitted in an ARBCA evaluation. The user should consult the most current version of the AEIRG document to ensure the proper collection of adequate site data. Other ADEM programs may not require a work plan due to the specificity of their guidance. The user should contact ADEM to establish if a work plan is required.

## PRELIMINARY SCREENING LEVEL EVALUATION

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The objective of the Preliminary Screening Level (PSL) evaluation is to perform a preliminary risk evaluation to identify COPC concentrations and all source areas and areas of interest within the site that may need further evaluation.

The screening level evaluation entails comparing *maximum* contaminant concentrations detected within each exposure domain with Preliminary Screening Values (PSVs). Table 2-2 contains the PSVs for groundwater, soil and soil screening levels protective of groundwater. A brief description of this step and the data needed to perform a PSL evaluation is presented below.

### 5.1 INITIAL SITE CHARACTERIZATION

Performance of a PSL evaluation begins with the collection of site soil, soil vapor, sediment and groundwater data to locate the highest current concentrations within each exposure domain (see Figure 2-1). Additionally, for inorganic chemicals, the objective would also include the collection of background soil and groundwater concentrations. For certain organic and inorganic chemicals (e.g., pesticides and arsenic), an anthropogenic background source at a site may exist. Anthropogenic substances are natural and human-made substances present in the environment as a result of human activities (not specifically related to the site in question). In order to determine if a natural or an anthropogenic background source exists at a site, the guidance found in Section 4.4 of the AEIRG should be followed. Approval by the Department to use the anthropogenic source in the ARBCA evaluation as a background source is necessary. At sites with multiple exposure domains, samples should be collected from within each exposure domain. Depending on the nature of activities, sources anticipated at the site, and size of the site, the site may be divided into several exposure domains.

If it is determined by the Department and/or the ARBCA evaluator that the indoor inhalation pathway is potentially complete, the facility may need to collect and analyze (sub-slab or other appropriate) soil vapor samples. The models located in Appendix B should be used to determine if the collected soil vapor concentrations exceed the acceptable risk within the exposure domain. If the risk has been exceeded, it is appropriate to develop RBTLs using the models located in Appendix B.

The exact number of samples, analytical methods to be used, and the procedures for collecting the data may vary from site to site. The responsible party should develop a work plan and have it reviewed and approved by ADEM prior to implementing the work plan. Investigative guidance documents of the various ADEM regulatory programs should be referenced as well. Other ADEM programs may not require a work plan due to the specificity of their guidance. The user should contact ADEM to establish if a work plan is required.

## 5.2 COMPARISON OF DATA WITH PRELIMINARY SCREENING VALUES

The data collected during the preliminary characterization should be evaluated to ensure the following:

- The exposure domains are adequately characterized to identify the maximum current concentrations
- Site characteristics are comparable to default values used to develop PSVs
- Analytical methods used are consistent with the COPCs for the site based on site history
- All QA/QC requirements are met
- Detection limits do not exceed the PSVs
- Appropriate background data has been collected

If the data satisfies the above requirements, the maximum soil and groundwater concentrations should be compared with the Preliminary Screening Values (PSVs) within each AOI.

With respect to groundwater, certain COPCs have established MCLs; therefore, preliminary screening level evaluations should be made against the established MCLs. In the absence of an MCL, the user has the following options:

1. Calculate a *Direct Ingestion of Groundwater* value in accordance with the equation located on page B-1 or other appropriate model (see the description in Section 3.7.1).
2. Utilize Table 2-2 of this guidance

If neither an MCL nor the necessary information needed to calculate a *Direct Ingestion of Groundwater* value as contained within Tables 3-3 and 3-4 of this guidance exists for a chemical, an approved Lifetime Health Advisory (Lifetime HA) value may be utilized to

compare against the representative concentrations at the POE.

With respect to target soil screening levels protective of groundwater, RM-1 levels may need to be developed. These values should be developed assuming the POE is located at the source. The default values in Tables 3-1 through 3-4 were used to develop the soil PSVs.

If an acceptable level of site investigation has been performed as determined by ADEM, and the maximum media-specific concentrations at each exposure domain do not exceed the PSVs, then additional site evaluation may not be necessary. If the maximum site concentrations exceed the PSVs, then a RM-1 evaluation should be conducted for those constituents. The COPCs that do not exceed the PSVs within an exposure domain are no longer a concern. Only the chemicals that exceed the PSVs become COCs and are used to assess the cumulative risk within each exposure domain in the RM-1 and/or RM-2 stage. Sites with adequate site-specific information as described in Sections 4.0 and 7.0 may move directly into the RM-2 phase following a PSL evaluation. The ARBCA evaluator may also choose to adopt the PSVs as the cleanup levels and develop a CAP if the facility wishes not to go through the RM-1 or RM-2 process. Since a site may be granted no further action under a PSL evaluation, it is very important that the site evaluation identify the maximum media-specific concentrations. If there is a potentially complete pathway that does not appear to be adequately addressed by the PSVs, a RM-1 and/or RM-2 evaluation should be undertaken to include all appropriate pathways.

The Risk Management-1 (RM-1) evaluation requires the calculation of the cumulative risk present within each exposure domain. If it is determined that the cumulative risks do not exceed acceptable risk levels, there are no groundwater resource protection-related exceedences, and no surface water protection-related exceedences an NFA may be granted by the Department. Certain requirements for LUCs may apply depending on the regulatory program applicable to the site. If it is determined that the cumulative risks at the site exceed appropriate levels, the user may either conduct a RM-2 evaluation or develop RM-1 RBTLs for each COC, complete pathway, and receptor as identified in the SCEM. An RM-1 evaluation requires the following:

- Characterization of the site
- Development of Site Conceptual Exposure Model
- Determination of the cumulative risk present within each exposure domain
- Evaluation of the groundwater resource protection and surface water protection criterion
- Development of RM-1 target levels
- Comparison of RM-1 target levels with site representative concentrations
- Risk management recommendations

### **6.1 CHARACTERIZATION OF THE SITE**

The site should be characterized to ensure that the source areas are adequately assessed and the contamination levels are delineated in a horizontal and vertical extent to the screening levels. The site should be classified into exposure domains and described based on the level of known risk(s) from the release at the site.

### **6.2 DEVELOPMENT OF SITE CONCEPTUAL EXPOSURE MODEL**

The development of a detailed SCEM is necessary for the RM-1 evaluation. SCEM development has been described in detail in Section 3.0. Particular elements of the SCEM are also described in Section 4.0. A graphical example of a SCEM is provided as Figure 3-1. The SCEM must be sufficiently detailed so that all complete receptor-route-exposure pathways are identified for evaluation.



### **6.3 DEVELOPMENT OF RM-1 TARGET LEVELS**

For each complete exposure pathway identified in the SCEM, the risk should be calculated using the default values in Tables 3-1 through 3-4 and if the acceptable cumulative risk is exceeded, RM-1 levels should be developed. The Department has established the models/equations in Appendix B to be used to develop the RM-1 target levels. The user should compare the default fate and transport parameters to the known site characteristics. If the default parameters are not representative of the site conditions, then an RM-2 evaluation will be required. In some cases, models other than those located in Appendix B may be more suitable due to site-specific conditions. The most current toxicity values recommended by the Department must be used for ARBCA evaluations. For COCs that may not have a preferred reference, please contact the Department. For additional information regarding toxicity values, see Table 3-4 and Section 3.7.2.

### **6.4 COMPARISON OF RM-1 TARGET LEVELS WITH EXPOSURE DOMAIN REPRESENTATIVE CONCENTRATIONS**

If target cumulative risk has been exceeded, it is necessary to either move to the RM-2 stage or develop RM-1 target levels. If the ARBCA evaluator decides to develop RM-1 target levels, they should be compared with the representative site concentrations within each exposure domain following remediation activities. Depending on the site conditions, multiple representative concentrations may have to be developed for a site. Representative concentrations should be developed for each exposure domain. Appendix A provides detailed procedures for determining exposure units and for calculating representative concentrations.

Following remediation activities at a site, representative concentrations should be updated within each exposure domain. Before remediation may be considered complete, the target cumulative risk must be met within each exposure domain.

The representative concentrations should be evaluated as follows:

#### **6.4.1 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 source dimensions used in developing the

target levels. Representative concentrations should be determined as necessary and compared to the target levels.

The soil data from the most recent investigation(s) (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 ADEM. If a new release has occurred, soil assessment activities should occur to adequately characterize the extent of the new release.

#### **6.4.1.1 Surficial Soil**

The representative concentrations should be determined based on the available surficial soil concentration data. The representative surficial soil concentrations from the most recent investigations should be identified and noted. Appendix A discusses the calculation of representative site concentrations. The RM-1 target levels for surficial soil should be compared with the representative site concentrations and used as a guide to determine when it is probable that the exposure domain have been remediated to a level that does not exceed acceptable cumulative risk levels.

#### **6.4.1.2 Subsurface Soil**

The representative concentrations should be determined based on the available subsurface soil concentration data. The representative soil concentrations from the most recent investigations should be identified and noted. Appendix A discusses the calculation of representative site concentrations. The RM-1 target levels for subsurface soil should be compared with the representative site concentrations and used as a guide to determine when it is probable that the exposure domain has been remediated to a level that does not exceed acceptable cumulative risk levels.

### **6.4.2 Groundwater**

A variety of representative groundwater concentrations may have to be estimated at a site depending on the SCEM. The procedures to select and properly calculate the groundwater representative concentrations are described in Appendix A. The appropriate representative concentrations should be selected for each groundwater exposure. A comparison of the appropriate representative concentrations with the appropriate RM-1 target level should be conducted.

An RM-1 evaluation should be performed with a minimum of four (4) consecutive groundwater monitoring events (this may be done using data collected quarterly or semi-annually). If semi-annual data is utilized, the sampling events should be conducted during the wet and dry seasons (i.e. March and September) to account for seasonal variations. Current groundwater data may need to be obtained if the groundwater data is not current. A data acquisition plan should be developed to include the proposed methods that will be conducted to collect and analyze additional groundwater data as needed to establish accurate representative site concentrations. Subsequent to the evaluation, confirmatory groundwater monitoring data may be necessary to confirm decreasing trends of COCs in groundwater impacted by the release.

#### **6.4.2.1 RM-1 Groundwater Resource Protection Evaluation**

For the RM-1 evaluation, the POE for the groundwater resource protection evaluation will be at the closest downgradient residential property boundary where a well could be installed but at a distance no greater than 500 feet from the property boundary. Certain programs (e.g., RCRA, CERCLA, VCP) may not allow the POE to be located beyond the property boundary. The Department should be consulted so that the POE well will be located appropriately. The determination of the likely installation of a well and resulting POE will depend on considerations such as availability of public water supply, potability and use of shallow water (quality and yield), history of aquifer use, property ownership, existence of municipal restrictions to install wells, and the most likely future land use setting. For sites with soil and/or groundwater COC concentrations that exceed the RM-1 target levels for groundwater resource protection, the site should be remediated to the RM-1 target levels or an RM-2 evaluation may be conducted to further evaluate these exceedences.

#### **6.4.3 Surface Water and Sediments**

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 for COC analyses. A surface water sample for determination of hardness may also need to be collected if the target surface water value for the COC is hardness or pH dependent as described in ADEM Admin. Code Rule 335-6-10-.07(1). It should be noted that the *Toxic Pollutant Criteria Applicable to State Waters* are based on dissolved phased surface water concentrations. During the RM-1 stage of the evaluation, in locations where groundwater or a stream is entering into a stream, it may be necessary to conduct a mixing zone calculation. For information on how to conduct mixing zone calculations, see Section 3.11. In addition, sediment samples may be collected if the site conditions warrant.

## 6.5 RISK MANAGEMENT RECOMMENDATIONS

If the site concentrations exceed the target cumulative risk levels, the groundwater resource protection standards, or the surface water protection criteria using the RM-1 inputs, the following three risk management alternatives are available:

- 1) **Localized Exceedances.** For localized exceedances where site concentrations exceed the RM-1 target levels in a small portion of the site, the owner/operator, with ADEM's approval, may choose to conduct interim remediation to meet cumulative risk levels. An example of this scenario is the presence of a small exposure domain which exceeds the RM-1 levels. Remediation of this exposure domain may be sufficient to allow the site to achieve the target risk level and receive an NFA provided all other conditions are satisfied.
- 2) **Conduct RM-2 Evaluation.** The owner/operator may conduct an RM-2 evaluation. An RM-2 evaluation may be necessary when any of the fate and transport assumptions used in the RM-1 evaluation are significantly different from the site-specific conditions, and those conditions make the RM-1 risk levels less conservative. For fate and transport parameters used to estimate the RM-1 target levels, refer to Table 3-2. For example, at sites where the depth to groundwater is less than the RM-1 default depth of 300 cm, it will be necessary to conduct an RM-2 evaluation using the site-specific depth to groundwater. An RM-2 evaluation is also necessary if a COC is not present on the RM-1 target level list.
- 3) **Remediation to RM-1 Target Levels.** The owner/operator may elect to develop a CAP to remediate the site to RM-1 target levels. The corrective action plan would have to be approved by ADEM.

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

- An acceptable level of site investigation has been performed as determined by ADEM
- Target cumulative risk levels are not exceeded
- There are no groundwater resource protection-related exceedances
- There are no surface water protection-related exceedances
- Representative concentrations meet the criteria in Section 6.4 and Appendix A
- No nuisance conditions exist at the site
- Free product has been removed to the maximum extent practicable

- The site-specific fate and transport parameters are not significantly different than the RM-1 default values
- The plume must be stable or decreasing
- ADEM agrees with the overall RM-1 evaluation
- Any necessary LUCs have been implemented and a monitoring plan if necessary has been developed and approved

An NFA granted with restrictions (e.g., with LUCs, long term monitoring) is valid only so long as the restrictions are maintained.

A Risk Management-2 (RM-2) evaluation may be conducted (i) when RM-1 target levels are exceeded and it is not appropriate to remediate the site to RM-1 levels, (ii) RM-1 assumptions are significantly different from site-specific conditions, so that the estimated RM-1 cumulative risks may not be representative of site-specific conditions, (iii) the COCs are not listed in the PSV table, or (iv) the site has a significant ecological risk that must be evaluated on a site-specific basis.

As indicated in Table 2-1, the RM-2 evaluation allows site-specific decision-making for the selection of alternative fate and transport models, and input parameters that will result in a cumulative Target Cancer Risk of  $1 \times 10^{-5}$  and/or Hazard Index of 1.0. Since the RM-2 provides considerable site-specific decision making, it may be necessary for the responsible party to develop an overall work plan clearly outlining the methodology as well as the input parameters to be used to develop RM-2 target levels. Depending on the differences between RM-1 and the proposed RM-2 evaluation, the work plan may vary in the amount of details contained in the plan. For example, if the proposed RM-2 evaluation will use all default models and parameters except site-specific soil geotechnical parameters, a letter work plan may be sufficient. However, if the proposed RM-2 evaluation includes the use of alternative models or complex measurement of any site-specific parameters, a very detailed work plan will be necessary. The responsible party should receive ADEM approval prior to proceeding with the RM-2 evaluation.

## **7.1 CONTENTS OF AN RM-2 WORK PLAN**

### **7.1.1 Site Background**

A brief description of the site should be in this section. This portion of the work plan may refer to the documents previously submitted to ADEM and it will not be necessary to repeat the entire site background. In order to determine if a natural or anthropogenic background source exists at a site, the guidance found in Section 4.4 of the AEIRG should be followed. Approval by the Department to use the anthropogenic source in the ARBCA evaluation as a background source is necessary.

### **7.1.2 Site Conceptual Exposure Model**

The owner/operator should develop the SCEM if it has not already been developed and identify the complete exposure routes and pathways. Refer to Sections 3.0 and 4.0 for details regarding content and development of the SCEM. All COCs and all complete routes of exposure should be evaluated under the RM-2 evaluation (even those that satisfy RM-1 levels). Thus, the SCEM for the RM-2 evaluation will be exactly the same as the SCEM for the RM-1 evaluation unless additional information warrants a change. In most cases where an RM-1 has been completed, this step will involve reference to the previously developed SCEM if no revisions are necessary.

### **7.1.3 Target Risk**

The acceptable cumulative carcinogenic risk for an RM-2 evaluation is  $1 \times 10^{-5}$ . For non-carcinogenic risk the cumulative hazard index must be less than or equal to 1.0. See Section 3.7.1 for a more detailed discussion of the target risk.

### **7.1.4 Exposure Factors**

The evaluator may choose to utilize the default exposure factors provided in Table 3-1. The evaluator may propose alternate exposure factors in the work plan. These factors must be justified and acceptable to ADEM.

### **7.1.5 Physical and Chemical Properties**

The evaluator should utilize the physical and chemical properties of the COCs as provided in Table 3-3. If a COC is not listed the evaluator must propose and justify the use of physical and chemical properties as previously discussed in this guidance. Alternate physical and chemical properties must be approved by ADEM prior to use.

### **7.1.6 Toxicological Properties**

The current toxicity values accepted by the Department must be used. Table 3-4 provides the current acceptable values as of the date of this guidance. If toxicity values for a COC are not listed the evaluator must propose and justify the use of toxicological properties as previously discussed in Sections 3.7.2. Alternate toxicological properties must be justified and approved by ADEM prior to use.

### **7.1.7 Fate and Transport Parameters**

The evaluator may choose to utilize the default fate and transport parameters provided in Table 3-2. ADEM also allows representative site-specific fate and transport parameters to be used for an RM-2 evaluation. Sections 4.6 and 4.7 describe some of the methods appropriate for determining site-specific values. At a minimum, site measured values of soil source dimensions, depth to subsurface soil sources, thickness of vadose zone, depth to groundwater, hydraulic gradient, hydraulic conductivity, and the distances to the point of exposure and sentry well must be used. Where site-specific values are not available for parameters, professional judgment has to be used to determine whether to perform additional assessment or to use appropriate literature values. If additional data is necessary, a data acquisition work plan should be developed and approved by ADEM prior to performing the RM-2 evaluation.

ADEM will allow the use of chemical-specific biological decay rates in the fate and transport models, based preferably on site-specific evaluation of historic monitoring well data, or alternatively, on justifiable literature values. Note that the use of decay rates in RM-2 evaluations must be justified based on site-specific information, including but not limited to:

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

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

### **7.1.8 Fate and Transport Models**

The user may utilize the same models and algorithms used to develop RM-1 target levels for an RM-2 evaluation. Alternate models may be used to calculate the RM-2 target levels with ADEM approval. The specific models to be used must be identified in the work plan. These models must be approved by ADEM prior to their implementation and acceptance of the calculated cumulative risk level and RM-2 target levels.

### **7.1.9 Calculation of Representative Concentrations**

The representative soil and groundwater concentrations are calculated the same as for an RM-1 evaluation (Section 6.4) and as discussed in Appendix A. These representative concentrations may be used to estimate the site risk. If the site risk exceeds the acceptable risk level, a risk management plan will have to be developed which will include the



development of RM-2 levels. The work plan should include a discussion of how the representative concentrations will be calculated.

#### **7.1.10 Segregation by Target Organ**

An RM-2 work plan could propose the procedure of segregation by target organ for noncarcinogenic effects in accordance with Chapter 8 of USEPA's *Risk Assessment Guidance for Superfund (Part A)*.

#### **7.1.11 RM-2 Groundwater Resource Protection Evaluation**

The use of groundwater as a current and a future drinking water supply is the basis of the groundwater resource protection component of the ARBCA evaluation. A determination of allowable soil and groundwater contaminant levels must be made when there are water supply wells onsite or offsite. At sites where there are no water supply wells present, the cleanup levels for soil and groundwater are required to be protective of the groundwater resource for likely future use. If the *likely future use* of a site is determined to be a use other than unrestricted land use (i.e., residential scenario), LUCs (e.g., restrictive covenant) should be installed in perpetuity or until the Department has determined that an unrestricted land use is appropriate at the site. Section 2.9 further describes LUCs.

For the RM-2 evaluation, the POE will be at the closest downgradient residential property boundary where a well could be installed or at another location or distance. Certain programs (e.g., RCRA, CERCLA, VCP) may not allow the POE to be located beyond the property boundary. The Department should be contacted so that the POE well will be located appropriately. The evaluation of the likely installation of a well and resulting POE will depend on considerations such as availability of public water supply, potability and use of shallow water (quality and yield), history of aquifer use, property ownership, existence of municipal restrictions to install wells, the types of COCs including their impact, mobility and persistence, and the documented occurrence of biodegradation of the contaminant plume. Other site-specific features and/or program-specific requirements may influence the final location of the POE and the most likely future land use setting. Justification of an alternate POE location must be based on site-specific characteristics such as the current and likely future land and water use, the types of COCs (including their impact, mobility and persistence), and their potential for biodegradation.

The SW is a monitoring well(s) that must be located between the COC source area and the POE. The SW serves as a sentry or guard well(s) for the protection of the POE. For RM-2 evaluations, SW target levels will be developed that will be compared to the source soil and

groundwater representative concentrations. For most sites, several SWs should be selected for the groundwater resource evaluation. For sites with variable or radial flow, multiple POEs and SWs may have to be evaluated. The groundwater resource protection evaluation procedure is described in Appendix D.

#### **7.1.12 Vapor Intrusion Pathway Evaluation**

If it is determined by the Department and/or the ARBCA evaluator that the indoor inhalation pathway is potentially complete, the facility may need to collect and analyze (sub-slab or other appropriate) soil vapor samples. The models located in Appendix B should be used to determine if the collected soil vapor concentrations exceed the acceptable risk within the exposure domain. If the risk has been exceeded, it is appropriate to develop RM-2 levels using the models located in Appendix B.

#### **7.1.13 Source Water Assessment Evaluation**

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

#### **7.1.14 Surface Water Evaluation**

Potential impacts to streams and other surface water bodies from a release must be determined. Sampling for COCs in surface water bodies may need to occur when COC migration is known or suspected to affect a surface water body. Target levels represent the lesser of the suggested surface water quality criteria values being utilized for (i) freshwater acute exposure, (ii) freshwater chronic exposure, and (iii) human consumption of fish and water. A surface water sample for determination of hardness may also need to be collected if the target surface water value for the COC is hardness or pH dependent as described in ADEM Admin. Code R. 335-6-10-.07(1). It should be noted that the *Toxic Pollutant Criteria Applicable to State Waters* are based on dissolved phased surface water concentrations. When addressing ecological impacts, the target levels should be consistent with the hierarchy presented in Section 3.3. For a more detailed, site-specific determination of risks present to ecological receptors at a site, the *Ecological Risk Assessment for Superfund (ERAGS): Process for Designing and Conducting Ecological Risk Assessments* should be followed. The values determined should not be exceeded in the groundwater discharging/seeping into a

stream. For an RM-1 evaluation, target levels must be met at the discharge point since mixing within the stream is only allowed under a RM-2 evaluation.

ERAGS is located online at:

<http://www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm>

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.  $C_{\text{soil}}$  = Allowable soil source concentrations
- ii.  $C_{\text{gws}}$  = Allowable source groundwater concentrations
- iii.  $C_{\text{sw}}$  = Allowable sentry well concentrations in groundwater at different distances between the surface water and the source

Items (ii) and (iii) above are considered SW concentrations protective of the surface water. Details of this procedure are discussed in Appendix D. If the RM-1 fate and transport assumptions are not representative of the site, or, the measured soil source or the SW concentration(s) exceed the corresponding target concentrations, an RM-2 stream impact evaluation should be performed.

For an RM-2 evaluation, the surface water target levels are applicable at the downstream edge of the mixing zone formed by the mixing of the discharge of the contaminated groundwater into the stream. Biodegradation of chemicals as they migrate from the source to the stream may be utilized in an RM-2 evaluation if adequate justification is provided.

If representative COC concentrations at the soil source, groundwater source or SW exceed the RM-1 levels for the stream, then remediation may be required at the site or an RM-2 evaluation may be performed. Under an RM-2 evaluation, alternate fate and transport models may be used. Prior approval of alternate models must be obtained through approval of an RM-2 work plan by ADEM.

For impacts to surface waters of the state, target surface water concentrations should consider both the target risk levels determined above and water quality standards developed in accordance with ADEM Admin. Code R. 335-6-10-.07. The most conservative (lowest) value should be used. In the absence of a constituent addressed in 335-6-10, the most current version of the following USEPA guidance should be utilized.

USEPA National Recommended Water Quality Criteria (USEPA, 2002c)

<http://www.epa.gov/waterscience/criteria/wqcriteria.html>

For constituents not addressed in either of the above references, the Department should be contacted for guidance on the matter.

#### **7.1.15 Ecological Evaluation**

Surface water and sediment data collected during the assessment phase should be compared to the USEPA Region 4 Ecological Screening Values with respect to ecological receptors. In the absence of a Region 4 Ecological Screening Value for surface water, the surface water concentrations should be compared to the Water Quality Criteria located in ADEM Admin. Code R. 335-6-10 (the “Aquatic Life Criteria” should be used). If the surface water is a “water of the state” as defined in ADEM Admin. Code R. 335-6-10-.02(10), the surface water concentrations should be compared to the Water Quality Criteria regardless of whether a Region 4 Value exists, and the ADEM Water Division should be contacted. In the absence of a USEPA Region 4 Ecological Screening Value or an ADEM Water Quality Criteria Value, surface water and sediment should be compared to the appropriate Region 3 BTAG screening value. In the absence of a Region 4 Ecological Screening Value for sediment, the sediment concentrations should be compared to the Florida SQAGs. In the absence of a USEPA Region 4 Ecological Screening Value or a Florida SQAG, sediment should be compared to a Region 3 BTAG screening value. Additionally, sediment that is not saturated year round should be evaluated as surficial soil but also as sediment for the potential ecological impacts. Soils data should be compared to the USEPA EcoSSLs. In the absence of a USEPA EcoSSL, the soil concentrations should be compared to the USEPA Region 4 Ecological Screening Values with respect to soils. In absence of an ecological screening value in one of the referenced locations, risk assessors should go to the scientific literature and identify an applicable value. If an alternate value is needed, the Department should be contacted to ensure that the value chosen is appropriate for use.

USEPA Region 4 Ecological Screening Values are available online at:

<http://www.epa.gov/waterscience/criteria/wqcriteria.html>

ADEM Water Quality Criteria Regulations can be accessed online at:

<http://www.adem.state.al.us/Regulations/regulations.htm>

Florida Sediment Quality Assessment Guidelines can be accessed online at:

[http://www.dep.state.fl.us/waste/quick\\_topics/publications/pages/default.htm](http://www.dep.state.fl.us/waste/quick_topics/publications/pages/default.htm)

Region 3 BTAG Screening Values can be accessed online at:

<http://www.epa.gov/reg3hwmd/risk/eco/index.htm>

USEPA Ecological Soil Screening Levels can be accessed online at:

<http://www.epa.gov/ecotox/ecossl/>

For a more detailed, site-specific determination of risks present to ecological receptors at a site, the *Ecological Risk Assessment for Superfund (ERAGS): Process for Designing and Conducting Ecological Risk Assessments* should be followed.

ERAGS is located online at:

<http://www.epa.gov/oswer/riskassessment/ecorisk/ecorisk.htm>

#### **7.1.16 Evaluation of Other Pathways**

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

#### **7.1.17 Schedule of Implementation and Deliverables**

The work plan should include an overall project schedule and any deliverables that may be submitted to ADEM.

### **7.2 IMPLEMENTATION OF THE WORK PLAN**

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

Upon completion of the work, the responsible party should document the results and submit it to ADEM in accordance with Appendix C. The report must include recommendations and the future course of action as discussed below.

### 7.3 RISK MANAGEMENT RECOMMENDATIONS

If representative site concentrations within an exposure domain exceed the acceptable cumulative risk levels, a CAP or RMP will be required to address the exceedances and RM-2 target levels should be developed to guide the remediation activities. The contents of an RMP are discussed in Section 8.0. The following risk management alternatives are available:

- 1) Remediation to RM-2 Target Levels. The owner/operator develops a CAP to remediate the site to RM-2 target levels. The CAP must be approved by ADEM. Following the completion of the CAP activities, confirmatory sampling should be conducted to ensure that the cumulative risk levels within each exposure domain meet acceptable levels.
- 2) Conduct Compliance Monitoring Program. Representative site concentrations minimally exceed acceptable cumulative risk levels and the owner/operator conducts compliance monitoring to confirm site concentrations are not increasing and/or natural attenuation is occurring. Furthermore, the site should install engineering controls in addition to any other LUCs to limit the exposure time below the period of time used in the RM-2 evaluation. These additional controls should be maintained until such time that the cumulative risk level within each exposure domain is reduced to an acceptable level.

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

- An acceptable level of site investigation has been performed as determined by ADEM
- Target cumulative risk levels are not exceeded
- There are no groundwater resource protection-related exceedances
- There are no surface water protection-related exceedances
- Representative concentrations meet the criteria in Section 6.4 and Appendix A
- No nuisance conditions exist at the site
- Free product has been removed to the maximum extent practicable
- The site-specific fate and transport parameters are adequately justified
- The plume must be stable or decreasing
- ADEM agrees with the RM-2 evaluation and determines that additional confirmatory or compliance well monitoring is not necessary
- Any necessary LUCs have been implemented
- A monitoring plan if necessary has been developed and approved

An NFA granted with restrictions (e.g., with LUCs, long term monitoring) is valid only so long as the restrictions are maintained.

## **DEVELOPMENT AND IMPLEMENTATION OF RISK MANAGEMENT PLAN**

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A risk management plan is the last step in the ARBCA process and is required if a no further action is not granted by ADEM after the completion of the preliminary screening level, RM-1 or RM-2 evaluation. The specifics of the RMP will depend on the exceedances of the cumulative risk within each exposure domain.

Examples of activities that may be conducted under a risk management plan may include but are not limited to:

- Development of a Corrective Action Plan (CAP) to address exceedances
- Active remediation until the target cumulative risk levels have been achieved
- Ongoing monitoring to confirm the occurrence and effectiveness of natural attenuation processes in decreasing site COC concentrations
- Ongoing activities including implementation and maintenance of any LUCs to ensure that the site conditions assumed in the risk evaluation do not significantly change
- Confirmatory monitoring to ensure that the target cumulative risk levels have been achieved

Due to the large variation in the nature and extent of activities that may be required after the completion of the risk evaluation, ADEM requires the preparation and approval of an RMP prior to the initiation of such activities. Basic contents of an RMP are presented below. Detailed requirements for an RMP or CAP are within each regulatory program's statutory authority, regulations and program guidance.

### **8.1 CONTENTS OF A RISK MANAGEMENT PLAN**

An RMP must include each of the following:

- Site description
- Description of the accepted risk evaluation
- Description of the reasons why the RMP is required. Reasons may include but are not limited to (i) presence of free product or (ii) exceedances of cumulative risk target levels in one or more exposure domains.
- Description of the RBTLs for each relevant medium and each exposure domain

- The activities to be included as part of the RMP such as (i) removal of free product, (ii) operation and maintenance of an active remediation system, and, (iii) compliance monitoring, etc.
- Description of the data that will be collected during the implementation of the CAP/RMP
- Description of the method used to evaluate the data that will be collected during plan implementation and any adjustments that may be necessary if the risk management activities are not as effective as anticipated
- A clear description of the overall schedule and deliverables to ADEM of the RMP

Where remediation is necessary for a site, a CAP will be required to be submitted. The details of the contents of the corrective action plan are program-specific.

## **8.2 IMPLEMENTATION OF THE RMP**

Upon approval of the risk management plan, the responsible party must implement the plan as per the proposed schedule. Any major deviations from the schedule or the operation of the system must be communicated to ADEM along with recommended modifications if necessary. All performance data should be evaluated in a timely manner. Upon completion of the risk management activities, the responsible party should document the relevant activities and as appropriate request a no further action determination for the site.

## **8.3 OWNER IMPOSED LAND-USE CONTROLS**

The ARBCA process will recognize the presence of existing controls in the development of the SCEM. Existing implicit or explicit LUCs 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 calculation of RM-1 or RM-2 target levels.

After the completion of the tiered risk evaluation, ADEM may accept owner imposed land-use controls as a way to eliminate certain pathways. LUCs will be site-specific and it will be the responsible party's obligation to discuss with ADEM the need to impose the control, long-term implications and the method to be used to ensure their permanence.

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



## **8.4 PUBLIC NOTIFICATION**

The various regulatory programs may require that the CAP and/or RMP be public noticed, or that the release be posted on a registry of contaminated sites. The user should contact the appropriate program staff to determine what public notifications must be made regarding the site.

## **8.5 NO FURTHER ACTION PROCEDURE**

When the ARBCA evaluation has been performed and the site has been remediated to the acceptable cumulative risk levels and site conditions are otherwise acceptable to ADEM, a letter of “No Further Action” or a letter of “No Further Action with Conditions” may be issued.

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 must remain compatible with this land-use.

**The evaluator and/or responsible party must confer with the appropriate ADEM regulatory staff to determine what site limitations, LUCs, site listing, or additional monitoring, etc., may be required as part of the issuance of a decision for no further investigation or remedial actions.**

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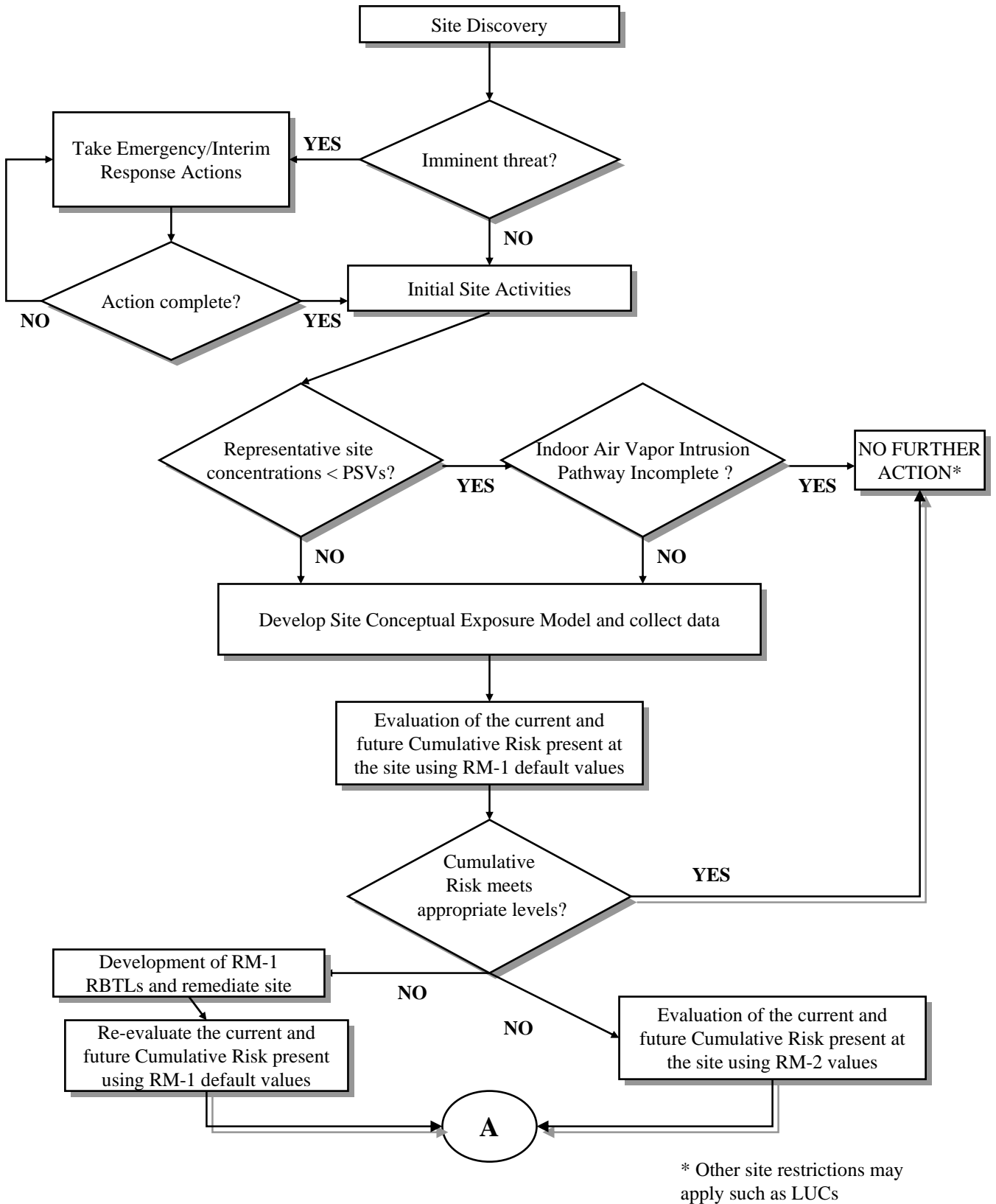
# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

## **TABLES AND FIGURES**

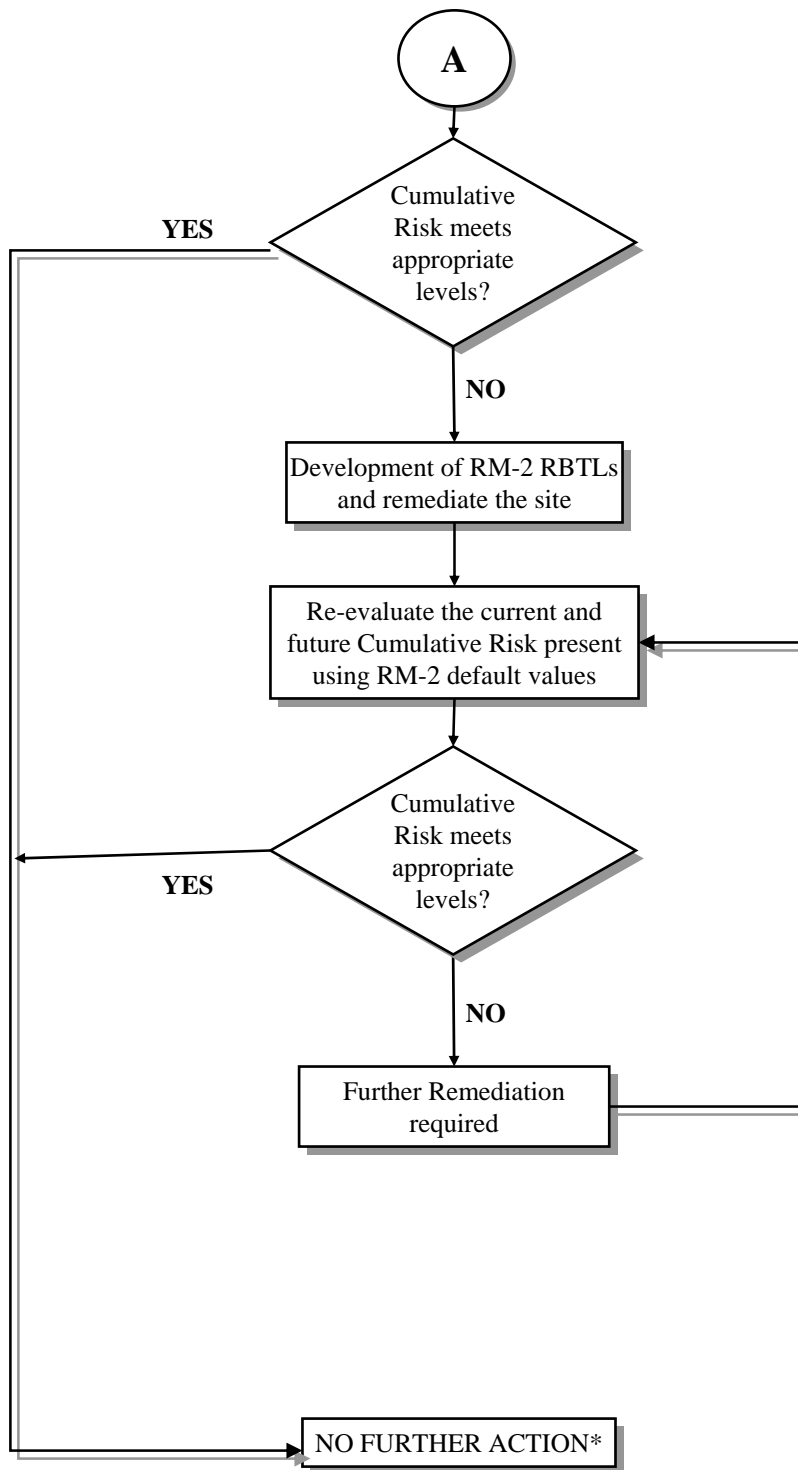
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**April 2008**



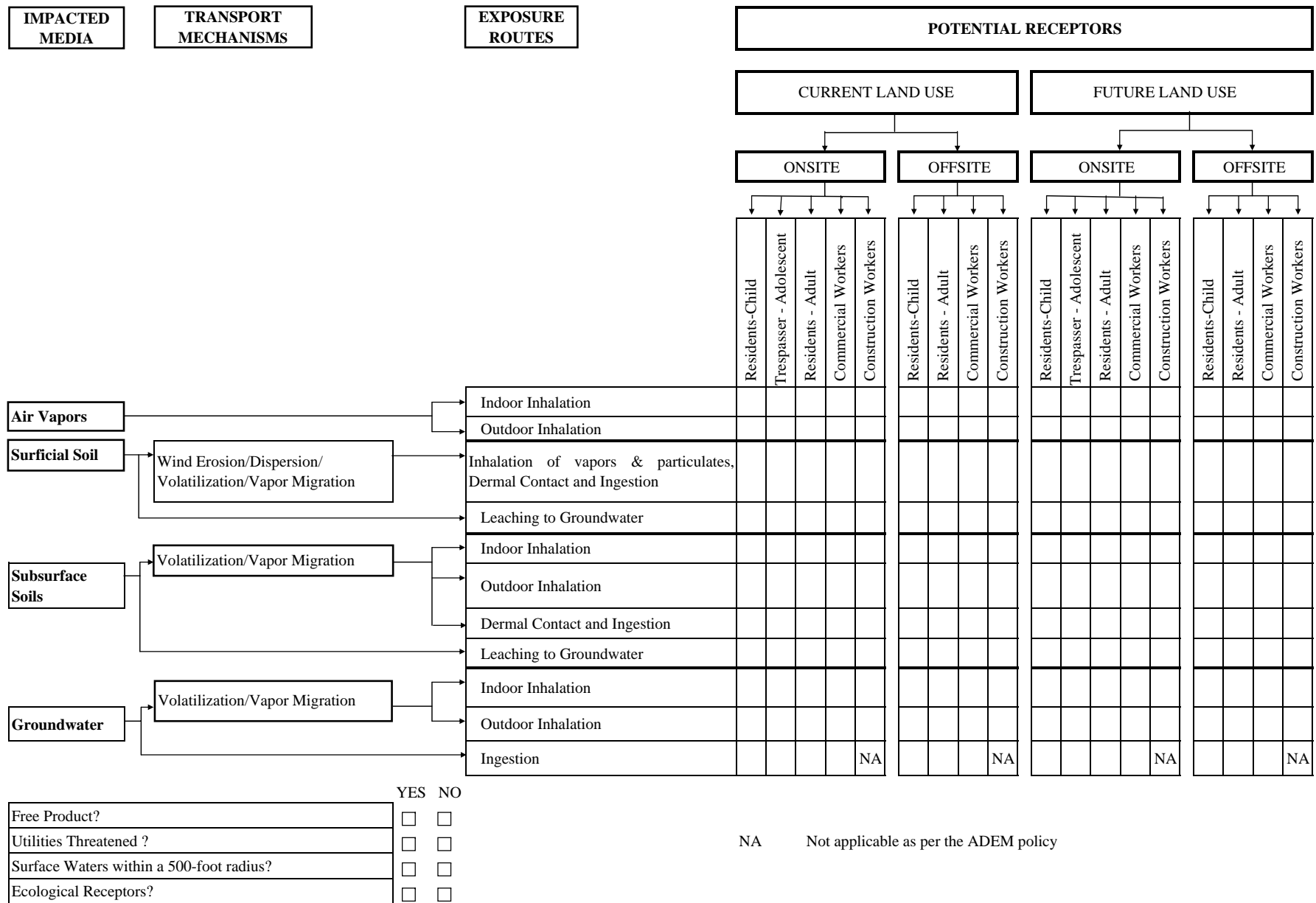


**Figure 2-1. ARBCA Process Flowchart (page 1 of 2)**



\* Other site restrictions may apply such as LUCs

**Figure 2-1. ARBCA Process Flowchart** (page 2 of 2)



**FIGURE 3-1. GRAPHICAL DISPLAY OF A SITE CONCEPTUAL EXPOSURE MODEL**

**TABLE 2-1****COMPARISON OF RISK MANAGEMENT OPTIONS (PSV, RM-1 and RM-2)**

<b>FACTORS</b>	<b>PRELIMINARY SCREENING VALUE</b>	<b>RM-1</b>	<b>RM-2</b>
<b>Exposure Factors</b>	Default	see Table 3-1	Site-Specific / Table 3-1
<b>Toxicity Factors</b>	Default	see Table 3-4	see Table 3-4
<b>Physical and Chemical Properties</b>	Default	see Table 3-3	see Table 3-3
<b>Fate and Transport Parameters</b>	Default	see Table 3-2	Site-Specific / Table 3-2
<b>Unsaturated Zone Attenuation</b>	None	None / Site-Specific based on model	Site-Specific based on model
<b>Fate and Transport Models</b>	Default	Appendices B & D	Appendices B & D / Acceptable to ADEM
<b>Representative Concentrations</b>	Statistical evaluation (see Appendix A)	Statistical evaluation (see Appendix A)	Statistical evaluation (see Appendix A)
<b>Target Cancer Risk</b>	$1 \times 10^{-6}$ (Individual)	$1 \times 10^{-5}$ (Cumulative)	$1 \times 10^{-5}$ (Cumulative)
<b>GW Protection</b>	see Table 2-2	MCL / Table 2-2 drinking water values / calculated value	MCL / Table 2-2 drinking water values / calculated value
<b>Hazard Quotient / Hazard Index</b>	HQ = 0.1	HI $\leq$ 1.0 (Cumulative)	HI $\leq$ 1.0 (Cumulative)
<b>Ecological Risk</b>	Media Specific (see Section 3.14)	Media Specific (see Section 3.14)	Detailed Evaluation (see Section 3.14)
<b>Outcome of Evaluation</b>	NFA, CAP, RM-1	NFA, CAP, RM-2, RMP	NFA, CAP, RMP
<b>Soil Concentration Protective of GW</b>	see Table 2-2	Model	Model
<b>Point of Exposure</b>	Source	Site-Specific	Site-Specific
<b>Institutional Controls</b>	May be required	May be required	May be required

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater			
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.	
<b>VOLATILES</b>												
Acetone	nc	67-64-1	5.50E-01	2	1.40E+03	2	5.40E+03	2	7.57E-02	4.18E-02	4	
Acetonitrile	nc	75-05-8	1.00E-02	2	4.20E+01	2	1.80E+02	2	2.12E-03	1.17E-03	4	
Acrolein	nc	107-02-8	4.20E-06	2	1.00E-02	2	3.40E-02	2	9.97E-07	5.50E-07	4	
Acrylonitrile	ca/nc	107-13-1	3.90E-05	2	2.10E-01	2	4.90E-01	2	5.44E-06	3.00E-06	4	
Aldrin	ca/nc	309-00-2	4.00E-06	2	2.90E-02	2	1.00E-01	2	4.74E-02	2.62E-02	4	
Allyl Chloride	nc	107-05-1	1.00E-03	2	1.70E+00	2	1.80E+01	2	4.79E-04	2.64E-04	4	
Benzene	ca/nc	71-43-2	5.00E-03	1	6.40E-01	2	1.40E+00	2	2.41E-03	1.33E-03	4	
Bromodichloromethane (THM) <sup>15</sup>	ca/nc	75-27-4	8.00E-02	1	8.20E-01	2	1.80E+00	2	3.35E-02	1.85E-02	4	
Bromoform (Tribromomethane) (THM) <sup>15</sup>	ca/nc	75-25-2	8.00E-02	1	6.20E+01	2	2.20E+02	2	4.41E-02	2.43E-02	4	
Bromomethane (Methyl Bromide)	nc	74-83-9	8.70E-04	2	3.90E-01	2	1.30E+00	2	2.16E-04	1.19E-04	4	
2-Butanone (Methyl Ethyl Ketone)	nc	78-93-3	7.00E-01	2	2.20E+03	2	1.10E+04	2	1.10E-01	6.04E-02	4	
sec-Butylbenzene	nc	135-9-88	2.40E-02	2	2.20E+02	2	2.20E+02	2	2.64E-01	1.45E-01	4	
tert-Butylbenzene	nc	98-06-6	2.40E-02	2	3.90E+02	2	3.90E+02	2	2.62E-01	1.45E-01	4	
Carbon disulfide	nc	75-15-0	1.00E-01	2	3.60E+01	2	7.20E+02	2	6.80E-02	3.75E-02	4	
Carbon Tetrachloride	ca/nc	56-23-5	5.00E-03	1	2.50E-01	2	5.50E-01	2	6.40E-03	3.53E-03	4	
Chlorobenzene (Monochlorobenzene)	nc	108-90-7	1.00E-01	1	1.50E+01	2	5.30E+01	2	1.36E-02	7.52E-03	4	
Chloroethane	ca/nc	75-00-3	4.60E-03	2	3.00E+00	2	6.50E+00	2	1.51E-03	8.32E-04	4	
Chloroform (THM) <sup>15</sup>	ca/nc	67-66-3	8.00E-02	1	2.20E-01	2	4.70E-01	2	2.95E-02	1.63E-02	4	
Chloromethane (methyl chloride)	ca/nc	74-87-3	1.60E-03	2	4.70E+01	2	1.60E+02	2	8.51E-04	4.69E-04	4	
2-Chlorotoluene (o-Chlorotoluene)	nc	95-49-8	1.20E-02	2	1.60E+01	2	5.60E+01	2	1.14E-02	6.27E-03	4	
Dibromochloromethane (THM) <sup>15</sup>	ca/nc	124-48-1	8.00E-02	1	1.10E+00	2	2.60E+00	2	1.94E-01	1.07E-01	4	
1,2-Dibromo-3-chloropropane (DBCP)	ca	96-12-8	2.00E-04	1	4.60E-01	2	2.00E+00	2	5.43E-05	3.00E-05	4	
1,2-Dibromoethane (Ethylene dibromide or EDB)	ca/nc	106-93-4	5.00E-05	1	3.20E-02	2	7.30E-02	2	1.37E-05	7.54E-06	4	
1,2-Dichlorobenzene (o-Dichlorobenzene)	nc	95-50-1	6.00E-01	1	6.00E+02	2	6.00E+02	2	1.89E+00	1.04E+00	4	
1,3-Dichlorobenzene (m-Dichlorobenzene)	nc	541-73-1	1.80E-02	2	5.30E+01	2	6.00E+02	2	5.68E-02	3.13E-02	4	
1,4-Dichlorobenzene (p-Dichlorobenzene)	ca/nc	106-46-7	7.50E-02	1	3.40E+00	2	7.90E+00	2	2.37E-01	1.31E-01	4	
Dichlorodifluoromethane	nc	75-71-8	3.90E-02	2	9.40E+00	2	3.10E+01	2	5.92E-02	3.26E-02	4	
1,1-Dichloroethane	nc	75-34-3	8.10E-02	2	5.10E+01	2	1.70E+02	2	2.85E-02	1.57E-02	4	
1,2-Dichloroethane (EDC)	ca/nc	107-06-2	5.00E-03	1	2.80E-01	2	6.00E-01	2	1.14E-03	6.27E-04	4	
1,2-Dichloroethene-(cis)	nc	156-59-2	7.00E-02	1	4.30E+00	2	1.50E+01	2	2.48E-02	1.37E-02	4	
1,2-Dichloroethene-(trans)	nc	156-60-5	1.00E-01	1	6.90E+00	2	2.30E+01	2	4.93E-02	2.72E-02	4	
1,1-Dichloroethene	nc	75-35-4	7.00E-03	1	1.20E+01	2	4.10E+01	2	5.01E-03	2.76E-03	4	

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
1,2-Dichloropropane	ca/nc	78-87-5	5.00E-03	1	3.40E-01	2	7.40E-01	2	1.89E-03	1.04E-03	4
1,3-Dichloropropene-(cis)	ca	542-75-6	4.00E-04	2	7.80E-01	2	1.80E+00	2	2.20E-04	1.22E-04	4
1,3-Dichloropropene-(trans)	ca	542-75-6	4.00E-04	2	7.80E-01	2	1.80E+00	2	2.20E-04	1.22E-04	4
Ethylbenzene	ca	100-41-4	7.00E-01	1	4.00E+02	2	4.00E+02	2	1.37E+00	7.58E-01	4
Formaldehyde	ca/nc	50-00-0	5.50E-01	2	9.20E+02	2	1.00E+04	2	TBC	TBC	
Hexachlorobutadiene	ca	87-68-3	8.60E-04	2	6.20E+00	2	2.20E+01	2	2.29E-01	1.26E-01	4
Isobutyl Alcohol (Isobutanol)	nc	78-83-1	1.80E-01	2	1.30E+03	2	4.00E+03	2	7.83E-02	4.32E-02	4
Isopropylbenzene (Cumene)	nc	98-82-8	6.60E-01	2	5.70E+01	2	2.00E+02	2	8.75E-01	4.83E-01	4
Methanol	nc	67-56-1	1.80E+00	2	3.10E+03	2	1.00E+05	2	TBC	TBC	
Methylene Chloride (Dichloromethane)	ca/nc	75-09-2	5.00E-03	1	9.10E+00	2	2.10E+01	2	1.08E-03	5.98E-04	4
4-Methyl-2-pentanone (Methyl Isobutyl Ketone)	nc	108-10-1	2.00E-01	2	5.30E+02	2	4.70E+03	2	1.22E-02	6.75E-03	4
Methyl-tert-butyl-ether (MTBE)	ca	1634-04-4	1.10E-02	2	3.20E+01	2	7.00E+01	2	1.87E-03	1.03E-03	4
Naphthalene	nc	91-20-3	6.20E-04	2	5.60E+00	2	1.90E+01	2	3.69E-03	2.03E-03	4
Styrene	nc	100-42-5	1.00E-01	1	1.70E+03	2	1.70E+03	2	3.94E-01	2.17E-01	4
1,1,1,2-Tetrachloroethane	ca/nc	630-20-6	4.30E-04	2	3.20E+00	2	7.30E+00	2	2.53E-04	1.40E-04	4
1,1,2,2-Tetrachloroethane	ca/nc	79-34-5	5.50E-05	2	4.10E-01	2	9.30E-01	2	3.24E-05	1.78E-05	4
Tetrachloroethene (PCE)	ca/nc	127-18-4	5.00E-03	1	4.80E-01	2	1.30E+00	2	5.55E-03	3.06E-03	4
Toluene	nc	108-88-3	1.00E+00	1	5.20E+02	2	5.20E+02	2	1.08E+00	5.95E-01	4
1,2,4-Trichlorobenzene	nc	120-82-1	7.00E-02	1	6.20E+00	2	2.20E+01	2	6.20E-01	3.42E-01	4
1,1,1-Trichloroethane	nc	71-55-6	2.00E-01	1	1.20E+03	2	1.20E+03	2	1.72E-01	9.46E-02	4
1,1,2-Trichloroethane	ca/nc	79-00-5	5.00E-03	1	7.30E-01	2	1.60E+00	2	1.93E-03	1.07E-03	4
Trichloroethene (TCE)	ca/nc	79-01-6	5.00E-03	1	5.30E-02	2	1.10E-01	2	5.35E-03	2.95E-03	4
Trichlorofluoromethane	nc	75-69-4	1.30E-01	2	3.90E+01	2	2.00E+02	2	2.58E-01	1.42E-01	4
1,2,3-Trichloropropane	ca/nc	96-18-4	5.60E-06	2	3.40E-02	2	7.60E-02	2	3.79E-06	2.09E-06	4
1,2,4-Trimethylbenzene	nc	95-63-6	1.20E-03	2	5.20E+00	2	1.70E+01	2	2.17E-02	1.20E-02	4
1,3,5-Trimethylbenzene	nc	108-67-8	1.20E-03	2	2.10E+00	2	7.00E+00	2	5.03E-03	2.77E-03	4
Vinyl Acetate	nc	108-05-4	4.10E-02	2	4.30E+01	2	1.40E+02	2	6.80E-03	3.75E-03	4
Vinyl Chloride	ca/nc	75-01-4	2.00E-03	1	7.90E-02	2	7.50E-01	2	1.04E-03	5.76E-04	4
Xylenes (Total)	nc	1330-20-7	1.00E+01	1	2.70E+01	2	4.20E+02	2	2.20E+01	1.21E+01	4

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
<b>SEMI-VOLATILES</b>											
Acenaphthene	nc	83-32-9	3.70E-02	2	3.70E+02	2	2.90E+03	2	8.83E-01	4.87E-01	4
Acenaphthylene	nc	208-96-8	9.39E-02	4	TBC		TBC		3.55E-01	1.96E-01	4
Aniline	ca/nc	62-53-3	1.20E-02	2	8.50E+01	2	3.00E+02	2	2.14E-03	1.18E-03	4
Anthracene	nc	120-12-7	1.80E-01	2	2.20E+03	2	1.00E+05	2	2.09E+01	1.15E+01	4
Azobenzene	ca	103-33-3	6.10E-04	2	4.40E+00	2	1.60E+01	2	7.70E-03	4.25E-03	4
Benzidine	ca/nc	92-87-5	2.90E-07	2	2.10E-03	2	7.50E-03	2	3.89E-06	2.14E-06	4
Benzo(a)anthracene	ca	56-55-3	9.20E-05	2	6.20E-01	2	2.10E+00	2	1.78E-01	9.83E-02	4
Benzo(a)pyrene	ca	50-32-8	2.00E-04	1	6.20E-02	2	2.10E-01	2	9.68E-01	5.34E-01	4
Benzo(b)fluoranthene	ca	205-99-2	9.20E-05	2	6.20E-01	2	2.10E+00	2	5.57E-01	3.07E-01	4
Benzo(g,h,i)perylene	nc	191-24-2	4.69E-02	4	2.28E+02	4	4.95E+03	4	4.37E+02	2.41E+02	4
Benzo(k)fluoranthene	ca	207-08-9	9.20E-04	2	6.20E+00	2	2.10E+01	2	5.57E+00	3.07E+00	4
Benzoic acid	nc	65-85-0	1.50E+01	2	1.00E+05	2	1.00E+05	2	2.06E+00	1.14E+00	4
Benzyl Alcohol	nc	100-51-6	1.10E+00	2	1.80E+03	2	1.00E+05	2	2.14E-01	1.18E-01	4
Bis(2-chloroethyl)ether	ca	111-44-4	1.00E-05	2	2.20E-01	2	5.80E-01	2	4.93E-06	2.72E-06	4
Bis(2-chloroisopropyl)ether	ca/nc	108-60-1	2.70E-04	2	2.90E+00	2	7.40E+00	2	1.16E-04	6.42E-05	4
Bis(2-ethylhexyl)phthalate (DEHP)	ca/nc	117-81-7	6.00E-03	1	3.50E+01	2	1.20E+02	2	4.36E+02	2.40E+02	4
Butyl benzyl phthalate	nc	85-68-7	7.30E-01	2	1.20E+03	2	1.00E+05	2	1.94E+02	1.07E+02	4
Carbazole	ca	86-74-8	3.40E-03	2	2.40E+01	2	8.60E+01	2	5.64E-02	3.11E-02	4
4-Chloroaniline	nc	106-47-8	1.50E-02	2	2.40E+01	2	2.50E+02	2	6.74E-03	3.72E-03	4
Chlorobenzilate	ca/nc	510-15-6	2.50E-04	2	1.80E+00	2	6.40E+00	2	TBC	TBC	
Chloro-m-cresol, p-	nc	59-50-7	1.41E-02	4	4.68E+01	4	4.56E+02	4	5.31E-03	2.93E-03	4
2-Chloronaphthalene (beta-Chloronaphthalene)	nc	91-58-7	4.90E-02	2	4.90E+02	2	2.30E+03	2	2.73E+00	1.51E+00	4
2-Chlorophenol	nc	95-57-8	3.00E-03	2	6.30E+00	2	2.40E+01	2	6.23E-03	3.43E-03	4
3-Chlorophenol (m-chlorophenol)	nc	108-43-0	7.82E-03	4	TBC		TBC		1.43E-02	7.89E-03	4
Chrysene	ca	218-01-9	9.20E-03	2	6.20E+01	2	2.10E+02	2	1.78E+01	9.83E+00	4
Di (2-ethylhexyl) adipate	ca/nc	103-23-1	4.00E-01	1	4.10E+02	2	1.40E+03	2	TBC	TBC	
Dichloroacetic acid <sup>16</sup>	nc	76-43-6	6.00E-02	1	TBC		TBC		TBC	TBC	
Di-n-Butyl phthalate (Dibutyl phthalate)	nc	84-74-2	3.60E-01	2	6.10E+02	2	6.20E+03	2	2.78E+00	1.54E+00	4
Di-n-Octyl phthalate (Dioctyl phthalate)	nc	117-84-0	1.50E-01	2	2.40E+02	2	2.50E+03	2	6.17E+04	3.40E+04	4
Dibenzo(a,h)anthracene	ca	53-70-3	9.20E-06	2	6.20E-02	2	2.10E-01	2	1.67E-01	9.21E-02	4
Dibenzofuran	nc	132-64-9	1.20E-03	2	1.50E+01	2	1.60E+02	2	4.55E-02	2.51E-02	4
3,3-Dichlorobenzidine	ca	91-94-1	1.50E-04	2	1.10E+00	2	3.80E+00	2	5.47E-04	3.01E-04	4

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
2,4-Dichlorophenol	nc	120-83-2	1.10E-02	2	1.80E+01	2	1.80E+02	2	9.31E-03	5.13E-03	4
Diethyl phthalate	nc	84-66-2	2.90E+00	2	4.90E+03	2	1.00E+05	2	4.39E+00	2.42E+00	4
2,4-Dimethylphenol	nc	105-67-9	7.30E-02	2	1.20E+02	2	1.20E+03	2	8.40E-02	4.63E-02	4
2,6-Dimethylphenol	nc	576-26-1	2.20E-03	2	3.70E+00	2	3.70E+01	2	TBC	TBC	
3,4-Dimethylphenol	nc	95-65-8	3.60E-03	2	6.10E+00	2	6.20E+01	2	TBC	TBC	
Dimethyl phthalate	nc	131-11-3	3.60E+01	2	1.00E+05	2	1.00E+05	2	1.09E+01	6.03E+00	4
2,4-Dinitrophenol	nc	51-28-5	7.30E-03	2	1.20E+01	2	1.20E+02	2	9.82E-04	5.42E-04	4
2,4-Dinitrotoluene	nc	121-14-2	7.30E-03	2	1.20E+01	2	1.20E+02	2	4.34E-03	2.39E-03	4
2,6-Dinitrotoluene	nc	606-20-2	3.60E-03	2	6.10E+00	2	6.20E+01	2	1.70E-03	9.40E-04	4
Fluoranthene	nc	206-44-0	1.50E-01	2	2.30E+02	2	2.20E+03	2	7.99E+01	4.41E+01	4
Fluorene	nc	86-73-7	2.40E-02	2	2.70E+02	2	2.60E+03	2	1.63E+00	8.99E-01	4
Hexachlorobenzene	ca/nc	118-74-1	1.00E-03	1	3.00E-01	2	1.10E+00	2	2.66E-01	1.47E-01	4
Hexachlorocyclopentadiene	nc	77-47-4	5.00E-02	1	3.70E+01	2	3.70E+02	2	4.84E+01	2.67E+01	4
Hexachloroethane	ca/nc	67-72-1	4.80E-03	2	3.50E+01	2	1.20E+02	2	4.22E-02	2.33E-02	4
HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	nc	2691-41-0	1.80E-01	2	3.10E+02	2	3.10E+03	2	TBC	TBC	
Indeno(1,2,3-cd)pyrene	ca	193-39-5	9.20E-05	2	6.20E-01	2	2.10E+00	2	1.54E+00	8.47E-01	4
Isophorone	ca/nc	78-59-1	7.10E-02	2	5.10E+02	2	5.10E+02	2	2.57E-02	1.42E-02	4
2-Methylnaphthalene	nc	91-57-6	6.26E-03	4	TBC		TBC		1.14E-01	6.29E-02	4
Methyl parathion	nc	298-00-0	9.10E-04	2	1.50E+00	2	1.50E+01	2	3.21E-03	1.77E-03	4
2-Methylphenol (o-Cresol)	nc	95-48-7	1.80E-01	2	3.10E+02	2	3.10E+03	2	1.03E-01	5.66E-02	4
3-Methylphenol (m-Cresol)	nc	108-39-4	1.80E-01	2	3.10E+02	2	3.10E+03	2	9.83E-02	5.42E-02	4
4-Methylphenol (p-Cresol)	nc	106-44-5	1.80E-02	2	3.10E+01	2	3.10E+02	2	9.83E-03	5.42E-03	4
Monochloroacetic acid <sup>16</sup>	nc	79-11-8	6.00E-02	1	TBC		TBC		TBC	TBC	
N-Nitroso di-n-propylamine	ca	621-64-7	9.60E-06	2	6.90E-02	2	2.50E-01	2	7.38E-06	4.07E-06	4
N-Nitrosodimethylamine	ca	62-75-9	1.30E-06	2	9.50E-03	2	3.40E-02	2	1.77E-07	9.74E-08	4
N-Nitrosodiphenylamine	ca	86-30-6	1.40E-02	2	9.90E+01	2	3.50E+02	2	9.00E-02	4.96E-02	4
2-Nitroaniline	nc	88-74-4	1.10E-02	2	1.80E+01	2	1.80E+02	2	4.94E-03	2.72E-03	4
Nitrobenzene	nc	98-95-3	3.40E-04	2	2.00E+00	2	1.00E+01	2	1.53E-04	8.43E-05	4
4-Nitrophenol (p-Nitrophenol)	nc	100-02-7	1.25E-02	4	TBC		TBC		2.32E-03	1.28E-03	4
Parathion	nc	56-38-2	2.20E-02	2	3.70E+01	2	3.70E+02	2	6.42E-01	3.54E-01	4
Pentachlorobenzene	nc	608-93-5	2.90E-03	2	4.90E+00	2	4.90E+01	2	2.45E-01	1.35E-01	4
Pentachlorophenol	ca/nc	87-86-5	1.00E-03	1	3.00E+00	2	9.00E+00	2	3.00E-03	1.65E-03	4
Phenanthrene	nc	85-01-8	4.69E-02	4	2.02E+02	4	3.06E+03	4	3.35E+00	1.85E+00	4



**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
Phenol	nc	108-95-2	1.10E+00	2	1.80E+03	2	1.00E+05	2	3.00E-01	1.65E-01	4
Propylene glycol	nc	57-55-6	1.80E+00	2	3.00E+03	2	1.00E+04	2	TBC	TBC	
Pyrene	nc	129-00-0	1.80E-02	2	2.30E+02	2	2.90E+03	2	9.59E+00	5.29E+00	4
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)	ca/nc	121-82-4	6.10E-04	2	4.40E+00	2	1.60E+01	2	TBC	TBC	
2,3,4,6-Tetrachlorophenol	nc	58-90-2	1.10E-01	2	1.80E+02	2	1.80E+03	2	1.64E-01	9.04E-02	4
Tetrahydrofuran	ca/nc	109-99-9	1.60E-03	2	9.40E+00	2	2.10E+01	2	TBC	TBC	
Trichloroacetic acid <sup>16</sup>	nc	76-03-9	6.00E-02	1	TBC		TBC		TBC	TBC	
2,4,5-Trichlorophenol	nc	95-95-4	3.60E-01	2	6.10E+02	2	6.20E+03	2	2.84E+00	1.56E+00	4
2,4,6-Trichlorophenol	nc	88-06-2	3.60E-04	2	6.10E-01	2	6.20E+00	2	7.12E-04	3.93E-04	4
1,3,5-Trinitrobenzene	nc	99-35-4	1.10E-01	2	1.80E+02	2	1.80E+03	2	2.25E-02	1.24E-02	4
Trinitrophenylmethylnitramine	nc	479-45-8	3.60E-02	2	6.10E+01	2	6.20E+02	2	TBC	TBC	
2,4,6-Trinitrotoluene	ca/nc	118-96-7	2.20E-03	2	1.60E+01	2	5.70E+01	2	TBC	TBC	
<b>PESTICIDES AND HERBICIDES</b>											
Ammonia	nc	7664-41-7	6.26E-01	4	TBC		TBC		4.79E-02	2.64E-02	4
Alachlor	ca/nc	15972-60-8	2.00E-03	1	6.00E+00	2	2.10E+01	2	1.73E-03	9.55E-04	4
Acrolein	nc	107-02-8	4.20E-06	2	1.00E-02	2	3.40E-02	2	5.91E-07	3.26E-07	4
Aldicarb	nc	116-06-3	3.00E-03	1	6.10E+00	2	6.20E+01	2	5.85E-04	3.23E-04	4
Aldicarb Sulfone	nc	1646-88-4	3.00E-03	1	6.10E+00	2	6.20E+01	2	TBC	TBC	
Aldicarb Sulfoxide	nc	1646-87-3	4.00E-03	1	TBC		TBC		TBC	TBC	
Atrazine	ca/nc	1912-24-9	3.00E-03	1	2.20E+00	2	7.80E+00	2	6.29E-03	3.47E-03	4
Bis(2-chloro-1-methylethyl)ether	ca/nc	108-60-1	2.70E-04	2	2.90E+00	2	7.40E+00	2	4.88E-04	2.69E-04	4
Carbofuran	nc	1563-66-2	4.00E-02	1	3.10E+01	2	3.10E+02	2	1.29E-02	7.10E-03	4
Chlordane	ca	12789-03-6	2.00E-03	1	1.60E+00	2	6.50E+00	2	2.70E-04	1.49E-04	4
Chlorobenzilate	ca/nc	510-15-6	2.50E-04	2	1.80E+00	2	6.40E+00	2	2.42E-02	1.34E-02	4
Chlorpyrifos	nc	2921-88-2	1.10E-02	2	1.80E+01	2	1.80E+02	2	9.28E-01	5.12E-01	4
Dalapon (2,2-dichloropropionic acid)(Sodium Salt)	nc	75-99-0	2.00E-01	1	1.80E+02	2	1.80E+03	2	TBC	TBC	
4,4' - DDD	ca	72-54-8	2.80E-04	2	2.40E+00	2	1.00E+01	2	1.36E+00	7.48E-01	4
4,4' - DDE	ca	72-55-9	2.00E-04	2	1.70E+00	2	7.00E+00	2	4.26E+00	2.35E+00	4
4,4' - DDT	ca/nc	50-29-3	2.00E-04	2	1.70E+00	2	7.00E+00	2	2.57E+00	1.42E+00	4
Diallate	ca/nc	2303-16-4	1.10E-03	2	8.00E+00	2	2.80E+01	2	1.39E-01	7.64E-02	4
2,4-Dichlorophenoxyacetic acid (2,4-D)	nc	94-75-7	7.00E-02	1	6.90E+01	2	7.70E+02	2	6.57E-02	3.62E-02	4
Dieldrin	ca/nc	60-57-1	4.20E-06	2	3.00E-02	2	1.10E-01	2	4.36E-04	2.40E-04	4
Dimethoate	nc	60-51-5	7.30E-04	2	1.20E+00	2	1.20E+01	2	1.15E-04	6.34E-05	4

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	nc	88-85-7	7.00E-03	1	6.10E+00	2	6.20E+01	2	1.58E-03	8.72E-04	4
Diquat	nc	85-00-7	2.00E-02	1	1.30E+01	2	1.40E+02	2	9.68E+01	5.34E+01	4
Disulfoton	nc	298-04-4	1.50E-04	2	2.40E-01	2	2.50E+00	2	5.83E-03	3.21E-03	4
Endosulfan	nc	115-29-7	2.20E-02	2	3.70E+01	2	3.70E+02	2	2.31E-01	1.27E-01	4
Endothall	nc	145-73-3	1.00E-01	1	1.20E+02	2	1.20E+03	2	1.36E-02	7.49E-03	4
Endrin	nc	72-20-8	2.00E-03	1	1.80E+00	2	1.80E+01	2	1.19E-01	6.58E-02	4
Glyphosate	nc	1071-83-6	7.00E-01	1	6.10E+02	2	6.20E+03	2	1.58E-01	8.70E-02	4
HCH (alpha) (alpha - BHC)	ca	319-84-6	1.10E-05	2	9.00E-02	2	3.60E-01	2	6.70E-05	3.69E-05	4
HCH (beta) (beta - BHC)	ca	319-85-7	3.70E-05	2	3.20E-01	2	1.30E+00	2	2.31E-04	1.27E-04	4
HCH (gamma) Lindane (gamma - BHC)	ca	58-89-9	2.00E-04	1	4.40E-01	2	1.70E+00	2	1.06E-03	5.86E-04	4
Heptachlor	ca/nc	76-44-8	4.00E-04	1	1.10E-01	2	3.80E-01	2	2.81E+00	1.55E+00	4
Heptachlor epoxide	ca/nc	1024-57-3	2.00E-04	1	5.30E-02	2	1.90E-01	2	7.75E-02	4.27E-02	4
Kepone	ca/nc	143-50-0	8.40E-06	2	6.10E-02	2	2.20E-01	2	TBC	TBC	
Malathion	nc	121-75-5	7.30E-02	2	1.20E+02	2	1.20E+03	2	TBC	TBC	
Methoxychlor	nc	72-43-5	4.00E-02	1	3.10E+01	2	3.10E+02	2	1.94E+01	1.07E+01	4
Oxamyl (Vydate)	nc	23135-22-0	2.00E-01	1	1.50E+02	2	1.50E+03	2	3.55E-02	1.96E-02	4
PCBs (Polychlorinated Biphenyls)	ca/nc	1336-36-3	5.00E-04	1	2.20E-01	2*	7.40E-01	2*	2.06E+00	1.13E+00	
PCB - Arochlor 1016	ca/nc	12674-11-2	9.60E-04	2	3.90E-01	2	2.10E+01	2	3.95E+00	2.18E+00	4
PCB - Arochlor 1221	ca/nc	11104-28-2	3.40E-05	2*	2.20E-01	2*	7.40E-01	2*	1.40E-01	7.72E-02	4
PCB - Arochlor 1232	ca/nc	1141-16-5	3.40E-05	2*	2.20E-01	2*	7.40E-01	2*	1.40E-01	7.72E-02	4
PCB - Arochlor 1242	ca/nc	53469-21-9	3.40E-05	2*	2.20E-01	2*	7.40E-01	2*	1.40E-01	7.72E-02	4
PCB - Arochlor 1248	ca/nc	12672-29-6	3.40E-05	2*	2.20E-01	2*	7.40E-01	2*	1.40E-01	7.72E-02	4
PCB - Arochlor 1254	ca/nc	11097-69-1	3.40E-05	2	2.20E-01	2	7.40E-01	2	1.40E-01	7.72E-02	4
PCB - Arochlor 1260	ca/nc	11096-82-5	3.40E-05	2*	2.20E-01	2*	7.40E-01	2*	1.40E-01	7.72E-02	4
Phorate	nc	298-02-2	7.30E-04	2	1.20E+00	2	1.20E+01	2	1.95E-02	1.08E-02	4
Picloram	nc	1918-02-1	5.00E-01	1	4.30E+02	2	4.30E+03	2	TBC	TBC	
Pronamide	nc	23950-58-5	2.70E-01	2	4.60E+02	2	4.60E+03	2	TBC	TBC	
Simazine	ca/nc	122-34-9	4.00E-03	1	4.10E+00	2	1.40E+01	2	8.15E-03	4.49E-03	4
Sulfotepp (Tetraethylthiopyrophosphate)	nc	3689-24-5	1.80E-03	2	3.10E+00	2	3.10E+01	2	6.69E-03	3.69E-03	4
2,3,7,8 TCDD (Dioxin)	ca	1746-01-6	3.00E-08	1	1.00E-03	12	5.00E-03	12	3.85E-04	2.12E-04	4
Toxaphene	ca/nc	8001-35-2	3.00E-03	1	4.40E-01	2	1.60E+00	2	3.70E+00	2.04E+00	4
2,4,5 TP (silvex) (2-(2,4,5-Trichlorophenoxy) propionic acid)	nc	93-72-1	5.00E-02	1	4.90E+01	2	4.90E+02	2	6.36E-01	3.51E-01	4

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater			
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.	
<b>INORGANICS</b>												
Aluminum	nc	7429-90-5	3.60E+00	2	7.60E+03	2	1.00E+05	2	TBC	TBC		
Antimony (and compounds)	nc	7440-36-0	6.00E-03	1	3.10E+00	2	4.10E+01	2	6.54E-01	3.61E-01	4	
Arsenic	ca/nc	7440-38-2	1.00E-02	1	4.00E-01	11	1.60E+00	11	7.03E-01	3.88E-01	4	
Barium (and compounds)	nc	7440-39-3	2.00E+00	1	5.40E+02	2	6.70E+03	2	1.99E+02	1.10E+02	4	
Beryllium (and compounds)	ca/nc	7440-41-7	4.00E-03	1	1.50E+01	2	1.90E+02	2	7.65E+00	4.22E+00	4	
Bromate	ca/nc	15541-45-4	1.00E-02	1	6.90E-01	2	2.50E+00	2	3.42E-03	1.89E-03	4	
Cadmium (and compounds)	ca/nc	7440-43-9	5.00E-03	1	3.70E+00	2	4.50E+01	2	9.08E-01	5.01E-01	4	
Chloramine (Monochloramine)	nc	10599-90-3	4.00E+00	1	6.10E+02	2	6.20E+03	2	TBC	TBC		
Chloride	nc	7647-14-5	2.50E+02	5	TBC		TBC		TBC	TBC		
Chlorine	nc	7782-50-5	4.00E+00	1	TBC		TBC		TBC	TBC		
Chlorine Dioxide	nc	10049-04-4	8.00E-01	1	TBC		TBC		TBC	TBC		
Chlorite	nc	7758-19-2	1.00E+00	1	TBC		TBC		TBC	TBC		
Chromium (III)	nc	16065-83-1	5.50E+00	2	1.00E+05	2	1.00E+05	2	2.40E+07	1.32E+07	4	
Chromium (VI)	ca/nc	18540-29-9	1.10E-02	2	3.00E+01	2	6.40E+01	2	5.07E-01	2.80E-01	4	
Chromium (Total)	ca/nc	7440-47-3	1.00E-01	1	3.00E+01	2#	6.40E+01	2#	4.61E+00	2.54E+00	4	
Cobalt	ca/nc	7440-48-4	7.30E-02	2	9.00E+02	2	1.90E+03	2	TBC	5.41E-03	4	
Copper (at tap)	nc	7440-50-8	1.30E+00	1	3.10E+02	2	4.10E+03	2	TBC	TBC		
Cyanide (hydrogen)	nc	74-90-8	6.20E-04	2	1.10E+00	2	3.50E+00	2	2.56E-02	1.41E-02	4	
Cyanide (free)	nc	57-12-5	7.30E-02	2	1.20E+02	2	1.20E+03	2	4.89E-01	2.70E-01	4	
Cyanide (Total)	nc	143-33-9	2.00E-01	1	1.10E+00	2	3.50E+00	2	TBC	TBC		
Fluoride	nc	7681-49-4	4.00E+00	1	3.70E+02	2~	3.70E+03	2~	4.36E+03	2.40E+03	4	
Iron	nc	7439-89-6	1.10E+00	2	2.30E+03	2	1.00E+05	2	TBC	TBC		
Lead	nc	7439-92-1	1.50E-02	1	4.00E+02	2	8.00E+02	2	4.00E+02	4.00E+02	7	
Manganese	nc	7439-96-5	8.80E-02	2	1.80E+02	2	1.90E+03	2	TBC	TBC		
Mercury	nc	7487-94-7	2.00E-03	1	2.30E+00	2	3.10E+01	2	2.52E-01	1.39E-01	4	
Mercury (methyl)	nc	22967-92-6	3.60E-04	2	6.10E-01	2	6.20E+00	2	4.68E-01	2.58E-01	4	
Nickel	nc	7440-02-0	1.00E-01	13	1.60E+02	2	2.00E+03	2	4.68E-01	2.58E-01	4	
Nitrate	nc	14797-55-8	1.00E+01	1	TBC		TBC		1.15E+01	6.34E+00		
Nitrite	nc	14797-65-0	1.00E+00	1	TBC		TBC		TBC	TBC		
Perchlorate	ca/nc	7601-90-3	2.45E-02	14	7.80E+00	2	1.00E+02	2	TBC	TBC		
Selenium	nc	7782-49-2	5.00E-02	1	3.90E+01	2	5.10E+02	2	TBC	TBC	4	
Silver	nc	7440-22-4	1.80E-02	2	3.90E+01	2	5.10E+02	2	6.12E-01	3.37E-01	4	

**TABLE 2-2  
PRELIMINARY SCREENING VALUES**

CHEMICAL OF CONCERN	Type	CAS #	"Direct Contact Exposure Pathways"						Soil Screening Levels Protective of Groundwater		
			Groundwater / Tap Water (mg/L)	Ref.	Residential Soil (mg/kg)	Ref.	Commercial Soil (mg/kg)	Ref.	Small Soil Source <sub>8</sub> (mg/kg)	Large Soil Source <sub>9</sub> (mg/kg)	Ref.
Strontium	nc	7440-24-6	2.20E+00	2	4.70E+03	2	1.00E+05	2	3.64E-01	2.01E-01	
Sulfate	nc	7757-82-6	2.50E+02	5	TBC		TBC		TBC	TBC	
Thallium	nc	7440-28-0	2.00E-03	1	5.20E-01	2	6.70E+00	2	TBC	TBC	4
Tin	nc	7440-31-5	2.20E+00	2	4.70E+03	2	1.00E+05	2	3.44E-01	1.90E-01	4
Vanadium	nc	7440-62-2	3.60E-03	2	7.80E+00	2	1.00E+02	2	TBC	TBC	4
Zinc	nc	7440-66-6	1.10E+00	2	2.30E+03	2	1.00E+05	2	6.29E+01	3.47E+01	4

**NOTE: THIS TABLE REPRESENTS CURRENT VALUES AS OF MAY 2006.  
THE MOST CURRENT SCREENING VALUES MUST BE CONFIRMED.**

**KEY**

- 1 MCL = Maximum Contaminant Level
- 2 PRG = Preliminary Remediation Goal, EPA Region 9
- 3 LHA = Lifetime Health Advisory
- 4 RM-1 = Risk Management-1 Levels per ADEM ARBCA
- 5 SDWR = Secondary Drinking Water Regulation
- 6 TT = Treatment Technique
- 7 SSL (Generic), USEPA Soil Screening Guidance, 1996
- 8 Small Soil Source = (270yd<sup>2</sup>) 1500cm x 1500cm, see Table 3-2
- 9 Large Soil Source = (1acre) 6362cm x 6362cm, see Table 3-2
- 10 ADEM 2005
- 11 USEPA Region 4 Recommendation (USEPA Memo dated February 5, 2004)
- 12 USEPA Recommendation (OSWER Directive 9200.4-26)
- \* Values were extrapolated from the USEPA Region 9 High Risk Levels for Aroclor 1254
- # Values were extrapolated from the USEPA Region 9 Soil PRGs for Hexavalent Chromium
- ~ Values based on Soluble Fluoride
- 13 ADEM MCL (ADEM Admin. Code R. 335-7-2-.03)
- 14 USEPA Recommendation (USEPA Memo dated January 26, 2006)
- 15 1998 Final Rule for Disinfectants and Disinfection By-Products: The total for trihalomethanes (THMs) is 0.08 mg/L
- 16 1998 Final Rule for Disinfectants and Disinfection By-Products: The total for haloacetic acids is 0.06 mg/L
- TBC To Be Calculated
- ca Carcinogenic Chemical
- nc Non-Carcinogenic Chemical

**TABLE 3-1  
RM-1 DEFAULT EXPOSURE FACTORS**

EXPOSURE FACTOR	SYMBOL	UNITS	ADEM DEFAULT VALUE	REFERENCE
<b>Averaging Time</b>				
Carcinogen	$AT_c$	Years	70	EPA, 1989
Noncarcinogen (equals exposure duration)	$AT_n$	Years	Receptor dependent = ED	EPA, 1989
<b>Body Weight</b>				
Adults – Resident, Commercial & Construction Worker	$BW$	Kg	70	EPA, 1989
Trespasser*	$BW$	Kg	45	EPA, 2000
Child	$BW$	Kg	15	EPA, 1989
<b>Exposure Duration</b>				
Resident - Child	$ED$	Years	6	EPA, 1989
Resident - Adult	$ED$	Years	30	EPA, 1989
Trespasser*	$ED$	Years	10	ADEM, 2004
Commercial Worker	$ED$	Years	25	EPA, 1989
Construction Worker	$ED$	Years	1	ADEM, 2001
<b>Exposure Frequency</b>				
Residents	$EF$	days/yr	350	EPA, 1989
Trespasser*	$EF$	days/yr	350	ADEM, 2007
Commercial Worker	$EF$	days/yr	250	EPA, 1989
Construction Worker	$EF$	days/yr	250	ADEM, 1997
<b>Soil Ingestion Rate</b>				
Resident – Child	$IRS$	mg/day	200	EPA, 1989
Resident – Adult	$IRS$	mg/day	100	EPA, 1989
Trespasser*	$IRS$	mg/day	100	ADEM, 2007
Commercial Worker	$IRS$	mg/day	75	ADEM, 2007
Construction Worker	$IRS$	mg/day	177	ADEM, 2007
<b>Daily Water Ingestion Rate</b>				
Child	$IRW$	L/day	1	EPA, 1997
Adult	$IRW$	L/day	2	EPA, 1997
<b>Hourly Indoor Inhalation Rate</b>				
Resident – Child	$IR_{ai}$	m <sup>3</sup> /hr	0.5	EPA, 1989
Resident – Adult	$IR_{ai}$	m <sup>3</sup> /hr	0.833	EPA, 1989
Trespasser*	$IR_{ai}$	m <sup>3</sup> /hr	1.5	EPA, 2000
Commercial Workers	$IR_{ai}$	m <sup>3</sup> /hr	1.5	EPA, 1997
Construction Worker	$IR_{ai}$	m <sup>3</sup> /hr	1.5	EPA, 1997
<b>Exposure Time for Indoor Inhalation</b>				
Resident – Child	$ET_{in}$	hr/day	24	ADEM, 2001
Resident – Adult	$ET_{in}$	hr/day	24	ADEM, 2001
Trespasser*	$ET_{in}$	hr/day	24	EPA, 2000
Commercial and Construction Workers	$ET_{in}$	hr/day	10	ADEM, 2001
<b>Hourly Outdoor Inhalation Rate</b>				
Resident – Child	$IR_{ao}$	m <sup>3</sup> /hr	0.5	EPA, 1989
Resident – Adult	$IR_{ao}$	m <sup>3</sup> /hr	0.833	EPA, 1989
Trespasser*	$IR_{ao}$	m <sup>3</sup> /hr	1.5	ADEM, 2004
Commercial and Construction Workers	$IR_{ao}$	m <sup>3</sup> /hr	1.5	EPA, 1997

**TABLE 3-1  
RM-1 DEFAULT EXPOSURE FACTORS**

EXPOSURE FACTOR	SYMBOL	UNITS	ADEM DEFAULT VALUE	REFERENCE
<b>Exposure Time for Outdoor Inhalation</b>				
Resident - Child and Adult	<i>ET<sub>out</sub></i>	hr/day	10	ADEM, 2001
Trespasser*	<i>ET<sub>out</sub></i>	hr/day	10	ADEM, 2004
Commercial and Construction Workers	<i>ET<sub>out</sub></i>	hr/day	10	ADEM, 2001
<b>Soil to Skin Adherence Factor</b>				
Resident – Child	<i>M</i>	mg/cm <sup>2</sup>	0.2	EPA, 2004
Resident – Adult	<i>M</i>	mg/cm <sup>2</sup>	0.07	EPA, 2004
Trespasser*	<i>M</i>	mg/cm <sup>2</sup>	0.2	EPA, 2004
Commercial and Construction Workers	<i>M</i>	mg/cm <sup>2</sup>	0.2	EPA, 2004
<b>Oral Relative Absorption Factor</b>	<i>RAF<sub>o</sub></i>	---	1	EPA, 1995
<b>Dermal Relative Absorption Factor</b>				
Organics	<i>RAF<sub>d</sub></i>	---	0.01	EPA, 2000
Inorganics	<i>RAF<sub>d</sub></i>	---	0.001	EPA, 2000
<b>Skin Surface Area for Dermal Contact</b>				
Adult receptors	<i>SA</i>	cm <sup>2</sup> /d	5700	EPA, 2004
Trespasser*	<i>SA</i>	cm <sup>2</sup> /d	5700	EPA, 2004
Child receptors	<i>SA</i>	cm <sup>2</sup> /d	2800	EPA, 2004
<b>Contact Rate in Surface Water</b>	<i>CR</i>	L/hr	0.05	EPA, 2004
<b>Target Risk</b>				
Hazard Quotient for individual constituents/routes	<i>HQ or THQ</i>	---	≤ 0.1	ADEM, 2001
Hazard Index ≤ 1.0	<i>HI</i>	---	≤ 1.0	ADEM, 2001
Individual Excess Lifetime Cancer Risk for individual constituents/routes	<i>TR</i>	---	1 x 10 <sup>-5</sup>	ADEM, 2004

\*The Trespasser receptor may also be used for a Recreational receptor. Use of default values as shown above are typically not representative of site conditions since not all sites provide the same opportunities. It is typically recommended that an RM-2 evaluation be completed using more site-specific values if either the Recreational or Trespasser are considered significant receptors (see Sec. 3.3).

**References**

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(Commercial worker IRS based on the EPA recommended value of 50 mg/d for an indoor worker and 100 mg/d for an outdoor worker. Construction worker IRS based on the construction worker spending 1/3 of their time in a soil-contact-intensive environment (IRS is 330 mg/d, EPA 2002) and 2/3 of their time in a "regular" outdoor environment (IRS is 100 mg/d, EPA 2002)).

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**TABLE 3-2  
RM-1 DEFAULT FATE AND TRANSPORT PARAMETERS**

PARAMETER	SYMBOL	UNIT	RM-1 VALUE
<b>SOIL:</b>			
Length of Soil Source Area Parallel to Wind Direction	$W_a$	cm	**
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	$\rho_s$	g/cm <sup>3</sup>	1.8
Fractional Organic Carbon Content in the Vadose Zone	$foc$	g-C/g-soil	0.002
Total Soil Porosity in the Vadose Zone	$\theta_T$	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.3
Volumetric Water Content in Vadose Zone	$\theta_{ws}$	cm <sup>3</sup> /cm <sup>3</sup>	0.1
Volumetric Air Content in Vadose Zone*	$\theta_{as}$	cm <sup>3</sup> /cm <sup>3</sup>	0.2
Volumetric Water Content in Capillary Fringe	$\theta_{wcap}$	cm <sup>3</sup> /cm <sup>3</sup>	0.27
Volumetric Air Content in Capillary Fringe*	$\theta_{acap}$	cm <sup>3</sup> /cm <sup>3</sup>	0.03
Volumetric Water Content in Foundation or Wall Cracks	$\theta_{wcrack}$	cm <sup>3</sup> /cm <sup>3</sup>	0.1
Volumetric Air Content in Foundation/Wall Cracks*	$\theta_{acrack}$	cm <sup>3</sup> /cm <sup>3</sup>	0.2
<b>GROUNDWATER:</b>			
Depth to Groundwater	$L_{gw}$	cm	300
Width of GW Source Perpendicular to the GW Flow Direction	$Y$	cm	**
Length of the GW Source Parallel to the GW Flow Direction	$W$	cm	**
Total Soil Porosity in the Saturated Zone	$\theta_{TS}$	cm <sup>3</sup> /cm <sup>3</sup> -soil	0.3
Dry Soil Bulk Density in the Saturated Zone	$\rho_{ss}$	g/cm <sup>3</sup>	1.8
Fractional Organic Carbon Content in the Saturated Zone	$foc_s$	g/g	0.002
Groundwater Mixing Zone Thickness	$\delta_{gw}$	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
<b>AMBIENT AIR:</b>			
Breathing Zone Height	$\delta_a$	cm	200
Wind Speed within the Breathing Zone	$U_a$	cm/s	225
<b>ENCLOSED SPACE:</b>			
Enclosed Space Air Exchange Rate:			
Residential	$ER$	1/sec	0.00014
Trespasser	$ER$	1/sec	0.00014
Commercial/Construction Worker	$ER$	1/sec	0.00023
Enclosed Space Volume/Infiltration Area Ratio:			
Residential	$L_B$	cm	200
Trespasser	$L_B$	cm	200
Commercial/Construction Worker	$L_B$	cm	300
Enclosed Space Foundation or Wall Thickness			
Residential	$L_{crack}$	cm	15
Trespasser	$L_{crack}$	cm	15
Commercial/Construction Worker	$L_{crack}$	cm	15
Areal Fraction of Cracks in Foundation/Walls			
Residential	$\eta$	cm <sup>2</sup> /cm <sup>2</sup>	0.01
Trespasser	$\eta$	cm <sup>2</sup> /cm <sup>2</sup>	0.01
Commercial/Construction Worker	$\eta$	cm <sup>2</sup> /cm <sup>2</sup>	0.01

**TABLE 3-2  
RM-1 DEFAULT FATE AND TRANSPORT PARAMETERS**

PARAMETER	SYMBOL	UNIT	RM-1 VALUE
<b>PARTICULATE EMISSION RATE:</b>			
Residential and Commercial	$P_e$	g/cm <sup>2</sup> sec	6.90E-14
Trespasser	$P_e$	g/cm <sup>2</sup> sec	6.90E-09
Construction Worker	$P_e$	g/cm <sup>2</sup> sec	6.90E-09
<b>AVERAGING TIME FOR VAPOR FLUX:</b>			
Resident Child	$\tau$	sec	1.89E+08
Resident Adult	$\tau$	sec	9.46E+08
Trespasser	$\tau$	sec	3.15E+08
Commercial Worker	$\tau$	sec	7.88E+08
Construction Worker	$\tau$	sec	3.15E+07
<b>GROUNDWATER RESOURCE PROTECTION:</b>			
Distance from the Downgradient Edge of the Groundwater Source to the Point of Exposure	$X_{poe}$	ft	Site-specific Variable
Longitudinal Dispersivity*	$\alpha_x$	ft	$X_{poe}/10$
Transverse Dispersivity*	$\alpha_y$	ft	$X_{poe}/30$
Vertical Dispersivity*	$\alpha_z$	ft	$X_{poe}/200$
Distance from the Downgradient Edge of the Groundwater Source to the Sentry Well	$X_{sw}$	ft	Site-specific Variable
Longitudinal Dispersivity*	$\alpha_x$	ft	$X_{sw}/10$
Transverse Dispersivity*	$\alpha_y$	ft	$X_{sw}/30$
Vertical Dispersivity*	$\alpha_z$	ft	$X_{sw}/200$
<b>STREAM PROTECTION:</b>			
Stream Flow Rate	$Q_{sw}$	ft <sup>3</sup> /day	-
Distance from the Downgradient Edge of the Groundwater Source to the Stream	$X_s$	ft	Site-specific Variable
Longitudinal Dispersivity*	$\alpha_x$	ft	$X_s/10$
Transverse Dispersivity*	$\alpha_y$	ft	$X_s/30$
Vertical Dispersivity*	$\alpha_z$	ft	$X_s/200$
Distance from the Downgradient Edge of the Groundwater Source to the Sentry Well	$X_{ssw}$	ft	Site-specific Variable
Longitudinal Dispersivity*	$\alpha_x$	ft	$X_{ssw}/10$
Transverse Dispersivity*	$\alpha_y$	ft	$X_{ssw}/30$
Vertical Dispersivity*	$\alpha_z$	ft	$X_{ssw}/200$

**KEY**

\* Calculated value

\*\* The Source Area (assumed to be a square) should be classified as either i) Small (270 yd<sup>2</sup>) = (1500cm x 1500cm), ii) Medium (1/2 acre) = (4,498cm x 4,498cm), or iii) Large (1 acre) = (6,362cm x 6,362cm).



**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
<b>VOLATILES</b>							
Acetone	1.00E+06	1.59E-03	5.75E-01	1.24E-01	1.10E-05	58.1	1, 2
Acetonitrile	1.00E+06	8.20E-04	1.60E+01	1.30E-01	1.70E-05	41.1	1
Acrolein	2.10E+05	4.90E-03	2.10E+01	1.05E-01	1.20E-05	56.1	1, 2
Acrylonitrile	7.90E+04	3.60E-03	8.50E-01	1.22E-01	1.30E-05	53.1	1, 2
Aldrin	1.80E-01	7.00E-03	2.45E+06	1.64E-02	3.73E-06	364.9	2
Allyl Chloride	3.37E+03	4.94E-01	4.38E+01	1.17E-01	1.08E-05	76.5	2
Benzene	1.80E+03	2.30E-01	5.90E+01	8.80E-02	9.80E-06	78.1	1, 2
Bromodichloromethane	6.74E+03	6.56E-02	5.50E+01	2.98E-02	1.06E-05	163.8	1, 2
Bromoform	3.10E+03	2.19E-02	8.50E+01	1.49E-02	1.03E-05	252.8	2
Bromomethane	1.50E+04	2.60E-01	9.00E+00	7.28E-02	1.20E-05	94.9	1, 2
2-Butanone (Methyl Ethyl Ketone)	2.70E+05	1.10E-03	4.50E+00	8.08E-02	9.80E-06	72.1	1, 2
sec-Butylbenzene	1.70E+01	7.70E-01	2.20E+03	7.50E-02	7.80E-06	134.2	1
tert-Butylbenzene	3.00E+01	5.20E-01	2.20E+03	7.50E-02	7.80E-06	134.2	1
Carbon disulfide	1.20E+03	1.20E+00	4.60E+01	1.04E-01	1.00E-05	76.1	1, 2
Carbon Tetrachloride	7.90E+02	1.20E+00	1.70E+02	7.80E-02	8.80E-06	153.8	1, 2
Chlorobenzene	4.70E+02	1.50E-01	2.20E+02	7.30E-02	8.70E-06	112.6	1, 2
Chloroethane	5.70E+03	4.50E-01	1.50E+01	1.00E-01	1.20E-05	64.5	1
Chloroform	7.92E+03	1.50E-01	4.00E+01	1.04E-01	1.00E-05	119.4	1, 2
Chloromethane	8.20E+03	9.80E-01	3.50E+01	1.10E-01	6.50E-06	50.5	1
2-Chlorotoluene (o-Chlorotoluene)	4.70E+02	1.40E-01	1.60E+02	5.50E-02	8.70E-06	126.6	1, 2
Dibromochloromethane	4.40E+03	3.50E-02	4.70E+02	1.96E-02	1.00E-05	208.2	1, 2
1,2-Dibromo-3-chloropropane	1.20E+03	6.00E-03	2.80E+01	2.12E-02	7.00E-06	236.4	1, 2
1,2-Dibromoethane (Ethylene dibromide)	3.40E+03	1.30E-02	2.80E+01	2.87E-02	8.10E-06	187.9	1, 2
1,2-Dichlorobenzene (o-Dichlorobenzene)	1.60E+02	7.80E-02	6.20E+02	6.90E-02	7.90E-06	147.0	1, 2
1,3-Dichlorobenzene (m-Dichlorobenzene)	1.60E+02	7.80E-02	6.20E+02	6.92E-02	7.90E-06	147.0	1, 2
1,4-Dichlorobenzene (p-Dichlorobenzene)	7.40E+01	1.00E-01	6.20E+02	6.90E-02	7.90E-06	147.0	1, 2
Dichlorodifluoromethane	2.80E+02	4.10E+00	5.80E+01	5.17E-02	1.10E-05	120.9	1, 2
1,1-Dichloroethane	5.10E+03	2.30E-01	3.20E+01	7.42E-02	1.10E-05	99.0	1, 2
1,2-Dichloroethane	8.50E+03	4.00E-02	1.70E+01	1.04E-01	9.90E-06	99.0	1, 2
1,2-Dichloroethene-(cis)	3.50E+03	1.70E-01	3.60E+01	7.36E-02	1.10E-05	97.0	1, 2
1,2-Dichloroethene-(trans)	6.30E+03	3.80E-01	5.30E+01	7.07E-02	1.20E-05	97.0	1, 2

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
1,1-Dichloroethene	2.30E+03	1.10E+00	5.90E+01	9.00E-02	1.00E-05	96.9	1, 2
Dichloromethane							
1,2-Dichloropropane	2.80E+03	1.10E-01	4.40E+01	7.82E-02	8.70E-06	113.0	1, 2
1,3-Dichloropropene-(cis)	2.80E+03	7.26E-01	4.57E+01	6.26E-02	1.00E-05	111.0	1, 2
1,3-Dichloropropene-(trans)	2.80E+03	7.26E-01	4.57E+01	6.26E-02	1.00E-05	111.0	1, 2
Ethylbenzene	1.70E+02	3.20E-01	3.60E+02	7.50E-02	7.80E-06	106.2	1, 2
Formaldehyde	5.50E+05	1.37E-05	9.00E-01	1.78E-01	1.98E-05	30.0	2
Hexachlorobutadiene	3.23E+00	3.34E-01	5.50E+04	5.61E-02	6.16E-06	260.7	2
Isobutyl Alcohol (Isobutanol)	8.50E+04	4.90E-04	6.20E+01	1.42E-01	9.30E-06	74.1	1, 2
Isopropylbenzene (Cumene)	6.10E+01	4.70E-01	2.20E+02	6.50E-02	7.10E-06	120.2	1, 2
Methanol	1.00E+06	1.86E-04	2.00E-01	1.50E-01	1.64E-05	32.0	2
Methylene Chloride (Dichloromethane)	1.30E+04	9.00E-02	1.20E+01	1.00E-01	1.20E-05	84.9	1
4-Methyl-2-pentanone (Methyl Isobutyl Ketone)	1.90E+04	5.70E-03	1.30E+02	7.50E-02	7.80E-06	100.2	1, 2
Methyl-tert-butyl-ether (MTBE)	1.50E+05	2.40E-02	6.00E+00	1.02E-01	1.00E-05	88.2	1, 2
Monochlorobenzene							
Naphthalene	3.10E+01	2.00E-02	1.20E+03	5.90E-02	7.50E-06	128.2	1, 2
Styrene	3.10E+02	1.10E-01	7.80E+02	7.10E-02	8.00E-06	104.2	1, 2
1,1,1,2-Tetrachloroethane	3.00E+03	1.40E-02	9.30E+01	7.10E-02	7.90E-06	167.9	1, 2
1,1,2,2-Tetrachloroethane	3.00E+03	1.40E-02	9.30E+01	7.10E-02	7.90E-06	167.9	1, 2
Tetrachloroethene	2.00E+02	7.50E-01	1.60E+02	7.20E-02	8.20E-06	165.8	1, 2
Toluene	5.30E+02	2.70E-01	1.80E+02	8.70E-02	8.60E-06	92.1	1, 2
1,2,4-Trichlorobenzene	3.00E+02	5.80E-02	1.80E+03	3.00E-02	8.20E-06	181.4	1, 2
1,1,1-Trichloroethane	1.30E+03	7.10E-01	1.10E+02	7.80E-02	8.80E-06	133.4	1, 2
1,1,2-Trichloroethane	4.40E+03	3.70E-02	5.00E+01	7.80E-02	8.80E-06	133.4	1, 2
Trichloroethene	1.10E+03	4.20E-01	1.70E+02	7.90E-02	9.10E-06	131.4	1, 2
Trichlorofluoromethane	1.10E+03	4.00E+00	1.60E+02	8.70E-02	1.30E-05	137.4	1, 2
1,2,3-Trichloropropane	2.70E+03	1.10E+00	5.10E+01	7.00E+00	7.90E-06	147.4	1, 2
1,2,4-Trimethylbenzene	5.70E+01	2.30E-01	3.70E+03	7.10E-02	7.10E-06	120.2	1, 2
1,3,5-Trimethylbenzene	4.80E+01	3.20E-01	8.20E+02	6.02E-02	7.10E-06	120.2	1, 2
Vinyl Acetate	2.00E+04	2.10E-02	5.30E+00	8.50E-02	9.20E-06	86.1	1, 2
Vinyl Chloride	2.80E+03	1.10E+00	1.90E+01	1.70E-01	1.20E-06	62.5	1, 2
Xylenes (Total)	1.60E+02	3.00E-01	4.10E+02	7.14E-02	7.80E-06	NA	1, 2

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
<b>SEMI-VOLATILES</b>							
Acenaphthene	4.20E+00	6.40E-03	4.90E+03	4.21E-02	7.70E-06	154.2	1, 2
Acenaphthylene	1.61E+01	4.60E-03	3.10E+03	4.39E-02	7.53E-06	152.1	2
Aniline	3.60E+04	1.00E-04	9.00E+00	7.00E-02	8.30E-06	93.1	2
Anthracene	4.30E-02	2.70E-03	2.40E+04	3.24E-02	7.70E-06	178.2	1, 2
Azobenzene	6.40E+00	6.00E-04	2.58E+03	3.26E-02	7.47E-06	182.2	2
Benzidine	5.00E+02	1.60E-09	2.74E+03	3.20E-02	7.64E-06	184.3	2
Benzo(a)anthracene	9.40E-03	1.37E-04	4.00E+05	5.10E-02	9.00E-06	228.3	2
Benzo(a)pyrene	1.62E-03	4.63E-05	1.00E+06	4.30E-02	9.00E-06	252.3	2
Benzo(b)fluoranthene	1.50E-03	4.55E-03	1.25E+06	2.26E-02	5.56E-06	252.3	2
Benzo(g,h,i)perylene	2.60E-04	5.78E-06	3.85E+06	2.10E-02	5.26E-06	276.3	2
Benzo(k)fluoranthene	8.00E-04	3.40E-05	1.25E+06	2.26E-02	5.56E-06	252.3	2
Benzoic acid	3.50E+03	6.31E-05	6.00E-01	5.36E-02	7.97E-06	122.1	2
Benzyl Alcohol	4.00E+04	1.60E-05	1.25E+01	7.12E-02	8.97E-06	108.1	2
Bis(2-chloroethyl)ether	1.70E+04	7.40E-04	7.60E+01	6.92E-02	7.50E-06	143.0	1, 2
Bis(2-chloroisopropyl)ether	1.70E+03	4.60E-03	6.10E+01	6.02E-02	6.40E-06	171.1	1, 2
Bis(2-ethylhexyl)phthalate	3.40E-01	4.18E-06	1.50E+07	3.51E-02	3.66E-06	390.6	2
Butyl benzyl phthalate	2.69E+00	5.17E-05	5.50E+04	1.99E-02	4.10E-06	312.4	2
Carbazole	7.48E+00	6.26E-07	3.40E+03	3.90E-02	7.03E-06	167.2	2
4-Chloroaniline (p-Chloroaniline)	5.30E+03	1.36E-05	6.50E+01	4.83E-02	1.01E-05	127.6	2
Chlorobenzilate	1.11E+01	3.01E-06	2.00E+04	1.89E-02	4.00E-06	325.2	2
Chloro-m-cresol, p-	3.80E+03	1.63E-05	5.00E+01	4.78E-02	7.83E-06	142.6	2
2-Chloronaphthalene (beta-Chloronaphthalene)	1.17E+01	1.29E-02	1.15E+04	4.02E-02	7.23E-06	162.6	2
2-Chlorophenol	2.20E+04	1.60E-02	4.00E+02	5.01E-02	9.50E-06	128.6	1, 2
3-Chlorophenol (m-chlorophenol)	2.50E+04	3.48E-05	3.50E+02	5.05E-02	9.37E-06	128.6	2
Chrysene	1.60E-03	3.90E-03	4.00E+05	2.48E-02	6.20E-06	228.3	1, 2
Di (2-ethylhexyl) adipate							
Dichloroacetic acid	1.00E+06	2.83E-06	7.50E+01	4.63E-02	1.08E-05	128.9	2
Di-n-Butyl phthalate (Dibutyl phthalate)	1.12E+01	4.02E-08	1.57E+03	4.38E-02	7.86E-06	278.3	2
Di-n-Octyl phthalate (Dioctyl phthalate)	2.00E-02	2.74E-03	8.50E+07	1.51E-02	3.58E-06	390.6	2
Dibenzo(a,h)anthracene	2.49E-03	6.03E-07	3.75E+06	2.00E-02	5.24E-06	278.4	2
Dibenzofuran	3.10E+00	5.30E-04	7.80E+03	2.67E-02	1.00E-05	168.2	1, 2
3,3-Dichlorobenzidine	3.11E+00	1.64E-07	7.25E+02	2.25E-02	5.55E-06	253.1	2
2,4-Dichlorophenol	4.50E+03	1.30E-04	1.47E+02	4.00E-02	7.22E-06	163.0	2
Diethylphthalate	1.08E+03	1.85E-05	2.85E+02	2.48E-02	6.35E-06	222.2	2

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
2,4-Dimethylphenol	7.87E+03	8.20E-05	2.10E+02	5.84E-02	8.69E-06	122.2	2
2,6-Dimethylphenol	5.90E+03	2.04E-04	1.30E+02	5.72E-02	9.15E-06	122.2	2
3,4-Dimethylphenol	5.10E+03	1.83E-05	1.24E+02	6.02E-02	8.33E-06	122.2	2
Dimethylphthalate	4.00E+03	4.31E-06	3.50E+01	5.68E-02	6.29E-06	194.2	2
2,4-Dinitrophenol	2.79E+03	1.82E-05	1.00E-02	2.73E-02	9.06E-06	184.1	2
2,4-Dinitrotoluene	2.70E+02	3.80E-06	9.50E+01	2.03E-01	7.06E-06	182.1	2
2,6-Dinitrotoluene	1.82E+02	3.06E-05	7.00E+01	2.99E-02	8.21E-06	182.1	2
Fluoranthene	2.06E-01	6.60E-04	1.10E+05	3.02E-02	6.35E-06	202.3	2
Fluorene	1.90E+00	3.20E-03	1.40E+04	3.67E-02	7.90E-06	166.2	1, 2
Hexachlorobenzene	5.00E-03	5.41E-02	5.50E+04	5.42E-02	5.91E-06	284.8	2
Hexachlorocyclopentadiene	1.80E+00	1.11E+00	2.00E+05	1.61E-02	7.21E-06	272.8	2
Hexachloroethane	5.00E+01	1.59E-01	1.78E+03	2.50E-03	6.80E-06	236.7	2
HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	1.40E+02	3.52E-08				296.2	7
Indeno(1,2,3-cd)pyrene	2.20E-05	6.56E-05	3.45E+06	2.01E-02	5.26E-06	276.3	2
Isophorone	1.20E+04	2.72E-04	4.70E+01	6.23E-02	6.76E-06	138.2	2
2-Methylnaphthalene	2.46E+01	2.12E-02	7.50E+03	4.80E-02	7.84E-06	142.2	2
Methyl parathion	5.50E+01	4.10E-06	7.00E+02	2.14E-02	5.42E-06	263.2	2
2-Methylphenol (o-Cresol)	2.60E+04	4.92E-05	9.00E+01	7.40E-02	8.30E-06	108.1	2
3-Methylphenol (m-Cresol)	2.27E+04	3.55E-05	8.50E+01	7.40E-02	1.00E-05	108.1	2
4-Methylphenol (p-Cresol)	2.15E+04	3.25E-05	8.50E+01	7.40E-02	1.00E-05	108.1	2
Monochloroacetic acid							
N-Nitroso-di-n-propylamine	1.00E+04	5.74E-05	1.31E+02	5.76E-02	7.76E-06	130.2	2
N-Nitroso-dimethylamine	1.00E+06	4.92E-05	2.75E-01	1.13E-01	1.24E-05	74.1	2
N-Nitroso-diphenylamine	3.51E+01	2.05E-04	1.30E+03	2.89E-02	7.19E-06	198.2	2
2-Nitroaniline	2.95E+02	7.42E-07	6.50E+01	7.30E-02	8.00E-06	138.1	2
Nitrobenzene	2.10E+03	9.80E-04	6.50E+01	7.60E-02	8.60E-06	123.1	1, 2
4-Nitrophenol (p-Nitrophenol)	1.16E+04	1.70E-08	4.89E+01	4.30E-02	9.61E-06	139.1	2
Parathion	6.54E+00	2.32E-05	6.00E+03	1.70E-02	5.79E-06	291.3	2
Pentachlorobenzene	1.33E+00	2.91E-02	1.74E+04	5.70E-02	6.30E-06	250.3	2
Pentachlorophenol	1.95E+03	1.00E-06	5.92E+02	5.60E-02	6.10E-06	266.3	2
Phenanthrene	1.15E+00	9.55E-04	2.95E+04	3.33E-02	7.47E-06	178.2	2
Phenol	8.28E+04	1.63E-05	2.85E+01	8.20E-02	9.10E-06	94.1	2
Propylene glycol	1.00E+06	5.36E-09	4.60E-02	9.30E-02	1.02E-05	76.1	2
Pyrene	1.40E-01	4.50E-04	1.10E+05	2.77E-02	7.20E-06	202.3	1, 2
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)	5.98E+01	2.58E-06	7.89E-02	2.09E-02	8.50E-06	222.1	2
2,3,4,6-Tetrachlorophenol	1.00E+02	1.80E-04	2.80E+02	2.17E-02	7.10E-06	231.9	2
Tetrahydrofuran	3.03E+05	7.14E-05			1.00E-05	72.1	
Trichloroacetic acid				3.31E-02		163.4	
2,4,5-Trichlorophenol	1.20E+03	1.78E-04	1.60E+03	2.91E-02	7.03E-06	197.5	2

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
2,4,6-Trichlorophenol	8.00E+02	3.19E-04	3.81E+02	3.18E-02	6.25E-06	197.5	2
1,3,5-Trinitrobenzene	3.50E+02	6.56E-07	1.45E+01	2.42E-02	7.69E-06	213.1	2
Trinitrophenylmethylnitramine	2.00E+02	4.09E-10	4.06E+02	1.60E-02	6.67E-06	287.2	2
2,4,6-Trinitrotoluene	1.24E+02	1.99E-07	3.75E+01	2.45E-02	6.36E-06	227.1	2
<b>PESTICIDES AND HERBICIDES</b>							
Ammonia	5.30E+05	1.31E-02	NA	4.46E-01	2.37E-05	17.0	2
Alachlor	1.83E+02	8.20E-08	1.51E+02	4.88E-02	7.70E-06	269.8	2
Acrolein	2.13E+05	5.00E-03	1.00E+00	1.05E-01	1.22E-05	56.1	2
Aldicarb	6.03E+03	5.90E-08	1.25E+01	3.74E-02	5.52E-06	190.3	2
Aldicarb Sulfone							
Aldicarb Sulfoxide							
Atrazine	7.00E+01	1.21E-07	4.05E+02	2.59E-02	6.66E-06	215.7	2
Bis(2-chloro-1-methylethyl)ether	1.31E+03	1.36E-02	3.45E+02	6.02E-02	6.41E-06	171.1	2
Carbofuran	3.20E+02	3.77E-03	3.85E+01	2.55E-02	6.57E-06	221.3	2
Chlordane	5.60E-02	1.99E-03	1.20E-05	1.18E-02	4.37E-06	409.8	2
Chlorobenzilate	1.11E+01	2.97E-06	2.00E+04	1.89E-02	4.00E-06	325.2	2
Chlorpyrifos	1.12E+00	5.04E-04	1.74E+04	1.31E-02	5.52E-06	334.5	2
Dalapon (2,2-dichloropropionic acid)						143.0	
4,4' - DDD	9.00E-02	1.64E-04	1.00E+06	1.93E-02	4.04E-06	320.0	2
4,4' - DDE	1.20E-01	8.61E-04	4.40E+06	1.95E-02	4.05E-06	318.0	2
4,4' - DDT	2.50E-02	3.32E-04	2.65E+06	1.47E-02	4.53E-06	354.5	2
Diallate	4.00E+01	1.56E-04	2.60E+04	1.96E-02	5.85E-06	270.2	2
2,4-Dichlorophenoxy acetic acid (2,4-D)	6.77E+02	4.18E-07	1.66E+02	5.88E-02	6.49E-06	221.0	2
Dieldrin	1.95E-01	6.19E-04	2.14E+04	1.56E-02	3.64E-06	380.9	2
Dimethoate	2.50E+04	2.52E-09	4.75E+00	2.58E-02	5.82E-06	229.3	2
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	5.20E+01	1.87E-05	1.89E+01	2.43E-02	5.66E-06	240.2	2
Diquat	7.08E+05	5.86E-12	1.00E+06	1.41E-02	5.21E-06	NA	2
Disulfoton	1.63E+01	1.64E-04	8.00E+03	1.96E-02	5.67E-06	274.4	2
Endosulfan	5.10E-01	4.59E-04	2.14E+03	1.43E+02	3.49E-06	406.9	2
Endothall	2.10E+04	1.06E-08	2.90E-01	2.19E-02	7.17E-06	186.2	2
Endrin	2.50E-01	3.08E-04	1.23E+04	1.56E-02	3.64E-06	380.9	2
Glyphosate (Roundup)	1.20E+04	3.92E-15	1.88E+01	4.37E-02	5.92E-06	169.1	2
HCH (alpha) (alpha - BHC)	2.00E+00	4.35E-04	1.23E+03	1.45E-02	7.35E-06	290.8	2
HCH (beta) (beta - BHC)	2.40E-01	3.05E-05	1.26E+03	1.44E-02	7.40E-06	290.8	2
HCH (gamma) Lindane (gamma - BHC)	6.80E+00	5.74E-04	1.07E+03	1.42E-02	7.34E-06	290.8	2
Heptachlor	1.80E-01	6.07E-02	1.45E+06	1.12E-02	5.69E-06	373.3	2
Heptachlor epoxide	2.00E-01	3.90E-04	8.00E+04	1.32E-02	4.23E-06	389.3	2
Kepone						490.6	
Malathion	1.43E+02	2.00E-07	6.50E+02	1.51E-02	5.24E-06	330.4	2

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
Methoxychlor	4.50E-02	6.48E-04	1.00E+05	1.76E-02	3.85E-06	345.7	2
Oxamyl (Vydate)	2.80E+05	9.72E-09	8.89E+00	2.81E-02	5.91E-06	219.3	2
<b>PCBs (Polychlorinated Biphenyls)</b>							
PCB - Arochlor 1016	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	NA	2
PCB - Arochlor 1221	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	NA	2
PCB - Arochlor 1232	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	NA	2
PCB - Arochlor 1242	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	258.0	2
PCB - Arochlor 1248	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	NA	2
PCB - Arochlor 1254	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	326.0	2
PCB - Arochlor 1260	7.00E-02	1.07E-01	8.50E+05	1.75E-02	8.00E-06	NA	2
Phorate	5.00E+01	1.80E-04	5.50E+03	1.75E-02	5.39E-06	260.4	2
Picloram						241.5	
Pronamide						256.1	
Simazine	6.20E+00	1.39E-07	3.93E+02	3.05E-02	6.28E-06	201.7	2
Sulfotepp (Tetraethyldithiopyrophosphate)	2.50E+01	1.19E-04	7.40E+02	9.10E-02	4.02E-06	322.3	2
2,3,7,8 TCDD (Dioxin)	7.91E-06	3.25E-03	2.65E+06	1.04E-01	5.60E-06	322.0	2
Toxaphene	7.40E-01	2.46E-04	2.55E+05	1.16E-02	4.34E-06	413.8	2
2,4,5 TP (silvex) (2-(2,4,5-Trichlorophenoxy) propionic acid)	1.40E+02	3.71E-07	2.60E+03	1.94E-02	5.83E-06	269.5	2
<b>INORGANICS</b>							
Aluminum	0.00E+00	NA	0.00E+00	4.68E-01	3.82E-05	27.0	2
Antimony	0.00E+00	NA	4.50E+01	2.89E-02	2.66E-05	121.8	2
Arsenic	0.00E+00	NA	2.90E+01	2.95E-01	3.25E-05	74.9	2, 3
Barium	0.00E+00	NA	4.10E+01	3.07E-02	1.68E-05	137.3	2
Beryllium	0.00E+00	NA	7.90E+02	9.91E-01	5.87E-05	9.0	2
Bromate	6.90E+04	3.86E-15	8.58E-02	3.45E-02	1.70E-05	127.9	2
Cadminum	0.00E+00	NA	7.50E+01	2.98E-02	3.26E-05	112.4	2
Chloramine							
Chloride						35.5	
Chlorine							
Chlorine Dioxide							
Chlorite							

**TABLE 3-3  
PHYSICAL AND CHEMICAL PROPERTIES**

CHEMICAL OF CONCERN	Water Solubility	Henry's Law Constant	Organic Carbon Adsorption Coefficient or Kd for metals	Diffusion Coefficient in Air	Diffusion Coefficient in Water	Molecular Weight	Reference
	<i>S</i> (mg/L)	<i>H</i> (L-water/L-air)	<i>K<sub>oc</sub></i> (mL/g)	<i>D<sup>a</sup></i> (cm <sup>2</sup> /s)	<i>D<sup>w</sup></i> (cm <sup>2</sup> /s)	<i>g/mol</i>	
Chromium (III)	0.00E+00	NA	1.80E+06	3.98E-01	4.60E-05	NA	2
Chromium (VI)	0.00E+00	NA	1.90E+01	3.98E-01	4.60E-05	NA	2
Chromium (Total)		NA	1.90E+01	0.00E+00	0.00E+00	NA	2
Cobalt	0.00E+00	NA	0.00E+00	3.93E-01	4.89E-05	58.9	2
Copper	0.00E+00	NA	0.00E+00	3.75E-01	4.68E-05	63.6	2
Cyanide (hydrogen)	1.00E+06	5.30E-03	1.70E+01		1.80E-05	27.0	1
Cyanide (free)	5.00E+05	1.27E-18	2.71E+00	2.51E-01	1.91E-05	26.0	2
Cyanide (Total)						NA	
Fluoride	4.20E+04	NA	4.50E+02	3.00E-01	2.19E-05	19.0	2
Iron	0.00E+00	NA	NA	3.92E-01	4.68E-05	55.9	2
Lead	0.00E+00	NA	1.22E+02	1.12E-02	2.66E-05	207.2	2, 3, 4
Manganese	0.00E+00	NA	NA	3.86E-01	4.49E-05	54.9	2
Mercury (and compounds) (Mercuric Chloride)	7.40E-02	5.80E-01	5.20E+01	1.56E-02	1.16E-05	271.5	8
Mercury (elemental)	5.60E-02	4.67E-01	5.20E+01	3.07E-02	6.30E-06	200.6	2
Mercury (methyl)	1.00E+03	5.80E-01	5.37E+02 (K <sub>oc</sub> )	1.56E-02	1.16E-05	215.6	2
Nickel	0.00E+00	NA	6.50E+01	3.93E-01	4.90E-05	58.7	2
Nitrate	9.21E+05	NA	NA	2.43E-01	2.08E-05	62.0	2
Nitrite	6.67E+05	NA	NA	3.00E-01	2.49E-05	46.0	2
Perchlorate	2.49E+05	NA	0.00E+00		1.30E-05	117.5	2, 5, 6
Selenium	0.00E+00	NA	5.00E+00	2.67E-01	2.81E-05	79.0	2
Silver	0.00E+00	NA	8.30E+00	2.98E-02	3.75E-05	107.9	2
Strontium	0.00E+00	NA	NA	2.03E-01	1.84E-05	87.6	2
Sulfate						NA	
Thallium	0.00E+00	NA	7.10E+01	1.12E-02	2.77E-05	204.4	2
Tin	0.00E+00	NA	NA	3.16E-02	2.47E-05	118.7	2
Vanadium	0.00E+00	NA	1.00E+03	3.86E-01	4.25E-05	50.9	2
Zinc	0.00E+00	NA	6.20E+01	3.45E-01	4.02E-05	65.4	2, 3

- 1 USEPA Region 9
- 2 Florida Department of Environmental Protection
- 3 USEPA, 1996
- 4 USEPA, 1990
- 5 ATHDR, 2005, *Draft Toxicological Profile for Perchlorates*
- 6 MADEP, 2005
- 7 U.S. National Library of Medicine, National Institutes of Health
- 8 2008 ADEM Guidance Decision Meeting

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>		
				1/(mg/kg-day)		1/(mg/kg-day)	(mg/kg-day)		(mg/kg-day)		
<b>VOLATILES</b>											
Acetone	nc	67-64-1						9.000E-01	i	9.000E-01	e
Acetonitrile	nc	75-05-8						1.700E-02	e	1.700E-02	i
Acrolein	nc	107-02-8						5.000E-04	i	5.714E-06	e
Acrylonitrile	ca/nc	107-13-1	5.400E-01	i	2.380E-01	e	1.000E-03	h	5.714E-04	e	
Aldrin	ca/nc	309-00-2	1.700E+01	i	1.715E+01	e	3.000E-05	i	3.000E-05	e	
Allyl Chloride	nc	107-05-1	2.100E-02	c	2.100E-02	c	5.000E-02	h	2.857E-04	e	
Benzene	ca/nc	71-43-2	5.500E-02	i	2.730E-02	i	4.000E-03	i	8.571E-03	e	
Bromodichloromethane	ca/nc	75-27-4	6.200E-02	i	6.327E-02	e	2.000E-02	i	1.960E-02	e	
Bromoform (Tribromomethane)	ca/nc	75-25-2	7.900E-03	i	3.850E-03	e	2.000E-02	i	1.500E-02	e	
Bromomethane (Methyl Bromide)	nc	74-83-9						1.400E-03	i	1.429E-03	e
2-Butanone (Methyl Ethyl Ketone)	nc	78-93-3						6.000E-01	i	1.429E+00	e
sec-Butylbenzene	nc	135-9-88						4.000E-02	n	4.000E-02	e
tert-Butylbenzene	nc	98-06-6						4.000E-02	n	4.000E-02	e
Carbon disulfide	nc	75-15-0						1.000E-01	i	2.000E-01	i
Carbon Tetrachloride	ca/nc	56-23-5	1.300E-01	i	5.250E-02	e	7.000E-04	i	5.714E-04	e	
Chlorobenzene (Monochlorobenzene)	nc	108-90-7						2.000E-02	i	1.700E-02	n
Chloroethane (Ethyl chloride)	ca/nc	75-00-3	2.900E-03	n	2.900E-03	e	4.000E-01	n	2.900E+00	i	
Chloroform	ca/nc	67-66-3	NA		8.050E-02	e	1.000E-02	i	1.400E-02	n	
Chloromethane (methyl chloride)	ca/nc	74-87-3	1.300E-02	h	3.500E-03	n	2.571E-02	e	2.571E-02	e	
2-Chlorotoluene (o-Chlorotoluene)	nc	95-49-8						2.000E-02	i	2.000E-02	e
Dibromochloromethane (THM)	ca/nc	124-48-1	8.400E-02	i	1.120E-01	e	2.000E-02	i	1.500E-02	e	
1,2-Dibromo-3-chloropropane (DBCP)	ca	96-12-8						5.714E-05	e	5.714E-05	e
1,2-Dibromoethane (Ethylene dibromide or EDB)	ca/nc	106-93-4	2.000E+00	i	2.000E+00	e	9.000E-03	i	2.571E-03	e	
1,2-Dichlorobenzene (o-Dichlorobenzene)	nc	95-50-1						9.000E-02	i	5.714E-02	e
1,3-Dichlorobenzene (m-Dichlorobenzene)	nc	541-73-1						3.000E-02	n	3.000E-02	e
1,4-Dichlorobenzene (p-Dichlorobenzene)	ca/nc	106-46-7	2.400E-02	h	2.200E-02	n	3.000E-02	n	2.286E-01	e	
Dichlorodifluoromethane	nc	75-71-8						2.000E-01	i	5.714E-02	e
1,1-Dichloroethane	nc	75-34-3						1.000E-01	h	1.429E-01	e
1,2-Dichloroethane (EDC)	ca/nc	107-06-2	9.100E-02	i	9.100E-02	e	3.000E-02	n	3.000E-02	e	
1,2-Dichloroethene-(cis)	nc	156-59-2						1.000E-02	h	1.000E-02	e
1,2-Dichloroethene-(trans)	nc	156-60-5						2.000E-02	i	2.000E-02	i
1,1-Dichloroethene	nc	75-35-4						5.000E-02	i	5.714E-02	e
1,2-Dichloropropane	ca/nc	78-87-5	6.800E-02	h	6.800E-02	h	NA		1.143E-03	e	
1,3-Dichloropropene-(cis)	ca	542-75-6	1.000E-01	i	1.400E-02	e					
1,3-Dichloropropene-(trans)	ca	542-75-6	1.000E-01	i	1.400E-02	e					
Ethylbenzene	nc	100-41-4						1.000E-01	i	2.900E-01	i
Formaldehyde	ca/nc	50-00-0			4.600E-02	i	2.000E-01	i	2.000E-01	e	



**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Hexachlorobutadiene	ca	87-68-3	7.800E-02	i	7.800E-02	i				
Isobutyl Alcohol (Isobutanol)	nc	78-83-1					3.000E-01	i	3.000E-01	i
Isopropylbenzene (Cumene)	nc	98-82-8					1.000E-01	i	1.143E-01	e
Methanol	nc	67-56-1					5.000E-01	i	5.000E-01	e
Methylene Chloride (Dichloromethane)	ca/nc	75-09-2	7.500E-03	i	1.645E-03	e	6.000E-02	i	8.571E-01	e
4-Methyl-2-pentanone (Methyl Isobutyl Ketone)	nc	108-10-1					8.000E-02	h	8.571E-01	e
Methyl-tert-butyl-ether (MTBE)	nc	1634-04-4					8.571E-01	e	8.571E-01	e
Naphthalene	nc	91-20-3					2.000E-02	i	8.571E-04	e
Perchlorate	nc	7601-90-3					7.000E-04	i		
Styrene	nc	100-42-5					2.000E-01	i	2.857E-01	e
1,1,1,2-Tetrachloroethane	ca/nc	630-20-6	2.600E-02	i	2.590E-02	e	3.000E-02	i	3.000E-02	e
1,1,2,2-Tetrachloroethane	ca/nc	79-34-5	2.000E-01	i	2.030E-01	e	6.000E-02	n	4.200E-02	e
Tetrachloroethene (PCE)	ca/nc	127-18-4	5.400E-01	c	2.100E-02	c	1.000E-02	i	1.400E-01	n
Toluene	nc	108-88-3					2.000E-01	i	2.857E+00	e
1,2,4-Trichlorobenzene	nc	120-82-1					1.000E-02	i	5.714E-02	e
1,1,1-Trichloroethane	nc	71-55-6					2.800E-01	n	2.860E-01	n
1,1,2-Trichloroethane	ca/nc	79-00-5	5.700E-02	i	5.600E-02	e	4.000E-03	i	3.240E-03	e
Trichloroethene (TCE)	ca/nc	79-01-6	1.300E-02	c	7.000E-03	c	6.000E-03	n	5.670E-03	e
Trichlorofluoromethane	nc	75-69-4					3.000E-01	i	2.000E-01	e
1,2,3-Trichloropropane	ca/nc	96-18-4	2.000E+00	n	2.000E+00	e	1.000E-02	s	5.714E-02	e
1,2,4-Trimethylbenzene	nc	95-63-6					5.000E-02	n	1.700E-03	n
1,3,5-Trimethylbenzene	nc	108-67-8					5.000E-02	n	1.700E-03	n
Vinyl Acetate	nc	108-05-4					1.000E+00	h	5.714E-02	e
Vinyl Chloride	ca/nc	75-01-4	7.200E-01	i	1.540E-02	e	3.000E-03	i	2.857E-02	e
Xylenes (Total)	nc	1330-20-7					2.000E-01	i	2.857E-02	e
<b>SEMI-VOLATILES</b>										
Acenaphthene	nc	83-32-9					6.000E-02	i	3.000E-02	e
Acenaphthylene	nc	208-96-8					3.000E-02	s	3.000E-02	e
Aniline	ca/nc	62-53-3	5.700E-03	i	5.700E-03	e	7.000E-03	n	2.857E-04	e
Anthracene	nc	120-12-7					3.000E-01	i	1.500E-01	e
Azobenzene	ca	103-33-3	1.100E-01	i	1.085E-01	e				
Benzidine	ca/nc	92-87-5	2.300E+02	i	2.345E+02	e	3.000E-03	i	3.000E-03	e
Benzo(a)anthracene	ca	56-55-3	7.300E-01	n	3.100E-01	n				
Benzo(a)pyrene	ca	50-32-8	7.300E+00	i	3.100E+00	n				
Benzo(b)fluoranthene	ca	205-99-2	7.300E-01	n	3.100E-01	n				
Benzo(g,h,i)perylene	nc	191-24-2					3.000E-02	s	1.500E-02	e
Benzo(k)fluoranthene	ca	207-08-9	7.300E-02	n	3.100E-02	n				
Benzoic acid	nc	65-85-0					4.000E+00	i	4.000E+00	e

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Benzyl Alcohol	nc	100-51-6					3.000E-01	h	3.000E-01	e
Bis(2-chloroethyl)ether	ca	111-44-4	1.100E+00	i	1.155E+00	e				
Bis(2-chloroisopropyl)ether	ca/nc	108-60-1	7.000E-02	h	3.500E-02	h	4.000E-02	i	4.000E-02	e
Bis(2-ethylhexyl)phthalate (DEHP)	ca/nc	117-81-7	1.400E-02	i	1.400E-02	n	2.000E-02	i	2.000E-02	e
Butyl benzyl phthalate	nc	85-68-7					2.000E-01	i	2.000E-01	e
Carbazole	ca	86-74-8	2.000E-02	h	2.000E-02	e				
4-Chloroaniline (p-Chloroaniline)	nc	106-47-8					4.000E-03	i	4.000E-03	e
Chlorobenzilate	ca/nc	510-15-6	2.700E-01	h	2.700E-01	h	2.000E-02	i	1.140E-02	e
Chloro-m-cresol, p-	nc	59-50-7					9.000E-03	o	9.000E-03	e
2-Chloronaphthalene (beta-Chloronaphthalene)	nc	91-58-7					8.000E-02	i	8.000E-02	e
2-Chlorophenol	nc	95-57-8					5.000E-03	i	5.000E-03	e
3-Chlorophenol (m-chlorophenol)	nc	108-43-0					5.000E-03	s	5.000E-03	e
Chrysene	ca	218-01-9	7.300E-03	n	3.100E-03	e				
Di (2-ethylhexyl) adipate	ca/nc	103-23-1	1.200E-03	i	1.200E-03	e	6.000E-01	i	6.000E-01	e
Dichloroacetic acid	nc	76-43-6					4.000E-03	i	4.000E-03	e
Di-n-Butyl phthalate (Dibutyl phthalate)	nc	84-74-2					1.000E-01	i	1.000E-01	e
Di-n-Octyl phthalate (Dioctyl phthalate)	nc	117-84-0					4.000E-02	p	4.000E-02	e
Dibenzo(a,h)anthracene	ca	53-70-3	7.300E+00	n	3.100E+00	n				
Dibenzofuran	nc	132-64-9					4.000E-03	n	4.000E-03	e
3,3-Dichlorobenzidine	ca	91-94-1	4.500E-01	i	4.500E-01	e				
2,4-Dichlorophenol	nc	120-83-2					3.000E-03	i	3.000E-03	e
Diethyl phthalate	nc	84-66-2					8.000E-01	i	8.000E-01	e
2,4-Dimethylphenol	nc	105-67-9					2.000E-02	i	2.000E-02	e
2,6-Dimethylphenol	nc	576-26-1					6.000E-04	i	6.000E-04	e
3,4-Dimethylphenol	nc	95-65-8					1.000E-03	i	1.000E-03	e
Dimethyl phthalate	nc	131-11-3					1.000E+01	h	1.000E+01	e
2,4-Dinitrophenol	nc	51-28-5					2.000E-03	i	2.000E-03	e
2,4-Dinitrotoluene	nc	121-14-2					2.000E-03	i	2.000E-03	e
2,6-Dinitrotoluene	nc	606-20-2					1.000E-03	h	1.000E-03	e
Fluoranthene	nc	206-44-0					4.000E-02	i	2.000E-02	e
Fluorene	nc	86-73-7					4.000E-02	i	2.000E-02	e
Hexachlorobenzene	ca/nc	118-74-1	1.600E+00	i	1.610E+00	e	8.000E-04	i	6.400E-04	e
Hexachlorocyclopentadiene	nc	77-47-4					6.000E-03	i	5.714E-05	e
Hexachloroethane	ca/nc	67-72-1	1.400E-02	i	1.400E-02	e	1.000E-03	i	1.000E-03	e
HMX (Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine)	nc	2691-41-0					5.000E-02	i	5.000E-02	e
Indeno(1,2,3-cd)pyrene	ca	193-39-5	7.300E-01	n	3.100E-01	n				
Isophorone	ca/nc	78-59-1	9.500E-04	i	9.500E-04	e	2.000E-01	i	2.000E-01	e
2-Methylnaphthalene	nc	91-57-6					4.000E-03	i	4.000E-03	e

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Methyl parathion	nc	298-00-0					2.500E-04	i	2.000E-04	e
2-Methylphenol (o-Cresol)	nc	95-48-7					5.000E-02	i	3.725E-02	e
3-Methylphenol (m-Cresol)	nc	108-39-4					5.000E-02	i	3.725E-02	e
4-Methylphenol (p-Cresol)	nc	106-44-5					5.000E-03	h	3.725E-03	e
Monochloroacetic acid (Chloroacetic acid)	nc	79-11-8					2.000E-03	h	2.000E-03	e
N-Nitroso di-n-propylamine	ca	621-64-7	7.000E+00	i	1.474E+01	e				
N-Nitrosodimethylamine	ca	62-75-9	5.100E+01	i	4.900E+01	e				
N-Nitrosodiphenylamine	ca	86-30-6	4.900E-03	i	4.900E-03	e				
2-Nitroaniline	nc	88-74-4					3.000E-03	p	3.000E-05	p
Nitrobenzene	nc	98-95-3					5.000E-04	i	5.714E-04	e
4-Nitrophenol (p-Nitrophenol)	nc	100-02-7					8.000E-03	n	8.000E-03	e
Parathion	nc	56-38-2					6.000E-03	h	6.000E-03	e
Pentachlorobenzene	nc	608-93-5					8.000E-04	i	8.000E-04	e
Pentachlorophenol	ca/nc	87-86-5	1.200E-01	i	2.400E-01	e	3.000E-02	i	1.500E-02	e
Phenanthrene	nc	85-01-8					3.000E-02	s	1.500E-02	e
Phenol	nc	108-95-2					3.000E-01	i	3.000E-01	e
Propylene glycol	nc	57-55-6					5.000E-01	p	8.600E-04	p
Pyrene	nc	129-00-0					3.000E-02	i	1.500E-02	e
RDX (Hexahydro-1,3,5-trinitro-1,3,5-triazine)	ca/nc	121-82-4	1.100E-01	i	1.100E-01	e	3.000E-03	i	3.000E-03	e
2,3,4,6-Tetrachlorophenol	nc	58-90-2					3.000E-02	i	3.000E-02	e
Tetrahydrofuran	ca/nc	109-99-9	7.600E-03	n	6.800E-03	n	2.100E-01	n	8.600E-02	n
Trichloroacetic acid	nc	76-03-9					1.300E-02	H	1.300E-02	e
2,4,5-Trichlorophenol	nc	95-95-4					1.000E-01	i	1.000E-01	e
2,4,6-Trichlorophenol	ca	88-06-2	1.000E-02	i	1.085E-02	e	1.000E-04	n	1.000E-04	n
1,3,5-Trinitrobenzene	nc	99-35-4					3.000E-02	i	3.000E-02	e
Trinitrophenylmethylnitramine	nc	479-45-8					1.000E-03	h	1.000E-03	e
2,4,6-Trinitrotoluene	ca/nc	118-96-7	3.000E-02	i	3.000E-02	e	5.000E-04	i	5.000E-04	e
<b>PESTICIDES AND HERBICIDES</b>										
Ammonia	nc	7664-41-7					4.000E-01	a	2.857E-02	e
Alachlor	ca/nc	15972-60-8	8.000E-02	h	8.000E-02	e	1.000E-02	i	1.000E-02	e
Acrolein	nc	107-02-8					5.000E-04	i	5.714E-06	e
Aldicarb	nc	116-06-3					1.000E-03	i	1.000E-03	e
Aldicarb Sulfone	nc	1646-88-4					1.000E-03	i	1.000E-03	e
Aldicarb Sulfoxide		1646-87-3								
Atrazine	ca/nc	1912-24-9	2.200E-01	h	2.200E-01	e	3.500E-02	i	3.500E-02	e
Bis(2-chloro-1-methylethyl)ether	ca/nc	108-60-1	7.000E-02	h	3.500E-02	h	4.000E-02	i	4.000E-02	e
Carbofuran	nc	1563-66-2					5.000E-03	i	5.000E-03	e
Chlordane	ca	12789-03-6	3.500E-01	i	3.500E-01	e				

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Chlorobenzilate	ca/nc	510-15-6	2.700E-01	h	2.700E-01	h	2.000E-02	i	1.140E-02	e
Chlorpyrifos	nc	2921-88-2					3.000E-03	i	2.700E-03	e
Dalapon (2,2-dichloropropionic acid)(Sodium Salt)	nc	75-99-0					3.000E-02	i	3.000E-02	e
4,4' - DDD	ca	72-54-8	2.400E-01	i	3.000E-01	e				
4,4' - DDE	ca	72-55-9	3.400E-01	i	4.250E-01	e				
4,4' - DDT	ca/nc	50-29-3	3.400E-01	i	3.395E-01	e	5.000E-04	i	4.000E-04	e
Diallate	ca/nc	2303-16-4	6.100E-02	h	6.100E-02	e	5.000E-03	o	5.000E-03	e
2,4-Dichlorophenoxyacetic acid (2,4-D)	nc	94-75-7					1.000E-02	i	1.000E-02	e
Dieldrin	ca/nc	60-57-1	1.600E+01	i	1.610E+01	e	5.000E-05	i	5.000E-05	e
Dimethoate	nc	60-51-5					2.000E-04	i	2.000E-04	e
2,4-Dinitro-6-sec-butylphenol (Dinoseb)	nc	88-85-7					1.000E-03	i	1.000E-03	e
Diquat	nc	85-00-7					2.200E-03	i	2.200E-03	e
Disulfoton	nc	298-04-4					4.000E-05	i	3.756E-05	e
Endosulfan	nc	115-29-7					6.000E-03	i	4.890E-03	e
Endothall	nc	145-73-3					2.000E-02	i		
Endrin	nc	72-20-8					3.000E-04	i	3.000E-04	e
Glyphosate	nc	1071-83-6					1.000E-01	i		
HCH (alpha) (alpha - BHC)	ca	319-84-6	6.300E+00	i	6.300E+00	e				
HCH (beta) (beta - BHC)	ca	319-85-7	1.800E+00	i	1.855E+00	e				
HCH (gamma) Lindane (gamma - BHC)	ca	58-89-9	1.300E+00	h	1.308E+00	e				
Heptachlor	ca/nc	76-44-8	4.500E+00	i	4.550E+00	e	5.000E-04	i	4.000E-04	e
Heptachlor epoxide	ca/nc	1024-57-3	9.100E+00	i	9.100E+00	e	1.300E-05	i	5.200E-06	e
Kepone	ca/nc	143-50-0	8.000E+00	p	8.000E+00	e	2.000E-04	p	2.000E-04	e
Malathion	nc	121-75-5					2.000E-02	i	2.000E-02	e
Methoxychlor	nc	72-43-5					5.000E-03	i	4.500E-03	e
Oxamyl (Vydate)	nc	23135-22-0					2.500E-02	i	2.500E-02	e
PCBs (Polychlorinated Biphenyls)	ca/nc	1336-36-3	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1016	ca/nc	12674-11-2	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1221	ca/nc	11104-28-2	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1232	ca/nc	1141-16-5	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1242	ca/nc	53469-21-9	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1248	ca/nc	12672-29-6	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1254	ca/nc	11097-69-1	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
PCB - Arochlor 1260	ca/nc	11096-82-5	2.000E+00	i	3.500E-01	e	2.000E-05	i	2.000E-05	e
Phorate	nc	298-02-2					2.000E-04	h	2.000E-04	e
Picloram	nc	1918-02-1					7.000E-02	i	7.000E-02	e
Pronamide	nc	23950-58-5					7.500E-02	i	7.500E-02	e
Simazine	ca/nc	122-34-9	1.200E-01	h	1.200E-01	e	5.000E-03	i	5.000E-03	e

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Sulfotepp (Tetraethyldithiopyrophosphate)	nc	3689-24-5					5.000E-04	i	5.000E-04	e
2,3,7,8 TCDD (Dioxin)	ca	1746-01-6	1.500E+05	h	1.500E+05	h				
Toxaphene	ca/nc	8001-35-2	1.100E+00	i	1.120E+00	e	2.500E-04	o	1.575E-04	e
2,4,5 TP (silvex) (2-(2,4,5-Trichlorophenoxy) propionic acid)	nc	93-72-1					8.000E-03	i	8.000E-03	e
<b>INORGANICS</b>										
Aluminum	nc	7429-90-5					1.000E+00	n	1.400E-03	n
Antimony (and compounds)	nc	7440-36-0					4.000E-04	i	4.000E-06	e
Arsenic	ca/nc	7440-38-2	1.500E+00	i	1.505E+01	e	3.000E-04	i	2.850E-04	e
Barium (and compounds)	nc	7440-39-3					7.000E-02	i	1.429E-04	e
Beryllium (and compounds)	ca/nc	7440-41-7			8.400E+00	e	2.000E-03	i	5.714E-06	e
Bromate	ca/nc	15541-45-4	7.000E-01	i	7.000E-01	e	4.000E-03	i	4.000E-03	e
Cadmium (and compounds)	ca/nc	7440-43-9			6.300E+00	e	1.000E-03	i	5.700E-05	n
Chloramine (Monochloramine)	nc	10599-90-3					1.000E-01	i	1.000E-01	e
Chloride		7647-14-5								
Chlorine		7782-50-5								
Chlorine Dioxide		10049-04-4								
Chlorite		7758-19-2								
Chromium (III)	nc	16065-83-1					1.500E+00	i	1.950E-02	e
Chromium (VI)	ca/nc	18540-29-9			4.100E+01	h	3.000E-03	i	2.286E-06	e
Chromium (Total)	ca/nc	7440-47-3			4.100E+01	h	3.000E-03	i	2.286E-06	e
Cobalt	nc	7440-48-4					2.000E-02	n	5.000E-03	e
Copper (at tap)	nc	7440-50-8					4.000E-02	h		
Cyanide (hydrogen)	nc	74-90-8					2.000E-02	i	8.600E-04	i
Cyanide (free)	nc	57-12-5					2.000E-02	i	2.000E-02	e
Cyanide (Total)		143-33-9								
Fluoride	nc	7681-49-4					6.000E-02	i	5.820E-02	e
Iron	nc	7439-89-6					6.000E-01	n		
Lead	nc	7439-92-1	*E		*E		*E		*E	
Manganese	nc	7439-96-5					4.700E-02	i	1.429E-05	e
Mercury (and compounds) (Mercuric Chloride)	nc	7487-94-7					3.000E-04	i		
Mercury (elemental)	nc	7439-97-6							8.570E-05	i
Mercury (methyl)	nc	22967-92-6					1.000E-04	i		
Nickel	nc	7440-02-0					2.000E-02	i	1.000E-03	e
Nitrate	nc	14797-55-8					1.600E+00	i	1.600E+00	e
Nitrite	nc	14797-65-0					1.000E-01	i	1.000E-01	e
Perchlorate	nc	7601-90-3					7.000E-04	i	7.000E-04	e
Selenium	nc	7782-49-2					5.000E-03	i	4.850E-03	e
Silver	nc	7440-22-4					5.000E-03	i	2.000E-04	e

**TABLE 3-4  
TOXICOLOGICAL PROPERTIES**

CHEMICAL OF CONCERN	TYPE	CAS #	SF <sub>o</sub>		SF <sub>i</sub>		RfD <sub>o</sub>		RfD <sub>i</sub>	
			1/(mg/kg-day)		1/(mg/kg-day)		(mg/kg-day)		(mg/kg-day)	
Strontium	nc	7440-24-6					6.000E-01	i	6.000E-01	e
Sulfate		7757-82-6								
Thallium	nc	7440-28-0					7.000E-05	i	7.000E-05	e
Tin	nc	7440-31-5					6.000E-01	h	1.680E-02	e
Vanadium	nc	7440-62-2					7.000E-03	h	1.820E-04	e
Zinc	nc	7440-66-6					3.000E-01	i	7.500E-02	e

**KEY**

SF<sub>i</sub>: Inhalation Cancer Slope Factor

SF<sub>o</sub>: Oral Cancer Slope Factor

RfD<sub>i</sub>: Inhalation Reference Dose

RfD<sub>o</sub>: Oral Reference Dose

a: ATSDR

c: Cal EPA

e: Extrapolated

\*E: <http://www.epa.gov/oswer/riskassessment/tools.htm>

h: HEAST

H: USEPA's 2002 Edition of Drinking Water Standards and Health Advisories

i: IRIS

n: NCEA

o: USEPA's Office of Pesticide Programs Reference Dose Tracking Report

p: PPRTV

r: EPA R4 Recommendations

s: Surrogate



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# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

## **APPENDIX A**

### **ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS**

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**April 2008**

**APPENDIX A**  
**ESTIMATION OF REPRESENTATIVE**  
**SOIL AND GROUNDWATER CONCENTRATIONS**

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## **A.1 BACKGROUND**

Representative site concentrations are defined as representative when a sample is collected by a selection method that is both accurate and reproducible. The Preliminary Screening Level (PSL) evaluation of the ARBCA process involves the comparison of representative site concentrations to screening levels (see Table 2-2) for each potentially complete exposure pathway for each COPC. Additionally, the PSL evaluation requires the comparison of representative site concentrations to the soil screening levels protective of groundwater (see Table 2-2) as well as any potentially affected surface water body (see the Water Quality Criteria established in ADEM Admin Code R. 335-6-10) and any potentially affected sediments (see Section 3.3). The site-specific application of the ARBCA process for Risk Management-1 (RM-1) and Risk Management-2 (RM-2) involves the comparison of representative site concentrations. Representative site concentrations may be compared to the back-calculated target levels for each complete pathway identified in the site conceptual exposure model (SCEM) and each COPC or COC. When the ARBCA process is performed in the forward mode, representative concentrations are necessary to estimate the risk (individual excess lifetime cancer risk for carcinogenic effects or the hazard index for non-carcinogenic adverse health effects) for each complete pathway 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. Thus, the outcome of an ARBCA evaluation critically depends on the representative concentrations.

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 95<sup>th</sup> UCL about the true mean (see Section A.2.1.2), (iii) an arithmetic average, (iv) a volumetric average, or (v) an area-weighted average. Because of uncertainty associated with any estimate of exposure concentration, the maximum detected concentration and the upper confidence limit (i.e., the 95<sup>th</sup> UCL) about the arithmetic average may be used. The Department recommends the utilization of representative concentrations based on the maximum detected concentration for the PSL stage and use of the 95<sup>th</sup> UCL on the mean at the RM-1 and RM-2 stages for all media with the exception of groundwater. An appropriate amount of data must exist to accurately estimate the 95<sup>th</sup> UCL



(see Section A.2.1.2 for more information on this topic). Where not enough sampling data exists to use the 95<sup>th</sup> UCL on the mean and sampling has been deemed appropriate by the Department, a maximum detected concentration may be used. The maximum detected concentrations are always recommended for use when evaluating groundwater.

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 domain** (an area or volume over which receptors will have equal and random contact with site COPCs and/or COCs) and the respective pathway. Since there may be several complete pathways within an exposure domain, several representative concentrations, one (1) for each complete pathway 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.

*The ARBCA evaluation should initially compare the maximum media-specific concentrations relevant for each pathway with the PSVs (see Table 2-2). If the maximum concentrations do not exceed the target levels, it may not be necessary to further evaluate the site.*

## **A.2 ARBCA GENERAL CONSIDERATIONS FOR ESTIMATING REPRESENTATIVE CONCENTRATIONS**

A representative site concentration is defined as representative when a sample is taken by a selection method that is both accurate and reproducible. Representative concentrations should be determined for specific COPCs for a particular medium (surficial soil, subsurface soil, groundwater, surface water) that represents the concentration for a particular exposure pathway. The representative concentration is then compared to the Preliminary Screening Values (PSVs) to determine if an unacceptable risk is present for the receptor of concern. In the RM-1 and RM-2 stages, representative concentrations are used to calculate the cumulative risk within an exposure domain and to determine if an unacceptable risk is present for the 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 and the selection of the appropriate exposure domain for a particular pathway. Prior to performing the ARBCA evaluation where representative concentrations are compared to screening levels or target levels, the appropriate representative concentration should be selected for the exposure domain for each medium and

pathway of concern. Care should be utilized when defining the exposure domain. An exposure domain that is not defined properly can lead to non-representative concentrations.

## **A.2.1 Types of Recommended Representative Concentration Values**

### **A.2.1.1 Maximum Concentration**

The maximum concentration for each chemical is compared with its appropriate PSV and, in the case of naturally occurring chemicals or anthropogenic background sources (see Section 5.1), with its site-specific background concentration. If the maximum representative concentrations for all chemicals within an exposure domain are below their respective PSV (or background), the site is considered to meet the Department's human health risk goals (surface water and/or sediments may still need to be evaluated for a potential ecological impact). For sites with one (1) or more chemicals present with representative maximum concentrations greater than their respective PSV (or background, if applicable), remediation of those chemicals to concentrations at or below the PSV or background is sufficient to meet the Department's human health risk goals (surface water and/or sediments may still need to be evaluated for a potential ecological impact). When utilizing a representative 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. Sites with limited amounts of data will need to use the historical maximums provided that the data is considered representative by the Department. When more site data, such as groundwater monitoring data, is available, the use of a recent maximum value would be appropriate.

The historical maximum is the highest detection ever recorded in each medium for each COC. The historical maximum should be used for the PSL evaluation performed for a site to see if there is an exceedance for a particular pathway. 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.

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. 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 Comprehensive Investigation, it will be necessary to look at both these data sets to choose the appropriate representative data.

For groundwater, a historical maximum may not be appropriate. The recent maximum value should be considered the highest detection for each COPC during the past one (1) to two (2) years of data, or the past four (4) to eight (8) sampling events, whichever yields a representative data set. Recent maximum concentrations are determined for the onsite scenario and the offsite scenario.

#### **A.2.1.2 95% Upper Confidence Limit (UCL) Concentration**

Typically it is assumed that an individual will be exposed over time within an area of contamination, rather than to a contaminated area at one specific location. If the individual's contact with the contaminated area is random, the representation of the concentration to which he/she is exposed is the true mean concentration over that area. The true mean concentration over an area or volume can never be known with absolute certainty. Therefore, an accurate estimate of the true mean is required. This assumption provides the basis for using a sample mean chemical concentration as the starting point in calculating a statistic parameter which will serve as a representative site concentration at the either the RM-1 or RM-2 stage of the ARBCA process.

The ability to accurately determine the true mean concentration over an area or volume is dependent upon sampling locations and the number of samples. Since there is uncertainty as to whether the sample average of any given set of samples in fact represents the true mean over the area or volume of interest, the Department recommends the use of a 95% UCL estimate of the true mean. Specifically, in circumstances in which the use of a mean concentration is appropriate, the 95% UCL of the true mean should be used.

Each site consists of one (1) or more exposure domains. Exposure domains must be clearly delineated and justified based on current and future activity patterns. An exposure sample mean concentration must be calculated for each exposure domain.

A site can have one (1) or more exposure domains, as well as different exposure domains for different receptors. For example, a recreational park may have some areas with very little opportunity for receptors to come in contact with contaminated media (e.g., paved areas), whereas other areas (e.g., playgrounds, creeks) may provide a higher potential for receptors to be exposed to contaminated media. In these situations, areas expected to differ in their potential exposure should be evaluated separately.

Calculation of the 95% UCL should be based on sample data only. EPA's *Guidance for the Data Quality Objectives Process (QA/G-4)* provides guidance on how to select the correct statistical test to use for each specific data set. This guidance is available online at:

[http://epa.gov/quality/qa\\_docs.html#guidance](http://epa.gov/quality/qa_docs.html#guidance)

Additionally, EPA has made available software that can assist in the proper selection and calculation of an appropriate 95% UCL of the true mean. The software developed to support the calculation of UCLs is called *ProUCL*. The most current version of *ProUCL* may be downloaded from the following website:

<http://www.epa.gov/esd/tsc/software.htm>.

The selection of a statistical test (e.g.: UCL) is dependent upon the frequency distribution for each COC within an exposure domain. For example, if all COCs are normally distributed then either a student-t or a z-test can be used depending on how well the true standard deviation for each COC is known. However, in virtually all cases, COCs are never normally (or symmetrically) distributed in the environment. Therefore, assuming a normal distribution will most likely lead to decision errors.

Two (2) basic guidelines may be used in order to justify using the 95% UCL of the true mean.

1. The collection of 30-50 or more discrete samples per exposure domain. Once the appropriate number of discrete samples are collected, the data can then be exported into data quality assurance software such as the *ProUCL*. The software then assesses the frequency distribution and selects the appropriate statistical test for calculation of the 95% UCL of the true mean.
2. In those media that are amenable to the collection of multi-increment samples (i.e., soils, sediments) a minimum of 5 multi-increment samples each comprised of 30-100 increments may be used instead of the method as described in guideline #1. A sample mean and standard deviation can be calculated for the 5 data points for each COC.

Consequently, since the sample design is equivalent to collecting 150-500 discrete samples, the **Central Limit Theorem (CLT)** may be invoked. The CLT may be invoked when the distribution of an average tends to be normal, even when the distribution from which the average is computed is decidedly non-normal. As a result of the CLT, parametric statistics are then appropriate for use in the calculation of the 95% UCL of the true mean. The Department recognizes the use of the student's-t test in such cases.

If site concentrations of a COC vary substantially, a 95% UCL can sometimes exceed the highest concentration observed on site. In order to minimize the chance of this occurring, exposure domains should be carefully delineated and an appropriate number of samples should be collected. Non-detect samples within the exposure domain should be replaced by half the detection limits if detection limits are less than the appropriate PSV. The ARBCA evaluator should use the detection limit as the sample concentration if the detection limits are greater than the screening levels.

Concentration data from most sites reflect biased sampling, given that sampling focuses primarily on areas where contamination is suspected. Data sets with concentrated sampling in one or a few areas and sparse sampling in other areas may satisfy the need to characterize the nature and extent of contamination, but are not suitable for calculating a representative 95% UCL. Biased sampling where contaminated areas are over-represented likely overestimates the true average, but because it is conservative and health protective, this approach is acceptable to the Department. However, biased sampling in which contaminated areas are under-represented spatially is not acceptable.

### **A.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 exposure domain over which the representative concentration will be calculated. The exposure domain is the area or volume over which the receptor is or may be exposed to the contaminated media (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 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 locations, but the risks requiring evaluation would likely be the same since the same human receptor, the commercial worker, is present on both properties. Separate representative concentrations would be established for the onsite commercial worker and 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 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), and (2) place this estimated building footprint over the exposure domain that contains the highest representative concentrations that would be attributed to the indoor inhalation pathway. The defined area yielding the highest representative concentration is likely to be different for surficial soil, subsurface soil, and groundwater.

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.

### **A.2.3 Documentation of the Selection of the Representative Concentrations**

Detailed documentation of the calculation and selection of the representative concentrations should be included in the ARBCA evaluation report. 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.
- Soil and groundwater data tables should be included as an attachment in the report. All data (current and historical) should be listed and the data utilized in the determination of the representative concentration should be clearly noted.
- Tables detailing the representative concentration for each exposure pathway and medium.

### **A.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:

#### **A.3.1 Surficial Soil**

The ARBCA process requires the evaluation of several pathways of exposure associated with surficial soil. These are (i) the ingestion of chemicals in groundwater due to leaching of residual chemicals in the surficial soil, and (ii) the 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 typical that the representative concentration within each exposure domain for surficial soil will 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.

##### **A.3.1.1 Representative Surficial Soil Concentrations for Protection of Groundwater or Surface Water**

The Domenico (1990) model is used to estimate soil concentrations protective of groundwater or surface water resources. In some cases, the Domenico Model (as presented within Appendix B) may not be suitable for use at a site. The ARBCA user should exercise caution to ensure that the models being applied are appropriate for the existing site conditions. If an alternate model is planned to be used at a site, it will generally be necessary to submit an

RM-1 or RM-2 work plan. Certain programs within ADEM may not require a work plan due to the specificity of the guidance used within the program. The user should contact ADEM to establish if a work plan is required. Figure D-1 illustrates the relationship between soil leaching to groundwater and the migration of groundwater to a point of exposure. The Domenico 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.

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 define 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 within this source area.

The surficial soil source representative concentrations should be compared with the subsurface soil source representative concentrations. The higher values should be used for the groundwater resource protection and stream protection evaluations.

#### **A.3.1.2 Representative Surficial Soil Concentrations for Protection of Dermal Contact, Ingestion, and Inhalation of Vapors and Particulates**

For this pathway, the representative surficial soil concentration should be found within each exposure domain. Under the current conditions scenario, the unpaved exposure domains are the only ones that need to be considered. For potential future exposures, assuming the pavement is removed and exposure to surficial soil is possible, all exposure domains throughout the site may be considered.

#### **A.3.2 Subsurface Soil**

The ARBCA process includes three pathways of exposure associated with subsurface soil. These three pathways 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 from subsurface soil, and (iii) outdoor inhalation of vapor emissions from subsurface soil (note that outdoor inhalation rarely needs to be evaluated). Therefore, three different subsurface soil representative concentrations may be required.

When evaluating the potential future exposures, it may also be necessary to evaluate the subsurface soils for direct contact exposure pathways as discussed in Section A.3.1. If the



ARBCA evaluator wishes not to evaluate the direct contact exposure pathways in subsurface soils, LUCs must be in place to ensure that those pathways remain incomplete.

#### **A.3.2.1 Representative Subsurface Soil Concentrations for Protection of Groundwater or Surface Water**

It is the responsibility of the facility to utilize an appropriate model or combination thereof to estimate soil concentrations protective of groundwater or surface water resources. Soil concentrations protective of groundwater can be determined through the use of a fate and transport model. This guidance contains the equations needed for the Domenico Model which is based on laminar flow in a homogeneous geologic environment. Figure D-1 illustrates the relationship between soil leaching to groundwater and the migration of groundwater to a point of exposure. The Domenico model assumes that the leachate from the subsurface soil source travels vertically downward to the water table without any lateral or transverse spreading. Thus, the horizontal dimensions of the subsurface soil source and the groundwater source are assumed to be identical. For sites in unique geologic environments not suited for the Domenico Model, another, more appropriate, model or modeling pack should be applied. Additional sampling (at a minimum) or corrective action may be required if the concentrations exceed the groundwater ingestion values at the POE well or values protective of the POE at the SW.

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 define 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 within this source area.

The representative subsurface soil concentration for this pathway should be based on the concentrations measured within the source area. The subsurface soil source representative concentrations should be compared with the surficial soil source representative concentrations. The higher values should be used in the groundwater resource protection and surface water protection evaluations.

#### **A.3.2.2 Representative Subsurface Soil Concentrations for 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 that are filled with vadose zone type soil. 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. If data are not available within the domain, the proper amount of data should be collected.

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

If determined by the Department, it may be necessary to evaluate the outdoor inhalation of vapors pathway. Subsurface soil concentrations protective of outdoor inhalation are estimated based on the model located on page B-6 (Outdoor Inhalation of Vapor Emissions). 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 representative soil concentration data available within each of these two domains. If data are not available within the domain, the proper amount of data should be collected. If the domains of the current and future outdoor inhalation areas are different, two different representative

concentrations, one for current conditions for each COC and one for future conditions for each COC, may be necessary.

Where subsurface soil contamination is 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 representative subsurface soil concentrations for a current scenario may be different from a future scenario, the higher of the two values should be selected as the representative concentration for the outdoor inhalation pathway for subsurface soil.

### **A.3.3 Groundwater**

The ARBCA process requires the evaluation of five (5) pathways 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 (if determined necessary by the Department), and (v) protection of surface water. Thus, five (5) or more different groundwater representative concentrations may be required.

#### **A.3.3.1 Representative Groundwater Concentrations 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. At many sites, the Department may ask that the POE well be located at the site’s property boundary. Therefore, it is not always necessary that a physical water supply well exist to justify the location of the POE. Two sets of data need to be evaluated for this pathway. Data from the POE well(s) allows for evaluating the current exposure. Data from other monitoring wells (e.g. source wells or **sentry wells (SW)**) may be used for an evaluation of a potential future impact to those existing well(s).

A representative concentration from the POE well is compared against the established MCLs. In the absence of an MCL, the user has the following options:

1. Utilize a modified (see Section 3.7.1) USEPA R9 PRG tap water value.
2. Calculate a *Direct Ingestion of Groundwater* value in accordance with the equation located on page B-1.
3. Utilize Table 2-2 of this guidance (note that the screening values used are up to the date of this publication and the user should confirm and use the most recent values.)

If neither an MCL, nor a PRG, or the necessary information needed to calculate a *Direct Ingestion of Groundwater* value as contained in Tables 3-3 and 3-4 of this guidance exists for a chemical, an approved lifetime HA value may be utilized for comparison with the concentrations at the POE.

After identifying the available groundwater monitoring data from the site, a source well(s) at the source area, and at least one (1) SW located between the source area and the POE well would need to be evaluated. Representative concentrations in those wells should be determined through an evaluation of the last 1-3 years of data.

Since this is a direct exposure pathway, care should be taken in ensuring protection of the water supply well. The presence of an onsite well may 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.

#### **A.3.3.2 Representative Groundwater Concentrations for Groundwater Resource Protection**

The Groundwater Resource Protection pathway is required for each ARBCA evaluation. This evaluation is performed to determine acceptable soil and groundwater concentrations protective of a current or future offsite drinking water well. A representative concentration from the POE well is compared against the established MCLs. 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 or at the site's property boundary. In the absence of an MCL, the user has the following options:

1. Utilize a modified (see Section 3.7.1) USEPA R9 PRG tap water value.
2. Calculate a *Direct Ingestion of Groundwater* value in accordance with the equation located on page B-1.

3. Utilize Table 2-2 of this guidance (note that the screening values used are up to the date of this publication and the user should apply the most recent values.)

If neither an MCL, nor a PRG, or the necessary information needed to calculate a *Direct Ingestion of Groundwater* value as shown in Tables 3-3 and 3-4 of this guidance exists for a chemical, an approved lifetime HA value may be utilized to compare against the representative concentrations at the POE.

An important aspect of the groundwater resource protection evaluation is the selection of existing monitoring wells as SWs. In addition to determining the POE for the groundwater resource protection evaluation, at least two (2) SWs must be selected and target concentrations must be calculated for these locations. This includes a sentry monitoring well(s) located at or very near the soil source (a source well), and at least one (1) sentry monitoring well located between the source well and the POE. For most sites, more than two (2) SWs located between the source and the POE should be included in the evaluation to allow for varying distances to the POE, fluctuating or unclear groundwater flow directions, and varying hydrogeologic conditions. Therefore, representative concentrations for several SWs located at different distances from the POE well may need to be established.

For the evaluation of this pathway, the representative concentration should be calculated based on the measured SW concentrations. The groundwater resource protection evaluation is a “well to well” comparison. The following discussion applies to both the groundwater source well and the SWs:

- For SWs with fluctuating concentrations, the representative concentration is estimated as maximum representative concentration of the last three (3) years of semi-annual monitoring events or last 1 - 2 years of quarterly monitoring events. Non-detect values should not be represented as zero but should be replaced by half the detection limits if detection limits are less than the appropriate PSV. The ARBCA evaluator should use the detection limit as the sample concentration if the detection limits are greater than the screening levels.
- For SWs with a clear decreasing trend, the representative concentration is estimated as the maximum concentration within the last four (4) sampling events (either semi-annual or quarterly monitoring).
- For SWs with a clear increasing trend, the representative concentration is estimated as the maximum concentration within the last four (4) sampling events (either semi-annual or quarterly monitoring). Note that for wells with increasing concentration trends, continued monitoring, at a minimum, will be required until the trend stabilizes.

- The intent of using the last four (4) sampling events is to ensure that the recent maximum concentration will be used when evaluating the groundwater resource.

Documentation of the well data utilized in determining the representative concentrations should be included in 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 ARBCA evaluation.

#### **A.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 (see Appendix B) 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 (2) different representative concentrations, one (1) for current conditions and one (1) 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 representative groundwater concentration within each footprint must be estimated. Both the current and future locations of buildings should be considered. Therefore, several different representative concentrations may have to be estimated.

Since the representative groundwater concentration for a current scenario may be different from a future scenario, the higher of the two (2) values should be selected as the representative concentration for the indoor inhalation pathway for groundwater.

#### **A.3.3.4 Representative Groundwater Concentrations for Protection of Outdoor Inhalation**

If determined by the Department, it may be necessary to evaluate the outdoor inhalation of vapors pathway. 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 A.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 representative groundwater concentration for a current scenario may be different from a future scenario, the higher of the two (2) values should be selected as the representative concentration for the outdoor inhalation pathway for groundwater.

#### **A.3.3.5 Representative Groundwater Concentrations 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. The surface water body is the “point of exposure”. Target levels for the stream must be calculated. The target surface water concentrations should be based on determinations developed by the ADEM Water Division in accordance with ADEM Admin. Code 335-6-10 (ADEM, 2001b). Target levels should be calculated based on the “Consumption of Fish/Water” pathway. Sentry monitoring well(s) for the source and between the source and the surface water body must be established. The source well is located in or near the soil source area. One (1) or more SWs 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 A.3.3.2.

### **A.4 GENERAL CONSIDERATIONS FOR SELECTION OF APPROPRIATE SITE DATA**

A representative site concentration is defined as representative when a sample is collected by a selection method that is both accurate and reproducible. The estimation of the representative

concentrations requires considerable professional judgement. The following should be considered prior to an ARBCA evaluation.

#### **A.4.1 Surficial and Subsurface Soil**

The following considerations are necessary to evaluate soils:

- Evaluate whether a representative data set has been collected within each exposure domain (see Section A.2.1). A representative data set may be necessary for both surficial and subsurface soils.
- If the data are “old” (> 4 years old) and the concentrations exceed the PSVs, 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.
- There are several pathways of exposure associated with soils and each pathway should be evaluated. The pathways are (i) the ingestion of chemicals in groundwater due to the leaching of chemicals in the soil, (ii) the ingestion of soils, (iii) the inhalation of vapors, (iv) the inhalation of soil particulates, and (v) dermal contact with soils.
- Non-detect samples within the exposure domain should be replaced by half the detection limits if detection limits are less than the appropriate PSV. The ARBCA evaluator should use the detection limit as the sample concentration if the detection limits are greater than the screening levels.

#### **A.4.2 Groundwater**

The following considerations are necessary to evaluate groundwater:

- Evaluate whether a representative data set has been collected within each exposure domain (see Section A.2.1).
- Trends should be determined for all groundwater monitoring wells utilizing consecutive quarterly sampling data. The past one (1) to two (2) years of quarterly data or the most recent four (4) to eight (8) sampling events should be utilized to determine if the well concentrations are increasing, decreasing or stable.
- A historical maximum concentration may not be appropriate to use when evaluating a representative groundwater concentration. The recent maximum value should be



considered the highest detection for each COPC during the past one (1) to two (2) years of data, or the past four (4) to eight (8) sampling events, whichever yields a representative data set.

- There are several pathways of exposure associated with groundwater and each pathway should be evaluated. The pathways are (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 (if determined necessary by the Department), and (v) the protection of surface water.
- Non-detect samples should be replaced by half the detection limits if detection limits are less than the appropriate PSV. The ARBCA evaluator should use the detection limit as the sample concentration if the detection limits are greater than the screening levels.
- For the current onsite and offsite ingestion of groundwater pathway, MCLs or equivalent concentrations have to be met at the POE well. At many sites, the Department may ask that the POE be located at the site's property boundary. Therefore, it is not always necessary that a physical water supply well exist to justify the location of the POE.
- For a well which contained free product during a sampling event, the concentration representative of that sampling event would be the effective solubility (see definition below) of the chemical or the highest measured concentration of the chemical at that site, whichever is higher. Note that wells currently containing free product will be required to undergo corrective actions to remove the product. The effective solubility is defined as the product of the mole fraction and the solubility of the chemical. More information describing the calculation of the effective solubility of a chemical as well as an effective solubility calculator may be found online at:

<http://www.epa.gov/athens/learn2model/part-two/onsite/es.htm>



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# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

## **APPENDIX B**

### **MODELS/EQUATIONS FOR ESTIMATING RISK- BASED TARGET LEVELS**

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**April 2008**

## DIRECT INGESTION OF GROUNDWATER

(USE FOR THE DEVELOPMENT OF TARGET LEVELS 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<sub>2</sub>O]
- $TR$  = 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-day)]<sup>-1</sup>

**DIRECT INGESTION OF GROUNDWATER**  
**(TO DETERMINE RISK LEVELS FOR COCs IN GROUNDWATER)**

Carcinogenic effects

$$R = \frac{C \times IRW \times ED \times EF \times SF_o}{BW \times AT \times 365 \text{ days/yr}}$$

Non-carcinogenic effects

$$HQ = \frac{C \times IRW \times ED \times EF}{BW \times AT \times 365 \text{ days/yr} \times RfD_o}$$

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

where:

- C* = Representative groundwater concentration [mg/L-H<sub>2</sub>O]
- R* = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
- HQ* = 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<sub>o</sub>* = The chemical-specific oral reference dose [mg/(kg-day)]
- SF<sub>o</sub>* = The chemical-specific oral cancer slope or potency factor [mg/(kg-day)]<sup>-1</sup>

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

### Carcinogenic effects

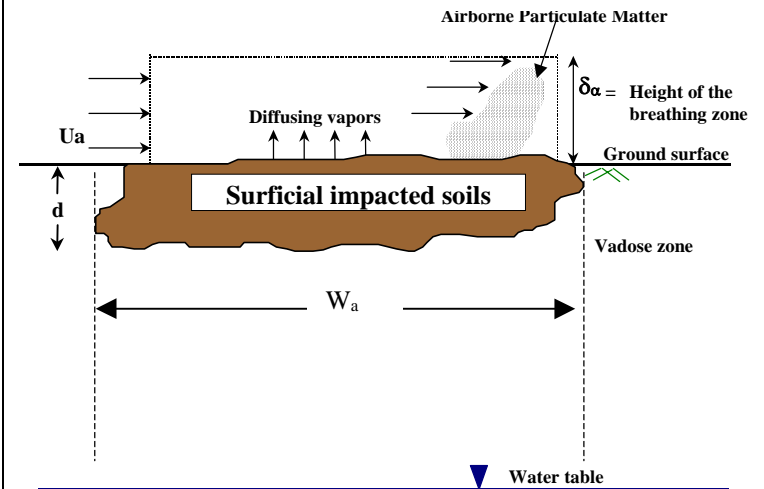
$$RBTL_{SS} = \frac{TR \times BW \times AT_c \times 365 \text{ days/yr}}{EF \times ED \times [(SF_o \times 10^{-6} \times (IRS \times RAF_o + SA \times M \times RAF_d)) + (SF_i \times IR_{ao} \times (VF_{ss} + VF_p))]}$$

### Non-carcinogenic effects

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

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]
- $AT_c$  = Averaging time for carcinogens [years]
- $AT_{nc}$  = 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<sup>2</sup>/day]
- $M$  = Soil to skin adherence factor [mg/cm<sup>2</sup>]
- $RAF_d$  = Dermal relative absorption factor [-]
- $IR_{ao}$  = Outdoor inhalation rate [m<sup>3</sup>/day] =  $IR_{ao}(\text{m}^3/\text{hr}) \times ET_{out}(\text{hr}/\text{day}) = \text{m}^3/\text{day}$
- $SF_o$  = Oral cancer slope factor [(mg/kg-day)<sup>-1</sup>]
- $SF_i$  = Inhalation cancer slope factor [(mg/kg-day)<sup>-1</sup>]
- $RfD_o$  = 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<sup>3</sup>-air)/(mg/kg-soil)]
- $VF_{ss}$  = Volatilization factor from surficial soil [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]



Source: adapted from ASTM E1739-95

**INGESTION OF CHEMICALS IN SURFICIAL SOIL**Carcinogenic effects

$$R = \frac{C \times EF \times ED \times SF_o \times 10^{-6} \text{ kg / mg} \times IRS \times RAF_o}{BW \times AT_c \times 365 \text{ days / yr}}$$

Non-carcinogenic effects

$$HQ = \frac{C \times EF \times ED \times 10^{-6} \text{ kg / mg} \times IRS \times RAF_o}{BW \times AT_{nc} \times 365 \text{ days / yr} \times RfD_o}$$

where:

- C* = Representative soil concentration [mg/kg]  
*R* = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]  
*HQ* = Hazard quotient for individual constituents [-]  
*BW* = Body weight [kg]  
*AT<sub>c</sub>* = Averaging time for carcinogens [years]  
*AT<sub>nc</sub>* = Averaging time for non-carcinogens [years]  
*ED* = Exposure duration [years]  
*EF* = Exposure frequency [days/year]  
*IRS* = Soil ingestion rate [mg/day]  
*RAF<sub>o</sub>* = Oral relative absorption factor [-]  
*SA* = Skin surface area [cm<sup>2</sup>/day]  
*M* = Soil to skin adherence factor [mg/cm<sup>2</sup>]  
*RAF<sub>d</sub>* = Dermal relative absorption factor [-]  
*IR<sub>ao</sub>* = Outdoor inhalation rate [m<sup>3</sup>/day] = IR<sub>ao</sub>(m<sup>3</sup>/hr) \* ET<sub>out</sub>(hr/day) = m<sup>3</sup>/day  
*SF<sub>o</sub>* = Oral cancer slope factor [(mg/kg-day)<sup>-1</sup>]  
*SF<sub>i</sub>* = Inhalation cancer slope factor [(mg/kg-day)<sup>-1</sup>]  
*RfD<sub>o</sub>* = The chemical-specific oral reference dose [(mg/kg-day)]  
*RfD<sub>i</sub>* = The chemical-specific inhalation reference dose [(mg/kg-day)]  
*VF<sub>p</sub>* = Volatilization factor of particulates [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]  
*VF<sub>ss</sub>* = Volatilization factor from surficial soil [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]

Source: RAGS, 1989, volume 1, Part A, Exhibit 6-14, page 6-40

**INHALATION OF VAPORS AND PARTICULATES IN SURFICIAL SOIL**Carcinogenic effects

$$R = \frac{C \times EF \times ED \times IR_{ao} \times SF_i \times (VF_{ss} + VF_p)}{BW \times AT_c \times 365 \text{ days / yr}}$$

Non-carcinogenic effects

$$HQ = \frac{C \times EF \times ED \times IR_{ao} \times (VF_{ss} + VF_p)}{BW \times AT_{nc} \times 365 \text{ days / yr} \times RfD_i}$$

Source: RAGS, 1989, Volume 1, Part A, Exhibit 6-16, page 6-44  
&  
ASTM E1739-95, 1995, pages 23 and 24

**DERMAL CONTACT OF CHEMICALS IN SURFICIAL SOIL**Carcinogenic effects

$$R = \frac{C \times EF \times ED \times SA \times SF_o \times 10^{-6} \text{ kg / mg} \times M \times RAF_d}{BW \times AT_c \times 365 \text{ days / yr}}$$

Non-carcinogenic effects

$$HQ = \frac{C \times EF \times ED \times SA \times M \times RAF_d \times 10^{-6} \text{ kg / mg}}{BW \times AT_{nc} \times 365 \text{ days / yr} \times RfD_o}$$

Source: RAGS, 1989, Volume 1, Part A, Exhibit 6-15, page 6-41 and 6-42

## 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 [ $\text{mg}/\text{m}^3$ ]
- $TR$  = 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 [ $\text{m}^3/\text{day}$ ] =  $IR_{ai}(\text{m}^3/\text{hr}) * ET_{in}(\text{hr}/\text{day}) = \text{m}^3/\text{day}$
- $ET_{in}$  = Exposure time for indoor inhalation [hr/day]
- $ED$  = Exposure duration [years]
- $EF$  = Exposure frequency [days/year]
- $RfD_i$  = The chemical-specific inhalation reference dose [ $\text{mg}/(\text{kg}\text{-day})$ ]
- $SF_i$  = The chemical-specific inhalation cancer slope or potency factor [ $\text{mg}/(\text{kg}\text{-day})$ ]<sup>-1</sup>

## 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 [ $\text{mg}/\text{m}^3$ ]
- $TR$  = 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 [ $\text{m}^3/\text{day}$ ] =  $IR_{ao}(\text{m}^3/\text{hr}) * ET_{out}(\text{hr}/\text{day}) = \text{m}^3/\text{day}$
- $ET_{out}$  = Exposure time for outdoor inhalation [hr/day]
- $ED$  = Exposure duration [years]
- $EF$  = Exposure frequency [days/year]
- $RfD_i$  = The chemical-specific inhalation reference dose [ $\text{mg}/(\text{kg}\text{-day})$ ]
- $SF_i$  = The chemical-specific inhalation cancer slope or potency factor [ $\text{mg}/(\text{kg}\text{-day})$ ]<sup>-1</sup>

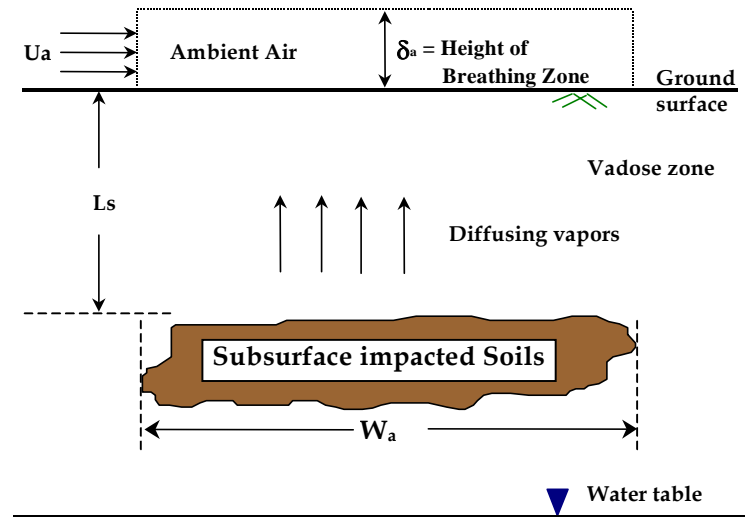
## SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

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

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

Source: ASTM E1739-95



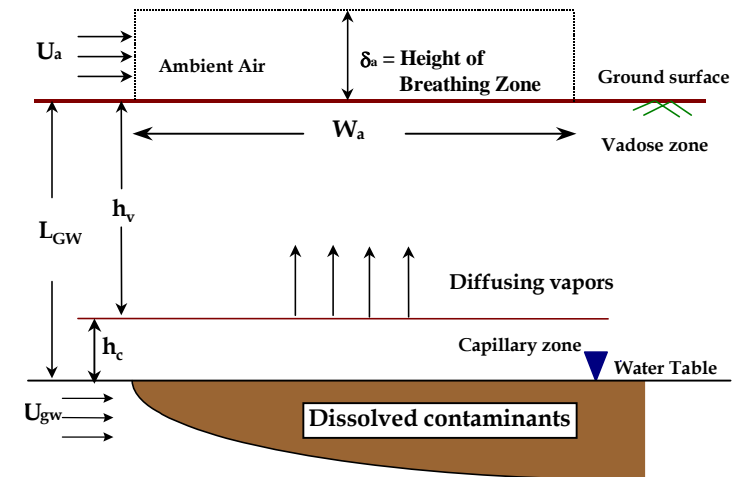
## GROUNDWATER CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

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

where:

- $RBTL_{wo}$  = Risk-based target level for outdoor inhalation of vapors from groundwater [ $\text{mg}/\text{l}\text{-H}_2\text{O}$ ]
- $RBTL_{ao}$  = Risk-based target level for outdoor inhalation of air [ $\text{mg}/\text{m}^3$ -air]
- $VF_{wamb}$  = Volatilization factor from groundwater to outdoor (ambient) air [ $(\text{mg}/\text{m}^3\text{-air})/(\text{mg}/\text{l}\text{-H}_2\text{O})$ ]

Source: ASTM E1739-95





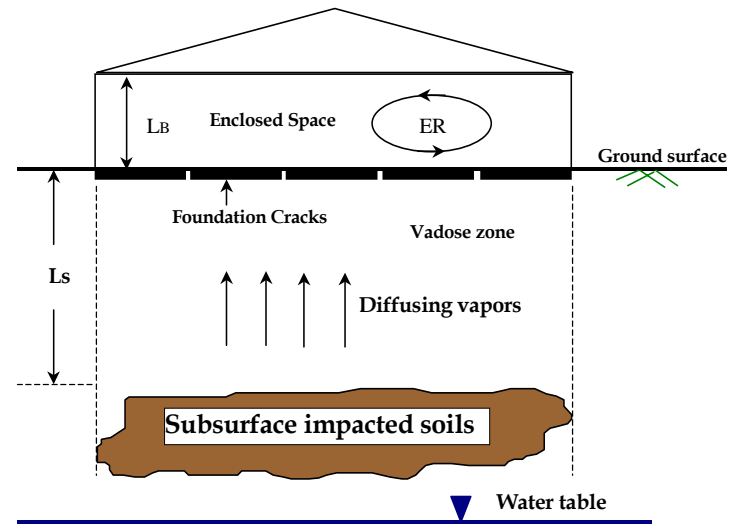
## SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

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

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

Source: ASTM E1739-95



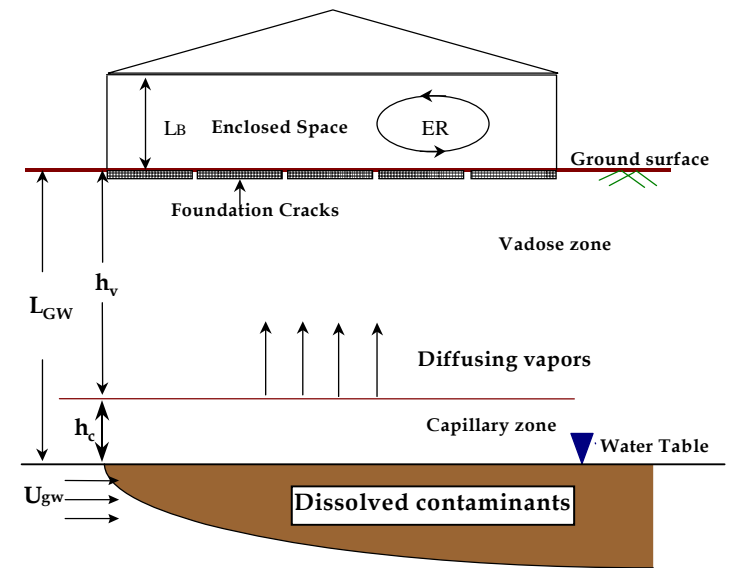
## GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

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

where:

- $RBTL_{wi}$  = Risk-based target level for indoor inhalation of vapors from groundwater [ $\text{mg}/\text{l-H}_2\text{O}$ ]
- $RBTL_{ai}$  = Risk-based target level for indoor inhalation of air ( $\text{mg}/\text{m}^3$ -air)
- $VF_{wesp}$  = Volatilization factor from groundwater to indoor (enclosed space) air [ $(\text{mg}/\text{m}^3\text{-air})/(\text{mg}/\text{l-H}_2\text{O})$ ]

Source: ASTM E1739-95



## VOLATILIZATION FACTORS

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

$VF_{wamb}$  : Volatilization factor from groundwater to outdoor (ambient) air [(mg/m<sup>3</sup>-air)/(mg/l-H<sub>2</sub>O)]

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

where:

- $H$  = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]
- $\rho_s$  = Dry soil bulk density [g-soil/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]
- $K_s$  =  $f_{oc} \times K_{oc}$   
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm<sup>3</sup>-H<sub>2</sub>O/g-soil]
- $\theta_{as}$  = Volumetric air content in vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $W_a$  = Length of soil source area parallel to wind direction [cm]
- $U_a$  = Wind speed at  $\delta_a$  above ground surface [cm/s]
- $\delta_a$  = 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<sup>2</sup>/s]
- $10^3$  = Conversion factor [(cm<sup>3</sup>-kg)/(m<sup>3</sup>-g)]

Source: ASTM E1739-95

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

where:

- $H$  = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]
- $U_a$  = Wind speed at  $\delta_a$  above ground surface [cm/s]
- $\delta_a$  = 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<sup>2</sup>/s]
- $10^3$  = Conversion factor [l/m<sup>3</sup>]

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

Source: ASTM E1739-95

$VF_{seep}$  : Volatilization factor from subsurface soil to indoor (enclosed space) air [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]

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

where:

- $H$  = Chemical specific Henry's Law constant [(l-H<sub>2</sub>O)/(l-air)]
- $\rho_s$  = Dry soil bulk density [g-soil/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]
- $K_s$  =  $f_{oc} \times K_{oc}$   
= Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm<sup>3</sup>-H<sub>2</sub>O/g-soil]
- $\theta_{as}$  = Volumetric air content in vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-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<sup>2</sup>/s]
- $D_{crack}^{eff}$  = Effective diffusion coefficient through foundation cracks [cm<sup>2</sup>/s]
- $\eta$  = Area fraction of cracks in foundation and/or walls [cm<sup>2</sup>-cracks/ cm<sup>2</sup>-total area]
- $10^3$  = Conversion factor [(cm<sup>3</sup>-kg)/(m<sup>3</sup>-g)]

Source: ASTM E1739-95

$VF_{wesp}$  : Volatilization factor from groundwater to indoor (enclosed space) air  
 [(mg/m<sup>3</sup>-air)/(mg/l-H<sub>2</sub>O)]

$VF_p$  : Delivery of particulate chemicals from soil to air  
 [(mg/m<sup>3</sup>-air)/(mg/kg-soil)]

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

where:

- $H$  = Chemical specific Henry's Law constant [(l-H<sub>2</sub>O)/(l-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<sup>2</sup>/s]
- $D_{crack}^{eff}$  = Effective diffusion coefficient through foundation cracks [cm<sup>2</sup>/s]
- $\eta$  = Area fraction of cracks in foundation and/or walls [cm<sup>2</sup>-cracks/ cm<sup>2</sup>-total area]
- $10^3$  = Conversion factor [l/m<sup>3</sup>]

Source: ASTM E1739-95

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

where:

- $P_e$  = Particulate emission rate [g-soil/cm<sup>2</sup>-sec]
- $W_a$  = Length of soil source area parallel to wind direction [cm]
- $U_a$  = Wind speed at  $\delta_a$  above ground surface [cm/s]
- $\delta_a$  = Breathing zone height [cm]
- $10^3$  = Conversion factor [(cm<sup>3</sup>-kg)/(m<sup>3</sup>-g)]

Source: ASTM E1739-95

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

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

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

where:

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

Source: ASTM E1739-95

## EFFECTIVE DIFFUSION COEFFICIENTS

$D_s^{eff}$  : effective diffusion coefficient in soil based on vapor-phase concentration [cm<sup>2</sup>/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<sup>2</sup>/s]
- $D^w$  = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]
- $\theta_{as}$  = Volumetric air content in vadose zone [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $\theta_{ws}$  = Volumetric water content in vadose zone [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]
- $\theta_T$  = Total soil porosity in the impacted zone [cm<sup>3</sup>/cm<sup>3</sup>-soil]
- $H$  = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]

$D_{ws}^{eff}$  : effective diffusion coefficient between groundwater and surface soil [cm<sup>2</sup>/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<sup>2</sup>/s]
- $D_s^{eff}$  = Effective diffusion coefficient in soil based on vapor-phase concentration [cm<sup>2</sup>/s]
- $L_{GW}$  = Depth to groundwater ( $h_{cap} + h_v$ ) [cm]

$D_{cap}^{eff}$  : effective diffusion coefficient for the capillary fringe [cm<sup>2</sup>/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<sup>2</sup>/s]
- $D^w$  = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]
- $\theta_{acap}$  = Volumetric air content in capillary fringe soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]
- $\theta_{wcap}$  = Volumetric water content in capillary fringe soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]
- $\theta_T$  = Total soil porosity [cm<sup>3</sup>/cm<sup>3</sup>-soil]
- $H$  = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]

$D_{crack}^{eff}$  : effective diffusion coeff. through foundation cracks [cm<sup>2</sup>/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<sup>2</sup>/s]
- $D^w$  = Chemical-specific diffusion coefficient in water [cm<sup>2</sup>/s]
- $\theta_{acrack}$  = Volumetric air content in foundation/wall cracks [cm<sup>3</sup>-air/cm<sup>3</sup>-total volume]
- $\theta_{wcrack}$  = Volumetric water content in foundation/wall cracks [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-total volume]
- $\theta_T$  = Total soil porosity [cm<sup>3</sup>/cm<sup>3</sup>-soil]
- $H$  = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]

Source: ASTM E1739-95

## SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER

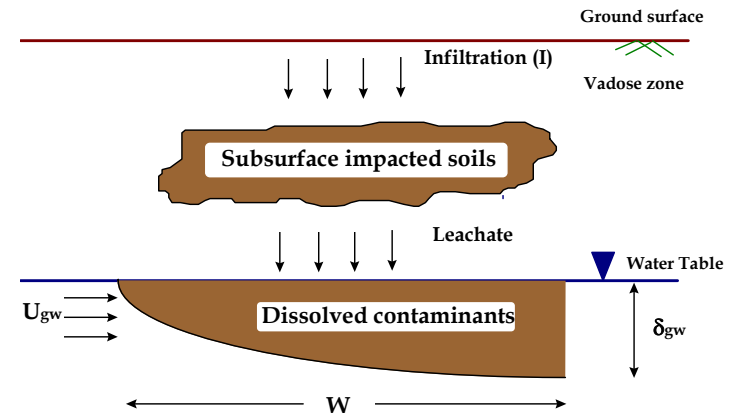
$$RBTL_{SL} = \frac{RBTL_w}{LF_{SW}}$$

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<sub>2</sub>O]

$LF_{SW}$  = Leaching Factor (from subsurface soil to groundwater) [(mg/L-H<sub>2</sub>O)/(mg/kg-soil)]



Source: ASTM E1739-95

## DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

At the centerline, for steady-state, the DAF without decay can be obtained by setting  $y = 0$ ,  $z = 0$ ,  $x \ll vt$ , and  $\lambda = 0$  as:

$$\frac{C(x_{poe})}{C_o} = \text{erf} \left[ \frac{Y}{4 \sqrt{\alpha_y x_{poe}}} \right] \times \text{erf} \left[ \frac{\delta_{gw}}{2 \sqrt{\alpha_z x_{poe}}} \right] \quad (1)$$

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 (after a long time) the DAF can be obtained by setting  $y = 0$ ,  $z = 0$ , and  $x \ll vt$  as:

$$\frac{C(x_{poe})}{C_o} = \exp \left[ \frac{x_{poe}}{2 \alpha_x} \left[ 1 - \sqrt{1 + \frac{4 \lambda \alpha_x}{v}} \right] \right] \times \text{erf} \left[ \frac{Y}{4 \sqrt{\alpha_y x_{poe}}} \right] \times \text{erf} \left[ \frac{\delta_{gw}}{2 \sqrt{\alpha_z x_{poe}}} \right] \quad (2)$$

Equation (2) is only applicable to petroleum hydrocarbons. At the centerline, for steady-state, the DAF with decay can be calculated using Equation (2). In Equation (2), the retarded seepage velocity ( $v$ ) is calculated as:

$$v = (K i) / (R_s \theta_s)$$

where:

- $K$  = Hydraulic conductivity [cm/year]
- $i$  = Hydraulic gradient [--]
- $\theta_s$  = Total porosity in the saturated zone [cm<sup>3</sup>/cm<sup>3</sup>-soil]
- $R_s$  = Retardation factor in the saturated zone [--]

- $DAF$  =  $C_o/C(x)$
- $C$  = dissolved-phase concentration [mg/l]
- $C_o$  = dissolved-phase concentration at the source (at  $x=y$ ,  $0 \leq z \leq \delta_{gw}$ ) [mg/l]
- $\text{erf}$  = Error function
- $\exp [ ]$  =  $e [ ]$
- $v$  = seepage velocity [cm/year]
- $\lambda$  = first order decay rate [1/year]
- $\alpha_x$  = longitudinal dispersivity [cm] =  $x_{poe}/10$
- $\alpha_y$  = lateral dispersivity [cm] =  $x_{poe}/30$
- $\alpha_z$  = vertical dispersivity [cm] =  $x_{poe}/200$
- $x, y, z$  = spatial coordinates [cm]
- $t$  = time [year]
- $x_{poe}$  = distance along the centerline from the downgradient edge of dissolved-plume source zone or source well [cm]
- $Y$  = width of soil source perpendicular to the groundwater flow direction [cm]
- $\delta_{gw}$  = groundwater mixing zone thickness [cm]

Source: Domenico, P.A. and F.W. Schwartz, 1990, Physical and Chemical Hydrogeology. John Wiley and Sons, NY, 824 p. (Eqn. 17.21)



<p><b><math>LF_{SW}</math></b>: Leaching Factor from subsurface soil to groundwater [(mg/L-H<sub>2</sub>O)/(mg/kg-soil)]</p>	<p><b><math>C_s^{SAT}</math></b>: Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]</p>
$LF_{SW} = \frac{\rho_s}{[\theta_{ws} + K_s \rho_s + H \times \theta_{as}] \times \left( 1 + \frac{U_{gw} \times \delta_{gw}}{IW} \right)}$ <p>where:</p> <p><math>\rho_s</math> = Dry soil bulk density [g-soil/cm<sup>3</sup>-soil]  <math>\theta_{ws}</math> = Volumetric water content in vadose zone soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]  <math>K_s</math> = <math>f_{oc} \times K_{oc}</math>  = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm<sup>3</sup>-H<sub>2</sub>O/g-soil]  <math>f_{oc}</math> = Fractional organic carbon content in the unsaturated zone [(g-C)/(g-soil)]  <math>H</math> = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]  <math>\theta_{as}</math> = Volumetric air content in the vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]  <math>U_{gw}</math> = Groundwater Darcy Velocity [cm/year]  <math>\delta_{gw}</math> = Groundwater mixing zone thickness [cm]  <math>I</math> = Infiltration rate of water through soil [cm/year]  <math>W</math> = Length of source area parallel to groundwater flow [cm]</p> <p>Source: ASTM E1739-95</p>	$C_s^{sat} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_s \rho_s]$ <p>where:</p> <p><math>S</math> = Pure component solubility in water [mg/L-H<sub>2</sub>O]  <math>\rho_s</math> = Dry soil bulk density [g-soil/cm<sup>3</sup>-soil]  <math>H</math> = Chemical-specific Henry's Law constant [(L-H<sub>2</sub>O)/(L-air)]  <math>\theta_{as}</math> = Volumetric air content in the vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]  <math>\theta_{ws}</math> = Volumetric water content in vadose zone soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]  <math>K_s</math> = <math>f_{oc} \times K_{oc}</math>  = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm<sup>3</sup>-H<sub>2</sub>O/g-soil]</p> <p>Source: ASTM E1739-95</p>

## ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

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

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

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

where:

$POE$	=	Point of exposure
$SW$	=	Sentry Well
$DAF_{POE}$	=	Dilution Attenuation Factor between the point of exposure and the source
$DAF_{SW}$	=	Dilution Attenuation Factor between the sentry well and the source
$LF_{SW}$	=	Dry soil leaching factor

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

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

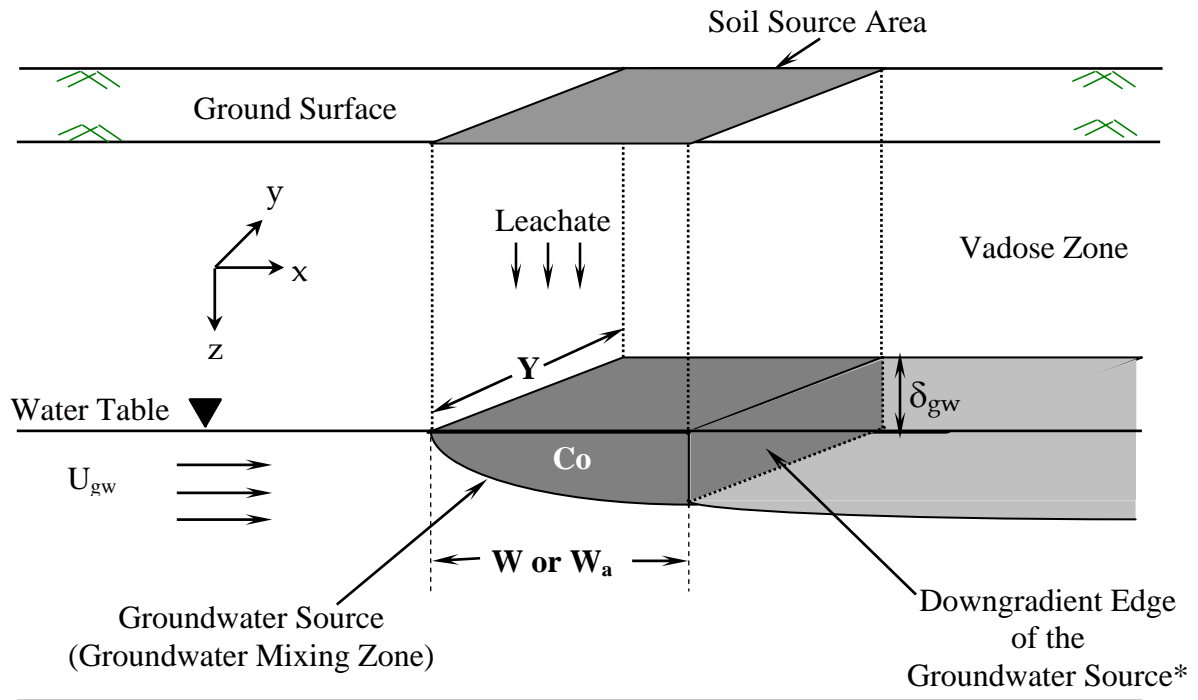
$$\text{Retardation Factor for Organics in the saturated zone } (R_s) = 1 + \left( \frac{\rho_{ss} \times K_{ss}}{\theta_{TS}} \right) \quad K_{ss} = fOC_s \times K_{oc}$$

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

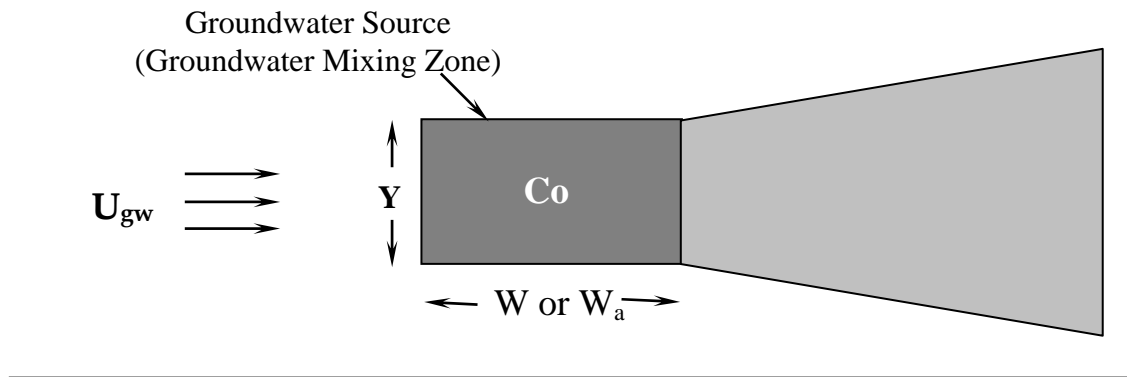
where:

$\rho_{ss}$	=	Saturated zone soil bulk density [g-soil/cm <sup>3</sup> -soil]
$K_{ss}$	=	Chemical-specific soil-water sorption coefficient in the saturated zone [cm <sup>3</sup> -H <sub>2</sub> O/g-soil]
$K_d$	=	Chemical-specific soil-water distribution coefficient for metals in the saturated zone [mL/g]
$\theta_{TS}$	=	Total porosity in the saturated zone [cm <sup>3</sup> /cm <sup>3</sup> -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.)



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# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

## **APPENDIX C**

### **ARBCA REPORT CONTENTS AND FORMAT**

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**April 2008**

**APPENDIX C**  
**ARBCA REPORT CONTENTS AND FORMAT**

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This section provides an outline format for the ARBCA Report. The format is established as a Table of Contents that lists all necessary information, appendices, tables, and figures that should be included in the ARBCA Report. The ARBCA Report does not have to be organized as suggested, but must contain all applicable information.

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# **ALABAMA RISK-BASED CORRECTIVE ACTION GUIDANCE MANUAL**

## **APPENDIX D**

### **RISK LEVEL CALCULATIONS**

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**April 2008**

## **D.1 INTRODUCTION**

The evaluation of risk at a site uses two (2) different methods of calculations to accurately evaluate the risk to human health and the environment. In the back-calculation method, the user specifies target risks and then calculates risk-based target levels. The back-calculation method was designed to be used prior to remediation in order to establish the objectives of the cleanup. This method uses default and/or site-specific information to provide the facility with estimated clean-up goals. The forward-calculation method calculates existing risk from the receptor point's representative concentrations and receptor input parameters. The forward-calculation method is typically conducted to determine if remediation is required in an area due to unacceptable cumulative risks present. This method is applied again following remediation to determine if the cumulative risk present is at or below acceptable levels. Upon determination that the cumulative risk is at or below the accepted levels, further remediation will not be required. Land-use scenarios other than an unrestricted land-use will likely require that LUCs be maintained in perpetuity.

### **D.1.1. Direct and Indirect Exposure Pathways**

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 medium. Examples of direct exposure include ingestion of soil or water, and dermal contact with soil. Indirect pathways are those where the exposure occurs away from the source. Examples of indirect exposure include the indoor inhalation of emissions from the volatilization of COCs from subsurface soil, or leaching of COCs 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 fate and transport models.

### **D.1.2 Identify Target Risk Level and Hazard Index**

The acceptable IELCR for carcinogenic effects requires the use of an IELCR of  $1 \times 10^{-5}$ . When calculating individual target levels for non-carcinogens, the acceptable hazard quotient (HQ) is 0.1. The acceptable Hazard Index (HI) (the sum of all the HQs for a designated area) for non-carcinogenic effects must be less than or equal to 1.0.

### **D.1.3 Determine 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). Table 3-4 contains the acceptable toxicity values for most of the COCs as of the date of this document. The most current values should be confirmed using the hierarchy as listed within Section 3.7.2 of this document. Alternative values will rarely be used and must be approved by ADEM.

### **D.1.4 Estimate the Allowable Dose**

For carcinogenic health effects, the allowable dose for the COC is estimated by dividing the acceptable risk (refer to D.1.2) with the Potency Value (refer to D.1.3). For non-carcinogenic adverse health effects, the allowable dose is equal to the hazard quotient multiplied by the reference dose.

### **D.1.5 Estimate the Allowable Point of Exposure (POE) Concentrations**

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

The default exposure factors that should be used to develop the RM-1 target levels are presented in Table 3-1. For RM-2 calculations, exposure factors should be the same as those used for RM-1 unless otherwise approved by the Department. The use of alternative exposure factors must be justified by site-specific conditions and be approved by ADEM.

For direct routes of exposure, the allowable concentration will be the risk-based target level. For indirect routes of exposure, additional analysis, as presented in the following step, is necessary to relate the exposure point concentrations to the source concentrations.

### **D.1.6 Estimate the Allowable Source Concentrations**

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 POE concentrations estimated in D.1.5 to back-calculate the allowable soil and groundwater source concentrations.

#### **D.1.6.1 Estimation of soil and groundwater concentrations protective of inhalation exposures**

For this exposure pathway, the POE concentrations estimated in D.1.5 are assumed to be the concentrations in the air that the receptor is breathing. A two-step procedure may be used to calculate allowable soil concentrations. Initially, if the receptor is located onsite, a closed-box model may be used to establish the allowable emission rate. Second, the allowable emission rate is calculated using the emission model which relates to the allowable soil concentration. These models are described in Appendix B. Implementation of these two (2) models requires several input parameters. Table 3-2 summarizes the default fate and transport parameters necessary to develop RM-1 target concentrations. Site-specific measured, estimated and/or default fate and transport parameters should be used for the RM-2 evaluation. The responsible party must clearly identify the data used and provide adequate justification for the specific input values used for the RM-2 evaluation.

#### **D.1.6.2 Estimation of soil and groundwater concentrations protective of groundwater ingestion, groundwater resources, and surface water**

For this exposure pathway, the concentration estimated in D.1.5 is assumed to be the concentration in the POE (water ingestion well, hypothetical POE, or the stream). The allowable leachate concentration at the source is calculated as the allowable concentration at the POE 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 the fate and transport models located in Appendix B, pages B-13 through B-16. The DAF (greater than or equal to one) depends on several site-specific factors such as the distance to the well, groundwater velocity, chemical properties, size of the source, etc. which are utilized in the groundwater models. Several coupled models may be required to estimate the DAF, 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 by assuming equilibrium partitioning between the soil concentration and the leachate concentration.

Soil and groundwater concentrations protective of a stream are calculated using the same process as the calculation of concentrations protective of groundwater ingestion and

groundwater resource protection. The only difference is that the target concentrations at the POE will be different from the target concentration in the stream.

For the RM-2 evaluation, the POE for the GRP evaluation will be at the closest downgradient residential property boundary where a well could be installed or at another location or distance. Certain programs may not allow the POE to be located beyond the property boundary. Justification of the POE location must be based on site-specific characteristics such as the current and likely future land and water use, the types of COCs (including their impact, mobility and persistence), and their potential for biodegradation.

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

Example D-3 describes details of the procedure for the GRP evaluation.

## **D.2 BACK-CALCULATION PROCEDURE**

The back-calculation of RBTLs establishes the soil and/or groundwater concentration objectives prior to remediation. The back-calculation method is used for the following:

- Determination of soil concentrations protective of an existing or potential drinking water well or a stream.
- Determination of soil concentrations protective of the risk due to direct contact exposure pathways.
- Determination of soil concentrations protective of the risk due to indirect contact exposure pathways.
- Determination of groundwater concentrations protective of the direct ingestion of groundwater pathway.

Within the ARBCA process, the estimated or back-calculated concentrations are termed the Risk Management-1 (RM-1) or Risk Management-2 (RM-2) levels 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.

For an example of a back-calculation see Example D-1.

### **D.3 FORWARD-CALCULATION PROCEDURE**

The forward-calculation of cancer risks and HQs for each COC determines if soil and/or groundwater concentrations at a site pose an unacceptable level of cumulative risk to a receptor. The forward-calculation method is used to determine if the contaminated medium left in-place exceeds the allowable risks (e.g., HI equal to 1 or an IELCR of  $1 \times 10^{-5}$ ) for all exposure pathways that exist within a particular zone of contamination. To calculate the cumulative risk, the individual risks for the COCs within each exposure domain must be summed for each appropriate exposure pathway when evaluating a specific receptor.

The equations used to calculate either a Target Risk (TR) or a Target Hazard Quotient (THQ) for the individual constituents are the same as those used in Appendix B. The equations must be manipulated to solve for either the TR or the THQ (this has been done for the user for many of the equations, see pages B-2 and B-4). Once either the Risk (R) or Hazard Quotient (HQ) is calculated for a constituent for all exposure pathways, the calculated risk must be summed together with the calculated risks of all the other COCs in the exposure domain. The summation of the calculated risks from all COCs within the exposure domain must not exceed the allowable risks. Once the calculated risks are below the allowable risks (e.g. remediation reduces the contaminant concentrations), further remediation is not required. Land-use scenarios other than an unrestricted land-use will likely require that LUCs be maintained in perpetuity.

For an example of a forward-calculation see Example D-2.

## EXAMPLE D-1

### EXAMPLE USING THE BACK-CALCULATION METHOD

**Given:** Location X (approximately ½ acre in size) was suspected to have soil contamination based on past operations at the site. A preliminary and a comprehensive investigation were completed and the COPCs were determined to be Benzene, Trichloroethene (TCE), Toluene, Benzo(a)pyrene (B(a)P), Benzo(g,h,i)perylene (B(g,h,i)P), and Cadmium. The site personnel used the maximum concentrations found at Location X as the representative soil concentrations. The representative surficial (0-1 ft. bgs) soil concentrations for the COCs were determined to be: Benzene (89.3 mg/kg), Toluene (0.53 mg/kg), TCE (74.2 mg/kg), B(a)P (4.6 mg/kg), B(g,h,i)P (7820 mg/kg), and Cadmium (12.4 mg/kg). Furthermore, it was determined that the indoor inhalation pathway onsite was incomplete; hence, the indoor inhalation pathway was not evaluated. Although Location X is in an industrial location, the site manager does not wish to have any LUCs so the facility has elected to use a residential scenario.

**Find:** Determine if the representative concentrations for each of the COPCs exceed the PSVs for the direct contact exposure pathways (for purposes of demonstrating the back-calculation method, ignore the migration from soil to groundwater pathway). If the representative concentration for a COPC exceeds its respective PSVs, then that COPC becomes a COC. Once the COCs are determined, the cumulative risk is calculated using the RM-1 values located in Tables 3-1 through 3-4 to determine if remediation will be necessary. If the cumulative risk exceeds the acceptable risks, then remediation will be necessary and RBTLs should be calculated.

**Solution:** The representative soil concentrations of the COCs should first be evaluated against the direct contact exposure pathway PSVs located in Table 2-2 (as stated above, for purposes of demonstrating the back-calculation method, the migration from soil to groundwater pathway will be ignored). The representative concentration of Toluene is below all of the PSVs that would be evaluated for surface soils. This eliminates Toluene as a COC at Location X for all of the surface soils. Benzene, TCE, B(a)P, B(g,h,i)P, and Cadmium all exceed their respective residential soil PSVs for direct contact exposure. Using the equations located within Appendix B, the Default Exposure Factors located in Table 3-1, the Default Fate and Transport Parameters located in Table 3-2, the Physical and Chemical Properties located in Table 3-3, and the Toxicity Parameters

located in Table 3-4, the cumulative risk addressing direct contact exposure should be calculated. The calculated cumulative risk for the “driver” receptor (see “driver” in parenthesis) was determined to be an IELCR = 4.68E-05 (child receptor) and a HI = 4.26 (child receptor). Therefore, since the cumulative risk has been exceeded, it is necessary to calculate a  $RBTL_{SS}$  for each of the COCs and remediate Location X.

Note: In the solution below, units are not shown throughout. For a reference to the units see the appropriate models located within Appendix B.

**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:**

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

Inspection of both of the equations reveals that it is first necessary to calculate  $VF_{SS}$  and  $VF_P$  for each of the COCs. See pages B-10 and B-11 for the necessary equations and units.

**Residential Child**

<b>COC</b>	<b><i>VF<sub>SS</sub></i></b>	<b><i>VF<sub>P</sub></i></b>
Benzene	2.90E-05	6.90E-12
TCE	2.90E-05	6.90E-12
B(a)P	5.32E-08	6.90E-12
B(g,h,i)P	2.07E-08	6.90E-12
Cadmium	0.00	6.90E-12

**Residential Adult**

<b>COC</b>	<b><i>VF<sub>SS</sub></i></b>	<b><i>VF<sub>P</sub></i></b>
Benzene	5.80E-06	6.90E-12
TCE	5.80E-06	6.90E-12
B(a)P	2.38E-08	6.90E-12
B(g,h,i)P	9.27E-09	6.90E-12
Cadmium	0.00	6.90E-12

It is helpful to develop a chart containing the needed parameters to be used in the appropriate RBTL equation:

**Carcinogenic Effects (adult)**

<b>COC</b>	<b><i>TR</i></b>	<b><i>BW</i></b>	<b><i>AT<sub>C</sub></i></b>	<b><i>EF</i></b>	<b><i>ED</i></b>	<b><i>SF<sub>O</sub></i></b>	<b><i>IRS</i></b>	<b><i>RAF<sub>O</sub></i></b>	<b><i>SA</i></b>	<b><i>M</i></b>	<b><i>RAF<sub>d</sub></i></b>	<b><i>SF<sub>i</sub></i></b>	<b><i>IR<sub>ao</sub></i></b>	<b><i>VF<sub>SS</sub></i></b>	<b><i>VF<sub>P</sub></i></b>
Benzene	1E-05	70	70	350	30	5.50E-02	100	1	5700	0.07	0.01	2.73E-02	8.33	5.80E-06	6.90E-12
TCE	1E-05	70	70	350	30	1.10E-02	100	1	5700	0.07	0.01	7.00E-03	8.33	5.80E-06	6.90E-12
B(a)P	1E-05	70	70	350	30	7.30E+00	100	1	5700	0.07	0.01	3.10E+00	8.33	2.38E-08	6.90E-12
B(g,h,i)P	1E-05	70	70	350	30	0.00	100	1	5700	0.07	0.01	0.00	8.33	9.27E-09	6.90E-12
Cadmium	1E-05	70	70	350	30	NA	100	1	5700	0.07	0.001	6.30E+00	8.33	0.00	6.90E-12

**Benzene *RBTL<sub>SS</sub>* = 242 mg/kg**

**TCE *RBTL<sub>SS</sub>* = 1010 mg/kg**

**B(a)P *RBTL<sub>SS</sub>* = 2.24 mg/kg**

**B(g,h,i)P *RBTL<sub>SS</sub>* = NA**

**Cadmium *RBTL<sub>SS</sub>* = 4,710,000 mg/kg**

**Carcinogenic Effects (child)**

<b>COC</b>	<b>TR</b>	<b>BW</b>	<b>AT<sub>c</sub></b>	<b>EF</b>	<b>ED</b>	<b>SF<sub>o</sub></b>	<b>IRS</b>	<b>RAF<sub>o</sub></b>	<b>SA</b>	<b>M</b>	<b>RAF<sub>d</sub></b>	<b>SF<sub>i</sub></b>	<b>IR<sub>ao</sub></b>	<b>VF<sub>SS</sub></b>	<b>VF<sub>P</sub></b>
Benzene	1E-05	15	70	350	6	5.50E-02	200	1	2800	0.2	0.01	2.73E-02	5	2.90E-05	6.90E-12
TCE	1E-05	15	70	350	6	1.10E-02	200	1	2800	0.2	0.01	7.00E-03	5	2.90E-05	6.90E-12
B(a)P	1E-05	15	70	350	6	7.30E+00	200	1	2800	0.2	0.01	3.10E+00	5	5.32E-08	6.90E-12
B(g,h,i)P	1E-05	15	70	350	6	0.00	200	1	2800	0.2	0.01	0.00	5	2.07E-08	6.90E-12
Cadmium	1E-05	15	70	350	6	0.00	200	1	2800	0.2	0.001	6.30E+00	5	0.00	6.90E-12

**Benzene RBTL<sub>SS</sub> = 120 mg/kg**

**TCE RBTL<sub>SS</sub> = 495 mg/kg**

**B(a)P RBTL<sub>SS</sub> = 1.22 mg/kg**

**B(g,h,i)P RBTL<sub>SS</sub> = NA**

**Cadmium RBTL<sub>SS</sub> = 8,400,000 mg/kg**

**Non-carcinogenic Effects (adult)**

<b>COC</b>	<b>THQ</b>	<b>BW</b>	<b>AT<sub>nc</sub></b>	<b>EF</b>	<b>ED</b>	<b>IRS</b>	<b>RAF<sub>O</sub></b>	<b>SA</b>	<b>M</b>	<b>RAF<sub>d</sub></b>	<b>IR<sub>ao</sub></b>	<b>VF<sub>SS</sub></b>	<b>VF<sub>P</sub></b>	<b>RfD<sub>O</sub></b>	<b>RfD<sub>i</sub></b>
Benzene	0.1	70	30	350	30	100	1	5700	0.07	0.01	8.33	5.80E-06	6.90E-12	4.00E-03	8.57E-03
TCE	0.1	70	30	350	30	100	1	5700	0.07	0.01	8.33	5.80E-06	6.90E-12	6.00E-03	5.67E-03
B(a)P	0.1	70	30	350	30	100	1	5700	0.07	0.01	8.33	2.38E-08	6.90E-12	0.00	0.00
B(g,h,i)P	0.1	70	30	350	30	100	1	5700	0.07	0.01	8.33	9.27E-09	6.90E-12	3.00E-02	1.50E-02
Cadmium	0.1	70	30	350	30	100	1	5700	0.07	0.001	8.33	0.00	6.90E-12	1.00E-03	5.70E-05

**Benzene RBTL<sub>SS</sub> = 231 mg/kg**

**TCE RBTL<sub>SS</sub> = 282 mg/kg**

**B(a)P RBTL<sub>SS</sub> = NA**

**B(g,h,i)P RBTL<sub>SS</sub> = 2100 mg/kg**

**Cadmium RBTL<sub>SS</sub> = 72.7 mg/kg**

**Non-carcinogenic Effects (child)**

<b>COC</b>	<b>THQ</b>	<b>BW</b>	<b>AT<sub>nc</sub></b>	<b>EF</b>	<b>ED</b>	<b>IRS</b>	<b>RAF<sub>O</sub></b>	<b>SA</b>	<b>M</b>	<b>RAF<sub>d</sub></b>	<b>IR<sub>ao</sub></b>	<b>VF<sub>SS</sub></b>	<b>VF<sub>P</sub></b>	<b>RfD<sub>O</sub></b>	<b>RfD<sub>i</sub></b>
Benzene	0.1	15	6	350	6	200	1	2800	0.2	0.01	5	2.90E-05	6.90E-12	4.00E-03	8.57E-03
TCE	0.1	15	6	350	6	200	1	2800	0.2	0.01	5	2.90E-05	6.90E-12	6.00E-03	5.67E-03
B(a)P	0.1	15	6	350	6	200	1	2800	0.2	0.01	5	5.32E-08	6.90E-12	0.00	0.00
B(g,h,i)P	0.1	15	6	350	6	200	1	2800	0.2	0.01	5	2.07E-08	6.90E-12	3.00E-02	1.50E-02
Cadmium	0.1	15	6	350	6	200	1	2800	0.2	0.001	5	0.00	6.90E-12	1.00E-03	5.70E-05

**Benzene RBTL<sub>SS</sub> = 22.9 mg/kg**

**TCE RBTL<sub>SS</sub> = 26.1 mg/kg**

**B(a)P RBTL<sub>SS</sub> = NA**

**B(g,h,i)P RBTL<sub>SS</sub> = 228 mg/kg**

**Cadmium RBTL<sub>SS</sub> = 7.8 mg/kg**

Following an evaluation of the calculated  $RBTL_{SS}$  for each chemical and applicable receptor, the most conservative value of all of the scenarios must be selected and then compared to the migration from soil to groundwater pathway.

The most conservative human health direct contact  $RBTL_{SS}$  is for the child receptor. Therefore, the values above will be used as the RBTLs during remediation activities at Location X or the site always has the option to conduct an RM-2 evaluation, which would essentially consist of the same calculations as demonstrated above but with more site-specific values.

<b>Benzene</b>	=	<b>22.9 mg/kg</b>
<b>TCE</b>	=	<b>26.1 mg/kg</b>
<b>B(a)P</b>	=	<b>1.22 mg/kg</b>
<b>B(g,h,i)P</b>	=	<b>228 mg/kg</b>
<b>Cadmium</b>	=	<b>7.8 mg/kg</b>

## EXAMPLE D-2

### EXAMPLE USING THE FORWARD-CALCULATION METHOD

- Given:** Remediation activities have occurred at Location X. Confirmatory sampling was completed to determine the current representative concentrations that remain in the surface soils. The representative concentrations were determined to be 42.6 mg/kg for Benzene, 35.9 mg/kg for TCE, 1.18 mg/kg for Benzo(a)pyrene (B(a)P), 52.3 mg/kg for Benzo(g,h,i)perylene (B(g,h,i)P), and 1.2 mg/kg for Cadmium. Although the representative concentrations are above some of the RBTLs as calculated in example D-1, the facility would still like to calculate the current cumulative risk before proceeding with additional remediation activities. As stated in the first example, Location X is approximately ½ acre in size.
- Find:** The total risk that currently exists in the surface soils at Location X and ensure that the representative concentrations are below the direct contact exposure pathways (Note: the indoor air vapor intrusion pathway has already been determined to be incomplete and a security fence has been installed as well as security personnel hired which eliminates the need to evaluate the trespasser. Also, for purposes of demonstrating the forward-calculation method, ignore the migration from soil to groundwater pathway).
- Solution** The equations located on page B-4 should be used to solve for the carcinogenic risk present (R) and the non-carcinogenic risk present (HQ). The risks for the carcinogens should be summed and the value should not exceed 1E-05. The hazard quotients for the non-carcinogens should be summed and the summation should not exceed the HI of 1.0. The current representative concentrations should be used as the concentration (C) term.

#### *Ingestion of Chemicals in Surficial Soils*

$$R = \frac{C \times EF \times ED \times SF_o \times 10^{-5} \text{ kg / mg} \times IRS \times RAF_o}{BW \times AT_c \times 365 \text{ days / yr}}$$



$$HQ = \frac{C \times EF \times ED \times 10^{-5} \text{ kg/mg} \times IRS \times RAF_o}{BW \times AT_{nc} \times 365 \text{ days/yr} \times RfD_o}$$

**Inhalation of Vapors and Particulates in Surficial Soils**

$$R = \frac{C \times EF \times ED \times IR_{ao} \times SF_i \times (VF_{ss} + VF_p)}{BW \times AT_c \times 365 \text{ days/yr}}$$

$$HQ = \frac{C \times EF \times ED \times IR_{ao} \times (VF_{ss} + VF_p)}{BW \times AT_{nc} \times 365 \text{ days/yr} \times RfD_i}$$

**Dermal Contact of Chemicals in Surficial Soils**

$$R = \frac{C \times EF \times ED \times SA \times SF_o \times 10^{-6} \text{ kg/mg} \times M \times RAF_d}{BW \times AT_c \times 365 \text{ days/yr}}$$

$$HQ = \frac{C \times EF \times ED \times SA \times M \times RAF_d \times 10^{-6} \text{ kg/mg}}{BW \times AT_{nc} \times 365 \text{ days/yr} \times RfD_o}$$

ADULT									
Chemical	Rep. Soil Conc. (mg/kg)	Inhalation of Vapors & Particulates in Surficial Soil		Dermal Contact with Surficial Soil		Ingestion of Surficial Soil		Sum of IELCR	Sum of HQ (HI)
		IELCR	HQ	IELCR	HQ	IELCR	HQ		
Benzene	42.6	3.30E-07	3.29E-03	1.57E-07	5.82E-04	1.38E-06	1.46E-02	1.86E-06	1.85E-02
TCE	35.9	7.12E-08	4.19E-03	1.46E-07	3.27E-04	2.74E-07	8.20E-03	4.91E-07	1.27E-02
B(a)P	1.18	4.26E-09	NA	2.69E-06	NA	5.06E-06	NA	7.75E-06	NA
B(g,h,i)P	52.3	NA	3.69E-06	NA	9.53E-05	NA	2.39E-03	NA	2.49E-03
Cadmium	1.2	2.55E-12	1.66E-08	NA	6.56E-06	NA	1.64E-03	2.55E-12	1.65E-03
Cumulative Risk		4.05E-07	7.48E-03	2.99E-06	1.01E-03	6.71E-06	2.68E-02	<b>1.01E-05</b>	<b>3.53E-02</b>

CHILD									
Chemical	Soil Conc. (mg/kg)	Inhalation of Vapors & Particulates In Surficial Soil		Dermal Contact with Surficial Soil		Ingestion of Surficial Soil		Sum of IELCR	Sum of HQ (HI)
		IELCR	HQ	IELCR	HQ	IELCR	HQ		
Benzene	42.6	9.23E-07	4.60E-02	7.19E-08	3.81E-03	2.57E-06	1.36E-01	3.56E-06	1.86E-01
TCE	35.9	2.00E-07	5.87E-02	1.43E-08	2.14E-03	5.11E-07	7.65E-02	7.25E-07	1.37E-01
B(a)P	1.18	5.33E-09	NA	2.64E-07	NA	9.44E-06	NA	9.71E-06	NA
B(g,h,i)P	52.3	NA	2.31E-05	NA	6.24E-04	NA	2.23E-02	NA	2.29E-02
Cadmium	1.2	1.43E-12	4.64E-08	NA	4.30E-05	NA	1.53E-02	1.43E-12	1.54E-02
Cumulative Risk		1.13E-06	1.05E-01	3.51E-07	6.62E-03	1.25E-05	2.50E-01	<b>1.40E-05</b>	<b>3.62E-01</b>

Inspection of the results of the forward calculations reveals that currently there is still a risk present due to potential carcinogenic effects. In the case of Location X for the direct contact exposure pathways, additional remedial action would be required until the target risk levels are met. (Note: In an actual situation, the migration from soil to groundwater pathway would need to be evaluated as well).

### EXAMPLE D-3

#### GROUNDWATER RESOURCE PROTECTION (GRP) EVALUATION

Assuming that the location of the source, the sentry well (SW), and the Point of Exposure (POE) have been determined per Sections 3.6 and 3.9 of this document, the GRP evaluation determines the target soil and groundwater levels allowed at the source. The target levels are then compared to representative source-area concentrations that are determined per Appendix A of this document. Figure D-1 illustrates the relationships between the soil and groundwater source, the sentry well(s) and the Point of Exposure.

In performance of the GRP evaluation, one first determines the soil concentrations protective of leaching to groundwater per the equation on page B-13:

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

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<sub>2</sub>O]
- $LF_{SW}$  = Leaching Factor (from subsurface soil to groundwater) [(mg/L-H<sub>2</sub>O)/(mg/kg-soil)]

The allowable soil concentration *at the source* may also be expressed as (see page B-16):

$$\text{Allowable Soil Concentration} = MCL_{POE} \text{ (or } RBTL_{POE}) \times (DAF_{POE}/LF_{sw})$$

At the centerline, for steady state, without biodecay, the Dilution Attenuation Factor (DAF) is determined using Equation 1 on page B-14:

$$1/DAF = \frac{C(x)}{C_o} = erf \left[ \frac{Y}{4\sqrt{\alpha_y x}} \right] \times erf \left[ \frac{\delta_{gw}}{2\sqrt{\alpha_z x}} \right]$$

where:

- $C(x)$  = dissolved-phase concentration at any position x along centerline [mg/l]
- $C_o$  = dissolved-phase concentration at the source (at  $x = y = 0, 0 \leq z \leq \delta_{gw}$ ) [mg/l]
- $\alpha_y$  = lateral dispersivity [cm] =  $X_{poe}/30$
- $\alpha_z$  = vertical dispersivity [cm] =  $X_{poe}/200$
- $x, y, z$  = spatial coordinates [cm]

- $x$  = distance along the centerline from the downgradient edge of dissolved-plume source zone or source well [cm]. For  $DAF_{POE}$ ,  $x = X_{POE}$  distance to POE. For  $DAF_{SW}$ ,  $x = X_{SW}$  distance to sentry well.  
 $Y$  = width of soil source perpendicular to the groundwater flow direction [cm]  
 $\delta_{gw}$  = groundwater mixing zone thickness [cm]  
 $DAF$  =  $C_0/C(x)$

The leaching factor from subsurface soil to groundwater is determined by (see page B-15):

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

where:

- $\rho_s$  = Dry soil bulk density [g-soil/cm<sup>3</sup>-soil]  
 $\theta_{ws}$  = Volumetric water content in vadose zone soils [cm<sup>3</sup>-H<sub>2</sub>O/cm<sup>3</sup>-soil]  
 $K_s$  =  $f_{oc} \times K_{oc}$  = Chemical-specific soil-water sorption coefficient for the unsaturated zone [cm<sup>3</sup>-H<sub>2</sub>O/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<sub>2</sub>O)/(L-air)]  
 $\theta_{as}$  = Volumetric air content in the vadose zone soils [cm<sup>3</sup>-air/cm<sup>3</sup>-soil]  
 $U_{gw}$  = Groundwater Darcy Velocity [cm/year]  
 $\delta_{gw}$  = Groundwater mixing zone thickness [cm]  
 $I$  = Infiltration rate of water through soil [cm/year]  
 $W$  = Length of source area parallel to groundwater flow [cm]

The allowable groundwater concentration *at the source* is determined by (see page B-16):

$$\text{Allowable Groundwater Concentration} = MCL_{POE} \text{ (or } RBTL_{POE}) \times DAF_{POE}$$

The allowable groundwater concentration *at the sentry well(s)* is determined by (see page B-16):

$$\text{Allowable Groundwater Concentration} = MCL_{POE} \text{ (or } RBTL_{POE}) \times DAF_{POE}/DAF_{SW}$$

where:

- $POE$  = Point of Exposure  
 $SW$  = Sentry well  
 $DAF_{POE}$  = Dilution Attenuation Factor between the point of exposure and the source  
 $DAF_{SW}$  = Dilution Attenuation Factor between the sentry well and the source  
 $LF_{SW}$  = Leaching Factor from soil to groundwater

The allowable groundwater concentration at the POE is the MCL or, in the absence of an MCL is either calculated using the equation on page B-1 or a value may be used as shown on Table 2-2. In some cases, the allowable groundwater concentration value at the POE may be based on other routes of exposure. The most conservative value from all of the routes of exposure should be used.

## **EXAMPLE D-4**

### **STREAM OR SURFACE WATER EVALUATION**

While performing an ARBCA evaluation at a site, it is necessary to identify surface water bodies (lakes, perennial streams, drainage ways, intermittent streams, wetlands, etc.) located near the site. These streams may be 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 sentry well(s) protective of the stream. The method used to develop these target levels is presented in the following sections.

#### **METHODOLOGY**

A schematic of the potential migration of chemicals of concern (COCs) from the soil source to the stream is shown in Figure D-2. Residual COC concentrations at the soil source could potentially leach into groundwater below the source. This leachate would mix with the regional groundwater directly below the site and migrate in the downgradient direction towards the stream. Upon reaching the stream, the plume would discharge into the stream and mix with the water in the stream. At a certain distance, downstream of the groundwater plume discharge point, the COCs discharged into the stream would completely mix with the water in the stream.

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

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. Typically, surface water bodies located within 500 feet of the downgradient edge of the site should be identified, unless

otherwise required by 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 determined per the Water Quality Criteria established in ADEM Admin. Code 335-6-10-.07 (the “Consumption Fish/Water” pathway should be used). This applies to surface water defined as a “water of the state” (see ADEM Admin. Code R. 335-6-10-.02(10)). In the absence of a constituent addressed in 335-6-10, the most current version of the USEPA National Recommended Water Quality Criteria should be utilized.

ADEM Water Quality Criteria Regulations can be accessed online at:

<http://www.adem.state.al.us/Regulations/regulations.htm>

USEPA National Recommended Water Quality Criteria can be accessed online at:

<http://www.epa.gov/waterscience/criteria/wqcriteria.html>

For constituents not addressed in either of the above references, the Department should be contacted for guidance.

This example is based on impacts to human health. Many times when evaluating surface water it will be necessary to evaluate potential ecological impacts. See Section 3.14 for more information on the evaluation of risk present to ecological receptors.

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

For an RM-1 evaluation, groundwater concentrations at the point of discharge,  $C_{gw}$ , are set equal to the allowable stream concentration,  $C_{sw}$ . Thus, for an RM-1 evaluation, mixing within the stream is neglected. For RM-2 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:

$$C_{gw} = \frac{C_{sw}(Q_{gw} + Q_{sw})}{Q_{gw}} - C_{su} \left( \frac{Q_{sw}}{Q_{gw}} \right) \quad (D-4.1)$$

Where:

- $Q_{gw}$  = Impacted groundwater discharge into the stream (ft<sup>3</sup>/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<sup>3</sup>/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,  $Q_{gw}$ , is estimated as follows:

$$Q_{gw} = U_{gw} \times 8.99 \times 10^{-5} \times A_{gw} \quad (D-4.2)$$

$$U_{gw} = K \times i \quad (D-4.3)$$

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<sup>2</sup>)



$8.99 \times 10^{-5}$  = Conversion factor [cm/year to ft/day]

In Equation D-4.2,  $A_{gw}$  is estimated as:

$$A_{gw} = L_p \times D_p \quad (D-4.4)$$

Where:

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

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

$$L_p = \frac{Y}{30.48} + 2\sqrt{\alpha_y X_s} \quad (D-4.5)$$

$$D_p = \frac{\delta_{gw}}{30.48} + \sqrt{\alpha_z X_s} \quad (D-4.6)$$

Where:

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

$\alpha_y$  and  $\alpha_z$  can be estimated as:

$$\alpha_y = \frac{X_s}{30} \quad (D-4.7)$$

$$\alpha_z = \frac{X_s}{200} \quad (D-4.8)$$

For an RM-2 evaluation, the width of the groundwater plume may be estimated using Equation D-4.5 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 ADEM. The method proposed should be included in a written plan submitted to ADEM.

For an RM-2 evaluation, ADEM requires that the 7Q10 flow (see Equation D-4.9) be used to estimate the upstream flow,  $Q_{sw}$ , in Equation D-4.1. For streams that are gauged, the 7Q10 can be obtained directly from Atkins and Pearman (1994) or by calling a local USGS office. Where gauging information is not available, 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:

$$7Q10 = 0.15 \times 10^{-5} \times (G - 30)^{1.35} (A)^{1.05} (P - 30)^{1.64} \quad (D-4.9)$$

Where:

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

See section 4.7.5 for sources of rainfall data.

For situations where the site is located in an area with more than one stream index, compute the 7Q10 for the entire drainage area using each index, then calculate the estimated 7Q10 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 7Q10 for both indices using the total drainage area as shown below:

Example:

Drainage using first index

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

**7Q<sub>10</sub> = 1.6 cfs**

Drainage using second index

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

**7Q<sub>10</sub> = 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
<hr/>	
Weighted avg	= 3.7 cfs, therefore the 7Q <sub>10</sub> = 3.7 cfs

The 7Q<sub>10</sub> estimated from Equation D-4.9 can be converted to Q<sub>sw</sub> using the following equation:

$$Q_{sw} = 7Q_{10} \times 86400 \tag{D-4.10}$$

Where:

$$86400 = \text{Conversion factor [seconds/day]}$$

7Q<sub>10</sub> is assumed to be zero for streams with a drainage area less than 5 square miles, streams with intermittent flow, or wetlands.

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

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:

$$C_{gws} = C_{gw} \times DAF_{stream} \quad (D-4.11)$$

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 D-4.1 in RM-2 [mg/L].  
In RM-1,  $C_{gw} = C_{sw}$

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

$$C_{SW} = \frac{DAF_{stream}}{DAF_{SW}} \times C_{gw} \quad (D-4.12)$$

Where:

- $C_{SW}$  = Allowable concentration at the sentry well [mg/L]
- $DAF_{stream}$  = Dilution attenuation factor in the saturated zone between the source and the stream [--]
- $DAF_{SW}$  = Dilution attenuation factor in the saturated zone between the source and the sentry well [--]

Note that the concept quantified by Equation D-4.12 is also used to develop the sentry well concentrations for the GRP evaluation (see Appendix B, page B-16). For RM-1 and RM-2 evaluations, the  $DAF_{stream}$  and  $DAF_{SW}$  may be calculated using the simplified version of Domenico's model as discussed in Section 7.1.14.

### 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:

$$C_{soil} = \frac{C_{gw} \times DAF_{stream}}{LF_{sw}} \quad (D-4.13)$$

Where:

$$\begin{aligned} C_{soil} &= \text{Allowable source soil concentration [mg/kg]} \\ LF_{sw} &= \text{Leaching factor from soil to groundwater [(mg/L-H}_2\text{O)/(mg/kg-soil)]} \end{aligned}$$

See Appendix B-15 for the equation to calculate the leaching factor.

### IMPLEMENTATION OF THE ABOVE METHOD

To implement the above method in RM-1, the user must determine (i) the distance from the source to the downgradient stream, (ii) the location of the sentry wells, and (iii) the distance from the source to the sentry wells. The allowable soil source concentrations have to be compared with the representative soil source concentrations at a site to determine if the representative soil source concentrations are protective of the stream. In addition, the allowable groundwater source concentration has to be compared with the representative groundwater source concentrations. The sentry well target concentrations have to be compared with the representative sentry well concentrations to determine whether the sentry well concentrations are protective of the stream. Refer to Appendix A for procedures to develop representative sentry well concentrations.

#### 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.

## **EXAMPLE D-5**

### **DEVELOPMENT OF A SITE-SPECIFIC BIODECAY RATE**

#### **BACKGROUND**

The application of the ARBCA process at impacted sites in Alabama ultimately results in remedial and/or risk management decisions based on the target levels 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 1) there is sufficient site-specific evidence to confirm that biodegradation is occurring, 2) sufficient data is available to estimate a site-specific biodegradation rate, 3) the calculated biodecay rate is technically correct, and 4) the plume is stable or decreasing. This example provides the methodology for determining site-specific decay rates. It is anticipated that this procedure will mostly be used to evaluate the impacts from petroleum hydrocarbon releases. Please note that the terms biodecay and biodegradation are used interchangeably in this document. 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 choice to utilize biodecay in calculating GRP target levels 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. However, at sites where the ARBCA evaluator proposes the application of the biodecay rate, an evaluation without the application of the biodecay rate should be presented in the event the evaluation utilizing the biodecay rate is not acceptable.

#### **JUSTIFICATION OF NATURAL ATTENUATION WITH BIODEGRADATION**

Several parameters (COCs, electron acceptors, microorganisms, nutrients, carbon dioxide, etc.) may be measured to demonstrate the occurrence of biodegradation.

These measurements are typically divided into three tiers, or “lines of evidence”, to demonstrate **natural attenuation (NA)**. These include: (i) primary, (ii) secondary, and (iii) tertiary lines of evidence. Data collected under each line of evidence can be evaluated qualitatively or quantitatively as discussed in the following sections.

## **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 COC 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) that have been placed in the proper locations with respect to groundwater flow direction variations and changing vertical distribution of the plume, (ii) adequate duration and frequency of chemical data collected from these points, (iii) an evaluation of the competency of the well network to monitor plume movement, and (iv) 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.

## **Secondary Lines of Evidence**

Secondary lines of evidence refer to the measurements of electron acceptors and products of metabolism. Secondary lines of evidence demonstrate the occurrence of biodegradation only and do not provide any data on the occurrence of other NA processes. These lines of evidence are

compared to 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 up-gradient locations, inside the plume near the source, and in the down-gradient locations.

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.

### **Tertiary Lines of Evidence**

Tertiary 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 all compounds. Further in the portion of the plume where biodegradation is occurring, the ratio of chemical degrading bacteria to the total number of bacteria is expected to be higher. Tertiary lines of evidence are seldom required at impacted sites, hence, they are not discussed further here.

### **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:

- Table of historical intrinsic indicators of biodegradation.
- Graphs of historical values of intrinsic indicators of biodegradation plotted as time vs. concentration per well.
- A series of contour map(s) illustrating trends of pertinent indicators of biodegradation over time.

Documentation of performance of Steps 1 – 9 discussed in the following section.



- **ESTIMATION OF SITE-SPECIFIC CHEMICAL HALF-LIVES**

The following step-by-step procedure may be used to develop a site-specific biodegradation rate or half-life for use in the groundwater resource protection evaluation. Note, the procedure should be repeated for each chemical of concern that exceeds the RM-2 GRP target levels without decay. The method follows the American Society for Testing And Materials guideline for remediation of groundwater by natural attenuation at petroleum-release sites (ASTM, 1998, pages 118-120).

- 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: Plot the natural log of the concentrations on the Y-axis and the distance from the downgradient face of the source area along the X-axis.
- 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. An example of this type of calculation can be found in Miller and Freund (1985, p. 298).
- Step 6: Estimate the groundwater seepage velocity and the longitudinal dispersivity using the formulas in Step 8.
- Step 7: Multiply the slope of the best-fit line calculated in Step 5 by the seepage velocity to estimate  $k$ , the overall natural attenuation rate (see Buscheck and Alcantar, 1995).

The NA rate represents the reduction in concentration due to the combined influence of the various NA processes. Note that this overall NA rate ( $k$ ) should not be confused with the biodegradation rate ( $\lambda$ ) that is an input to the Groundwater Resource Protection model used in ARBCA (see Equation 2 on page B-14).

Step 8: Estimate the biodegradation rate ( $\lambda$ ) using the below equation derived by Buscheck and Alcantar (1995, equation 9) based on the solution of the one-dimensional transport equation with biodegradation.

$$\lambda = \frac{v}{4\alpha_x} \left\{ \left[ 1 + 2\alpha_x \left( \frac{k}{v} \right)^2 \right] - 1 \right\}$$

Where:

- $\lambda$  = Biodegradation rate (1/yr)
- $\alpha_x$  = Longitudinal dispersivity (Xpoe/10)(cm)
- Xpoe = Distance from the source to the Point of Exposure (POE) (cm)
- $k$  = Overall attenuation rate (1/yr)
- $v$  = Seepage Velocity (Hydraulic gradient x Hydraulic conductivity/Porosity) (cm/yr)

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 ( $k$ ) and biodecay ( $\lambda$ ) rates. 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.

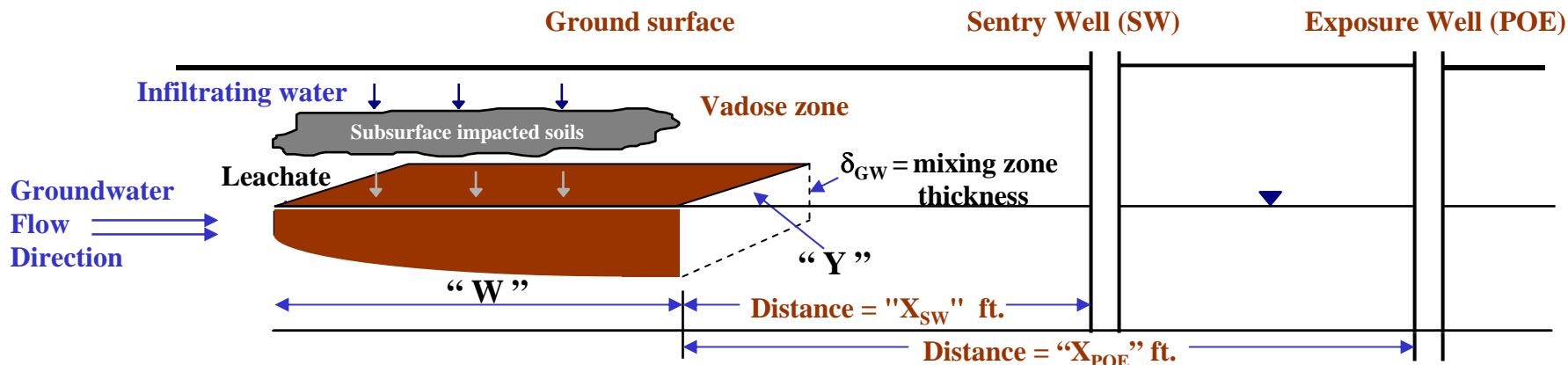
Professional judgment must be used to determine the most representative  $\lambda$  for use in the calculation of the chemical half-lives.

Step 9: Calculate a half-life for each chemical using the equation,  $\lambda = .693/\text{half-life}$ .  $\lambda$  should be written as 1/days for this calculation.

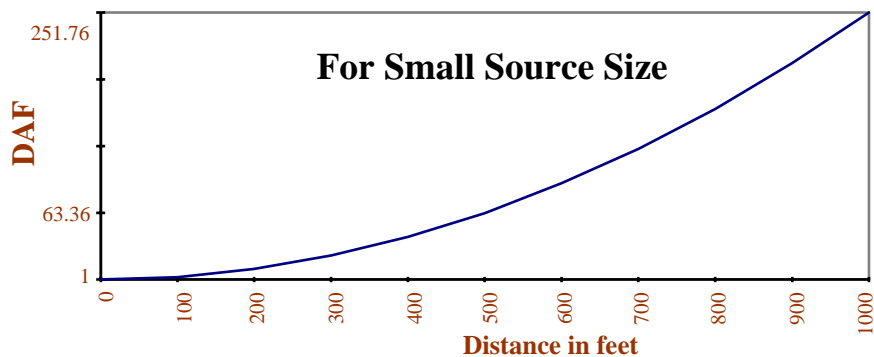
Utilize the derived site-specific half-lives in the calculation of the soil and groundwater target levels. The half-lives for each chemical of concern for which a biodecay-based target level is proposed should be tabulated.

## REFERENCES

- ASTM, 1998. *Standard Guide for Remediation of Ground Water by Natural Attenuation at Petroleum Release Sites*, Standard E1943-98 published by The American Society for Testing and Materials, Conshohocken, PA.
- 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.
- Miller, Irwin and Freund, John E. 1985, *Probability and Statistics for Engineers*, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 07632.



**POE** = Point of Exposure  
**SW** = Sentry Well  
**W** = Width of the groundwater source parallel to groundwater flow direction  
**Y** = Length of the groundwater source perpendicular to groundwater flow direction  
**DAF<sub>POE</sub>** = Dilution-attenuation factor between the POE & the source  
**DAF<sub>SW</sub>** = Dilution-attenuation factor between the SW & the source  
**LF<sub>SW</sub>** = Dry Soil Leaching Factor

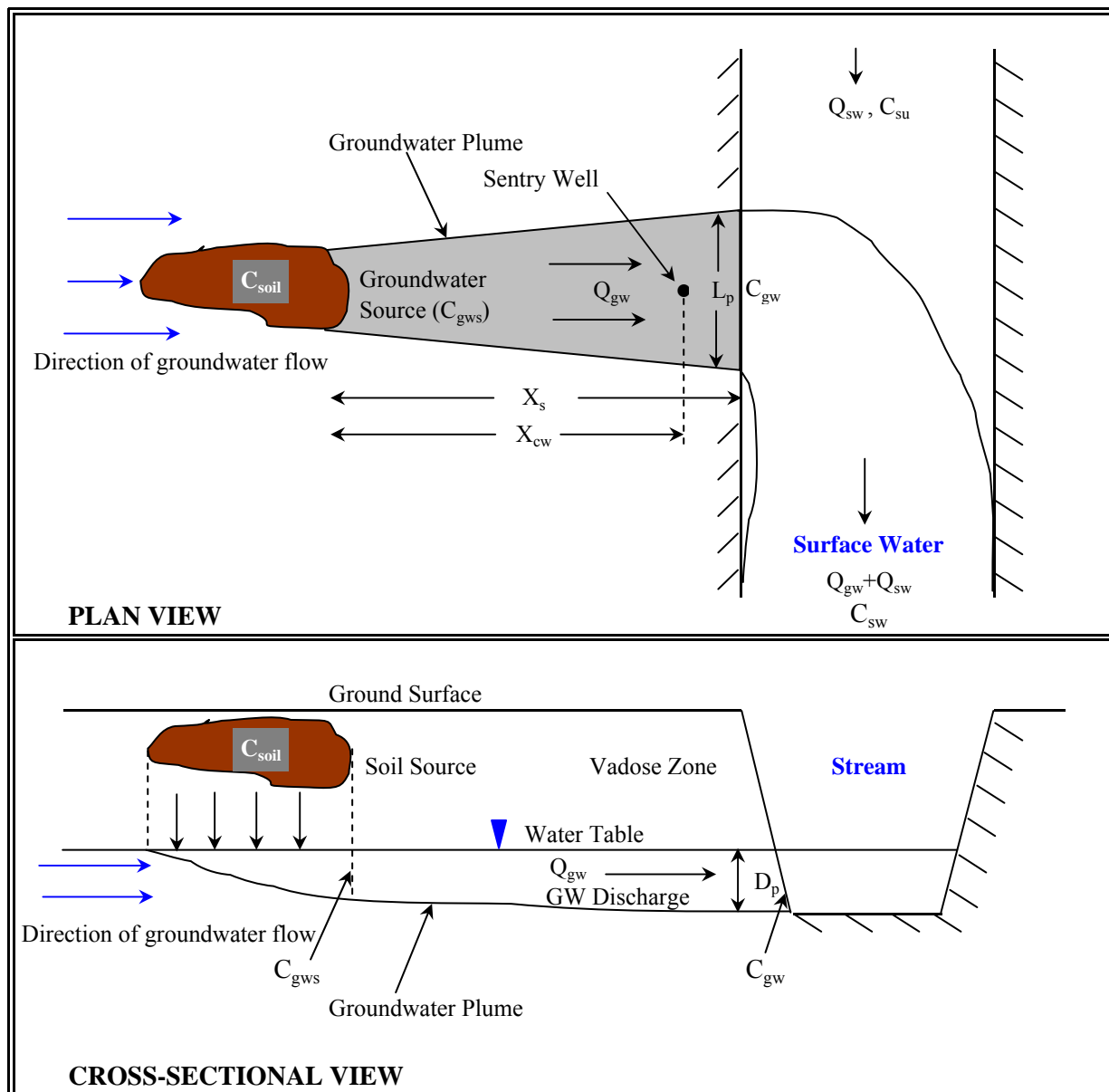


Allowable groundwater concentration at the source protective of a POE located at a distance " $X_{POE}$ " from the source =  $C_{POE} \times DAF_{POE}$

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

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

**FIGURE D-1. DOMENICO MODEL - CALCULATION OF GROUNDWATER RESOURCE PROTECTION TARGET LEVELS**



**Figure D-2: Schematic of leachate migration from the soil source to the stream**

**Legend**

- $Q_{sw}$  = Stream flow upstream of the point of groundwater discharge [ft<sup>3</sup>/day]
- $C_{su}$  = Concentration upstream of the groundwater discharge [mg/L]
- $Q_{gw}$  = Impacted groundwater discharge into the stream [ft<sup>3</sup>/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]
- $X_{sw}$  = Distance from the downgradient edge of the groundwater source to the sentry well [ft]
- $X_s$  = Distance from the downgradient edge of the groundwater source to the stream [ft]