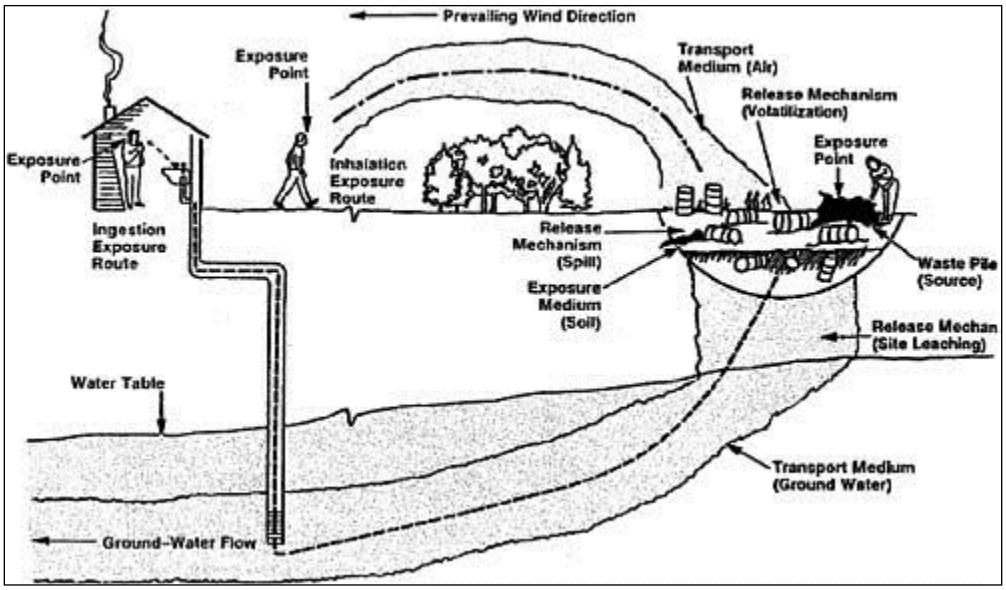
ISRAEL RISK-BASED CORRECTIVE ACTION (IRBCA) TECHNICAL GUIDANCE



Version 2

January 2020

(This version replaces Version 1 from August, 2014)

Developed by:
IRBCA Workgroup

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List of Acronyms

ALM	Adult Lead Methodology
AQL	Aquatic Life
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
AUL	Activity and Use Limitation
AWQC	Ambient Water Quality Criteria
BAT	Best Available Technology
BCF	Bioconcentration Factor
bgs	Below Ground Surface
CalEPA	California Environmental Protection Agency
CHHSL	California Human Health Screening Level
CLF	Cool Water Fishery
COCs	Chemicals of Concern
CSM	Conceptual Site Model
CTL	Cleanup Target Levels
DAF	Dilution Attenuation Factor
DCE	cis-1,2-Dichloroethene
DNAPL	Dense Non-Aqueous Phase Liquid
DOE	Department of Energy
DWS	Drinking Water Supply
EM	Exposure Model
ERA	Ecological Risk Assessment
ESA	Environmental Site Assessment
ESL	Environmental Screening Levels
ET	Ecotox Thresholds
HDPE	High Density Polyethylene
HEAST	Health Effects Assessment Summary Tables
HH	Human Health
HHRA	Human Health Risk Assessment
HI	Hazard Index

HQ	Hazard Quotient
IDWS	Israeli Drinking Water Standard
IELCR	Incremental Excess Lifetime Cancer Risk
IEUBK	Integrated Exposure uptake Biokinetic
IND	Industrial
IRBCA	Israel Risk-Based Corrective Action
IRIS	Integrated Risk Information System
IRR	Irrigation
ISC	Initial Site Characterization
ITRC	Interstate Technology & Regulatory Council
IWA	Israel Water Authority
LNAPL	Light Non-Aqueous Phase Liquid
LTS	Long-Term Stewardship
LWW	Livestock & Wildlife Watering
m	Meters
MDNR	Missouri Department of Natural Resources
MIP	Membrane Interface Probe
MNA	Monitored Natural Attenuation
MoEP	Ministry of Environmental Protection
MRBCA	Missouri Risk-Based Corrective Action
MRL	Minimal Risk Level
NAPL	Non-Aqueous Phase Liquid
NCEA	National Center for Environmental Assessment
NFA	No Further Action
NOAA	National Oceanic and Atmospheric Administration
ORNL	Oak Ridge National Laboratory
PCB	Polychlorinated Biphenyls
PCE	Tetrachloroethylene
PID	Photoionization Detector
POD	Point of Demonstration
POE	Point of Exposure

PVC	Poly Vinyl Chloride
QAPP	Quality Assurance Project Plan
QA/QC	Quality Assurance/Quality Control
RA	Risk Assessment
RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk Based Corrective Action
RBTL	Risk-Based Target Level
RC	Representative Concentration
RCRA	Resource Conservation and Recovery Act
RM	Risk Management
RMP	Risk Management Plan
RP	Responsible Party
SC	Site Characterization
SF	Slope Factor
SOP	Standard Operating Procedure
SSL	Soil Screening Levels
SSTL	Site-Specific Target Level
SWCTL	Surface Water Cleanup Target Level
TCE	Trichloroethylene
TRV	Toxicity Reference Value
TIC	Tentatively Identified Compound
UCL	Upper Confidence Limit
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Compound
VSL	Very Strict Level
WBR	Whole Body Recreation
Workgroup	IRBCA Workgroup
WQC	Water Quality Criteria
XRF	X-Ray Fluorescence

ACKNOWLEDGEMENTS

This document reflects the work of the IRBCA Workgroup in which representatives of the following organizations were involved:

- The Israeli Institute of Energy and Environment
- Ministry of Environmental Protection
- Israel's Water Authority
- Ministry of Health
- Israel Electric Corporation
- Manufacture's Association of Israel
- Adam Teva V'din - Israel Union for Environmental Defense

The attached Table 1 lists the members of the IRBCA Workgroup. The activities leading to the composition of this document were sponsored and organized by the Israeli Institute of Energy and Environment.

Members of the IRBCA Work group thank the RAM Group of Gannett Fleming, Inc. and in particular Dr. Atul M. Salhotra for skillfully guiding the activities of the committee and providing valuable education and training.

In 2018, the IRBCA methodology underwent a revision with the assistance of Golder Associates Ltd. and Ecolog Engineering Ltd.

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1 Disclaimer

This document provides information and technical assistance to the public, employees of the Israel Ministry of Environmental Protection (MoEP), employees of the Water Authority and all other relevant stakeholders regarding the program for performing Risk Based Corrective Action in Israel (IRBCA). The information should be interpreted and used in a matter that is fully consistent with MoEP and Water Authority policy. This document does not constitute rulemaking the Israeli regulators and may not be relied upon to create a right or benefit, procedure, or enforceable law by any person.

This document is supplemented with an Excel™ spreadsheet for conducting risk assessment. The spreadsheet model has been developed by Ecolog Engineering Ltd & Golder Associates Ltd, under contract to the MoEP. The model is strictly a spreadsheet-based implementation of the equations, algorithms, default parameters, and other information presented in the IRBCA guidance document. While the spreadsheet model is believed to be free of errors, neither Ecolog Engineering, Golder Associates, Israel Ministry of Environmental Protection, or The Israel Water Authority makes any representation or warranty as to the accuracy and completeness of the spreadsheet model, and the user should confirm all results.

2 Background and Objectives

2.1 Introduction

This technical guidance document describes the key elements and methodologies of the Israel Risk Based Corrective Action (IRBCA) process. It is based on the risk-based corrective action (RBCA) standards developed by the American Society for Testing and Materials (ASTM) E1739-95 (1995a) and E2081-00 (2000a). However, it has been modified to account for Israel specific conditions. The document also takes into account the guidance provided by United States of America Environmental Protection Agency (USEPA) in the development of Regional Screening Levels (RSLs) and several state documents including but not limited to Massachusetts, California and Hawaii.

This document has been developed by a diverse stake holder group, called the IRBCA Workgroup (Workgroup), listed in the acknowledgement section. The individuals in the Workgroup represented the authorities, government bodies, industries, and non-government organizations (NGOs). The Workgroup was supported by Dr. Atul Salhotra and his colleagues at the Houston, Texas office of Risk Assessment & Management (RAM) Group of Gannett Fleming, Inc., USA. In 2018, the IRBCA methodology underwent a revision with the assistance of Golder Associates Ltd. and Ecolog Engineering Ltd.

2.2 Applicability

This guidance applies to contaminated or potentially contaminated sites. It provides the framework to conduct site-specific characterization; calculate risk-based target levels (RBTLs) protective of human health and the environment; and implement appropriate remediation and risk management activities. The guidance must facilitate the restoration of contaminated sites (and sites suspected to be contaminated) for safe reuse for current and future site uses and receptors. The various media-specific concentrations described here are not to be interpreted as “a license to pollute the environment to these levels”. Ongoing business activities must be conducted in a manner that minimizes the release of chemicals to the environment, cleanup of contaminated sites, ensures sustainable development, and is protective of human health and the environment for current and reasonable future conditions.

IRBCA is applicable to all media and the entire contaminated site. Application to a specific media only (e.g., soil or groundwater only) is not allowed unless it can be demonstrated to the authorities that the medium is completely independent of the other media.

2.3 Implementation of the Guidance

This technical guidance has been written for environmental professionals with background in site characterization, risk assessment, and risk management (including remediation). Because the overall risk assessment process and practices are relatively new to Israel, they are described at length in this document. Prior experience and training is necessary for any individual risk assessor to correctly implement the IRBCA process to ensure efficient and safe site management.

The following are the requirements of the team performing risk assessments following the IRBCA methodology:

General Requirements

At least one team member must have a B.Sc. or higher degree in natural sciences, civil or environmental engineering, with specialization in hydrology, geology, soil and water science, environmental chemistry and statistics. Team members must have expertise or be trained in field work including the collection of soil, soil vapor, and water samples according to the Israeli guidelines. For some sites, a toxicologist must be included in the team. MoEP requires that individuals conducting risk assessment in Israel must have experience with the IRBCA methodology. Risk assessors must be approved by the MoEP and the IWA. Ecological risk assessment (ERA) can be conducted by an ecologist, biologist, toxicologist or other professionals approved by the MoEP. When the risk assessment involves groundwater or Tier 2 or 3 assessments, one of the team members must be versed in the application of fate and transport models to the unsaturated and saturated zones.

Professional requirements for the International Expert

The international expert must demonstrate project experience in performing risk assessment as per the RBCA methodology (or equivalent). Along with the above academic credentials outlined in the general requirements, a team performing risk assessment must have demonstrated experience in human health risk assessment (HHRA) and ERA. The international firms must have over 15 years of experience conducting risk assessments using the RBCA methodology (or equivalent) for at least 50 sites. The international consultants assisting the local consultants must also each have a minimum of 10 years of experience conducting HHRAs and/or ERAs. The risk assessments completed by the consulting team must cover a broad range of chemicals of concern, impacted media, exposure pathways, land use, size of the site, and tier level and include HHRA and ERA. In addition, at least one of the previous sites handled by the team must be similar in nature and involve exposure pathways and chemicals similar to the site for which a risk assessment is required. In addition to the

requirements for the international consulting firm, the international consultants assisting the local consultants must also each have a minimum of 10 years of experience conducting HHRAs and/or ERAs.

Professional Requirements for the Local Consultants

The regulator currently requires a risk assessment team which consists of foreign and local consultants who meet the requirements. After one year of experience performing risk assessments following the IRBCA methodology and using the IRBCA spreadsheet, the regulator may allow the local consultants to perform risk assessments. The local risk assessors must have completed prior risk assessments for at least three (3) sites under the following conditions:

- The three (3) sites contained similar exposure characteristics and chemicals to the proposed site being investigated.
- The risk assessments were performed according to the IRBCA methodology and its associated software.
- The risk assessments were performed in cooperation with an international firm approved by the MoEP and the IWA.

If requested, members of the consulting team will need to submit to the authorities a verifiable list of sites, clients, and projects details. The MoEP and IWA reserve the right to require, any time, the addition to the consulting team performing the risk assessment, an expert with the appropriate international experience.

The following additional factors must be considered:

1. The Responsible Party (RP) must decide whether they want to conduct a risk assessment at an early stage so they can design the sampling plans to follow the IRBCA methodology and the guidance received from

authorities regarding conducting site investigations to support risk assessment.

2. The Responsible Party (RP) must notify the authorities about their decision to conduct a risk assessment instead of cleanup to Very Strict levels/Israel Drinking Water Standards (VSL/IDWS).

3. After the acknowledgment from the authorities that they have received this notification, the responsible party will submit a detailed and thorough report which will include, at a minimum, (i) the preliminary site conceptual model, (ii) evaluation of existing data, (iii) data gap analysis, (iv) proposed method to be used to fill the data gaps (i.e. additional site characterization), (iv) models and parameters that will be used to perform the risk evaluation.

4. The responsible party will submit a site investigation work plan to address all comments received from the authorities. Upon approval of the site investigation work plan by the authorities, activities must be conducted to fill data gaps. The responsible party will submit a site characterization report to address the data gaps required to proceed with the risk assessment and request the relevant authorities' approval.

5. After completing the risk-oriented site characterization, the RP will submit to the relevant authorities a revised risk assessment work plan which will include, at a minimum, (i) an updated/revised site conceptual model, (ii) compilation and evaluation of all data and presentation of representative concentrations and rationale, (iii) updated models and parameters and assumptions that will be used to perform the risk evaluation. After the authorities' approval, the RP will then proceed with performing the risk assessment.

Upon completion of the risk assessment as per the approved work plan, a risk assessment draft report will be submitted for comments and approval to the relevant authorities. The final risk assessment report will be submitted to address all authorities' comments and will include conclusions and recommendations. The recommendations have to be approved by the relevant authorities before they can be deemed final. The final report must be submitted in electronic and printed formats for each government office. The authorities request the submission of Excel™ spreadsheets with the raw data used in the RA report. The IRBCA spreadsheet model must be submitted to the email address: irbcaspreadsheet@gmail.com.

This document will also be compatible with Israeli law and/or regulation requiring that contaminated sites be cleaned up, or at a minimum, managed in a manner that is protective of current and future human health, water resources and the environment. Further, Israeli law/regulation requires that businesses conduct ongoing activities in a manner that is protective of human health, water resources and the environment. The overall responsibility for the management of contaminated sites lies with the MoEP and the IWA.

The Workgroup expects that the IRBCA process will evolve as environmental professionals (regulators, consultants, responsible parties, and others) and the public gain familiarity with the process. Thus, this document will be updated from time to time.

2.4 Long-Term Stewardship

As part of a risk-based program, knowledge of and adherence to safe uses of any site must be ensured for as long as the site has any residual contamination above unrestricted use levels i.e., residential target levels. Therefore, the IRBCA process requires that, to fully protect human health and the environment, an appropriate system of controls, - referred to as "Long-Term Stewardship (LTS)" -

will be an integral part of the risk management plans (RMP). The MoEP will approve the No Further Action (NFA) only if the LTS is placed as part of a deed notice or embedded in any other legally binding document.

3 Overview of the IRBCA Process

The IRBCA process begins when a contaminated site has been identified or a site is suspected of being contaminated. The process includes all subsequent activities that may be needed to ensure that the site does not pose an unacceptable risk to human health, water resources and the environment under current and reasonable future conditions. The process also includes any necessary long-term stewardship requirements if residual chemicals remain on site.

the IRBCA process consists of the following three steps:

1) Site characterization (SC) and delineation of impacts to soil, groundwater, surface water, sediments, soil gas, indoor air, and outdoor air, to the extent necessary based on site-specific considerations. Site characterization information is used to develop a conceptual site model (CSM), which includes the development of an exposure model (EM).

2) Risk assessment (RA) Human Health Risk Assessment (HHRA) is used to estimate the risk to humans for the complete and potentially complete exposure pathways identified by the EM and the Chemicals of Concern (COCs) under current and reasonable future conditions. Ecological Risk Assessment (ERA) is used to qualitatively and quantitatively evaluate the risk to ecological receptors, and habitats. HHRA and ERA, collectively referred to as RA, is also used to develop risk-based target levels (RBTLs) and used to determine the nature and scope of the required site-specific risk management (RM) activities. Risk assessment requires the determination of the exposure pathways and the routes of exposure for the receptors (and ecological habitats). The exposure pathway is the way in which COC moves from a source to the receptor (i.e., transport route to

the receptor). The exposure route is the manner by which the COCs enter the receptor. A receptor is an organism that is to be protected and has or may be exposed to one or more COCs as a result of a release. An HHRA is conducted as a Tier 1, Tier 2, or Tier 3 risk assessment and ERA is conducted as Level 1, 2, or 3 risk assessment. These risk assessment options are defined further in this guidance.

3) Risk management is required if the estimated risk is unacceptable and includes activities required to protect human health and the environment under current and reasonable future conditions. Risk management activities include any necessary remediation activities and any long-term stewardship activities needed to guarantee that, for as long as residual chemicals remain on site above the unrestricted land use levels, there would be knowledge of and compliance with the terms and conditions that cause the risk to be acceptable.

The above activities are fundamentally technical and rely on a variety of scientific disciplines (such as geology, hydrology, engineering, chemistry, toxicology, land use planning, etc.). The Risk-Based Corrective Action (RBCA) process also includes assumptions and policy choices consistent with laws, regulations, public opinion, and socio-economic conditions - factors that distinguish the RBCA programs in different states in the US and different countries.

3.1 Israel Risk-Based Corrective Action Process

The decision-making process, for a site where contamination is suspected or discovered, is illustrated in Figure 1.

3.2 Target Levels within the IRBCA Process

In the IRBCA process, any of the following four target levels may be selected as cleanup levels by the responsible party:

1. Very Strict Levels (VSLs), Israel Drinking Water Standards (IDWS) and Water Quality Criteria (WQC), Israel Clean Air Target Values, and/or ecological VSLs. These are the most conservative concentrations that allow unrestricted use of the property. Because VSLs are the most conservative values, their application does not require evaluation of site-specific exposure pathways, the development of a conceptual site model, any Activity and Use Limitations (AULs), or the determination of groundwater use.

2. Tier 1 Risk Based Target Values (RBTLs) are calculated using conservative default parameters for different land uses, and different exposure pathways. These are provided in this guidance document and were calculated using the IRBCA software. The user does not have to recalculate these concentrations. When site conditions significantly deviate from the assumptions inherent in Tier 1 calculations, then a Tier 2 risk assessment should be conducted.

3. Tier 2 Site-Specific Target Values (SSTLs) are calculated using site-specific data and differ from Tier 1 RBTLs in that the Tier 2 SSTLs are based on site-specific fate and transport parameters and exposure parameters, whereas the Tier 1 RBTLs use default fate and transport parameters. For each receptor, additivity of risk (for each chemical and each route of exposure) and cumulative risk (for all chemicals and all routes of exposure over various exposure areas on site) must be considered. Typically, but not always, Tier 2 SSTLs will be higher than Tier 1 RBTLs and may require AULs.

4. Tier 3 SSTLs are calculated using data collected at the site and differ from Tier 2 SSTLs in that the Tier 3 SSTLs may be developed using fate and transport models and exposure scenarios different than those used to

perform the Tier 2 evaluation. Additivity of risk and cumulative risk must be considered. The application of Tier 3 SSTLs may also require AULs. The IRBCA spreadsheet model does not include a Tier 3 evaluation.

Table 1 compares the different tiers within the IRBCA framework. However, as the evaluation moves from VSLs through the tiers, if the target cleanup levels become lower, the RP does not have the option of using higher levels from the previous tier. The higher tier target levels are based on site-specific information and hence are expected to be more representative of potential risks at the site. Different sections of the site maybe managed using different target levels and different AULs.

3.3 Management of Imminent Threat(s) and Emergency Response Actions

In all cases, the relevant authorities must be notified immediately about suspected or confirmed imminent threats as discussed below.

The MoEP Information Center tel. *6911 or 08-9253321 or 1222-6911 must be informed immediately upon discovery of a release of any hazardous substance or soil and water contamination that may pose an imminent threat. The information center must inform the relevant authorities, according to the nature of the case and existing laws and regulations and business license conditions. The relevant authorities are: the MoEP, the IWA, the Health Ministry and/or any other authorities and local authorities.

4 Process of Site Discovery

The responsible party must refer to MoEP guidance documents for conducting Historical Surveys (Phase I).

5 Initial Site Characterization and Comparison with VSLs

The responsible party should refer to MoEP and Water Authority guidance documents for conducting Initial Site Characterization (Phase II).

5.1 Objective of The Initial Site Characterization (ISC)

The objective of ISC is to collect sufficient data to determine:

- The past activities at the site to locate the sources and the potential chemicals of concern (COCs);
- Determine the maximum concentration of each COC with a high degree of certainty;
- Compare the maximum concentration of COCs to VSLs and ECO-VSLs for protection of human and ecological health, respectively;
- Determine the path forward i.e., one of the following actions:
  - Request the authorities for a NFA letter;
  - Remediate to VSLs which is MoEP's preferred alternative; or
  - Move to a tiered risk assessment (human and/or ecological).

A brief description of the site characterization process is presented below.

5.2 Site Description

The responsible party should conduct a thorough site reconnaissance and a historic review of site use and site operations to identify past, existing, and potential sources of contamination as well as a Phase I – Environmental Site Assessment (ESA) historical survey.

Based on available information, the responsible party should prepare a list of potential COCs and the probable location of sources of COCs to develop the ISC

work plan that will be submitted to the authorities for review and approval. It may be useful to develop an initial Conceptual Site Models (CSM) to optimize sampling design in order to develop the characterization work plan. At some sites this may prevent the need for a second mobilization to collect additional data.

5.3 Collection of Data

The RP must submit the site investigation work plan for data (soil, water even if not used as a drinking water source, surface water, soil gas, etc.) collection to the MoEP for review and approval. For sites in which groundwater is contaminated, a work plan for groundwater sampling will be submitted to the IWA. The work plan must meet the minimum Data Quality Assurance/Quality Control requirements of the authorities' Quality Management Plan as published on the authorities' website. After approval, the RP should implement the work plan and collect samples of all media in all expected areas of concern. At sites with multiple discrete sources, data should be collected for each of the sources. The exact number of samples, analytical methods, field sampling techniques, and quality assurance/quality control (QA/QC) samples to be collected will vary from site to site.

A key objective of ISC is to identify with reasonable certainty the maximum concentration of each COC at each source and in each environmental medium. However, for sites that may progress to a Tier 2 or Tier 3 evaluation or sites that definitely require remediation, it may be more cost effective at this point to delineate the nature and extent of contamination rather than only identify the highest concentrations. At such sites, it may be necessary to estimate the 95% upper confidence limit of the mean (95% UCL) and it hence may be useful to collect additional data. The reliable estimation of the 95% UCL requires at least 10 discrete sampling points. For sites contaminated with inorganic chemicals, e.g., metals or other naturally occurring chemicals, the work plan may include a section to estimate the site specific natural background concentration. The

authorities may not require the RP to remediate the site to below natural background concentrations.

For sites where such data has already been collected, the RP must demonstrate that the available data meets appropriate QA/QC requirements.

5.4 Ecological Risk Assessment

At this step in the IRBCA process, a Level 1 or a Level 2 Ecological Risk Assessment (ERA) may be performed. This will be determined with the regulators during the development of the risk assessment work plan. The conclusion of a Level 1 ERA, which is qualitative, will be that no further ecological evaluation is necessary due to the absence of ecological receptors or pathways or that a Level 2 ERA is necessary. Level 2 ERA will require the comparison of the maximum site concentrations with the ecological screening levels.

5.5 Comparison with Ecological VSLs and WQCs

The next step after measuring the maximum concentrations in the various impacted media, requires that the measured concentrations be compared with the relevant (soil, sediment, surface water, groundwater, sea water) WQCs, VSLs and ECO-VSLs s.

5.6 Evaluation of the Next Course of Action

Based on the above comparison, the following alternatives are available:

Alternative 1: If the maximum media (soil, groundwater, soil gas, etc.) concentrations do not exceed any of the VSLs and ECO-VSLs ; there is no need to conduct further RA or RM activities. Thus, the RP may request the authorities for a NFA letter.

Alternative 2: If the maximum soil and groundwater concentrations exceed the VSLs (and no ecological risk is identified), the RP has two options:

1) Conduct a Tier 1, Tier 2, or Tier 3 HHRA; or
2) Select the VSLs as the cleanup levels. In this case the responsible party must develop a risk management plan.

Alternative 3: If the maximum soil and groundwater concentrations exceed the VSLs, and exceed the relevant ECO-VSLs, the RP has two choices:

1) Conduct a tiered HHRA and an ERA;
2) Select the lower of the VSLs and ECO-VSLs as the cleanup levels. In this case, the RP must develop a risk management plan.

Alternative 4: If the maximum soil and groundwater concentrations do not exceed any of the VSLs but exceed the ECO-VSLs, then an ERA must be completed.

5.7 Consideration of Concentrations Reported below the Reporting Limits

During the course of investigation, the analytical reporting limit for certain COCs in environmental media may be higher (sometimes by orders of magnitude) than the corresponding VSLs or WQC for that chemical. This happens because the concentrations of chemicals that can be positively detected in the environmental media (soil, groundwater, surface water sediments, and air) are limited by the capabilities of the analytical method used and interference due to the presence of multiple chemicals in the media being analyzed. In such cases, following are a few suggestions:

1. Check the data to confirm that the standard reporting limits are indeed higher than the VSLs or RBTLs and that no errors were made (for example, transposing numbers, misplacing a decimal point, or unit conversion).

2. Use alternative more sensitive analytical methods that achieve detection limits lower than the target levels.

3. Send samples to a certified and accredited laboratory approved by Israel Laboratory Accreditation Authority (ISRAC) that uses advanced technologies which achieve the required detection limits using the analytical method required by MoEP.

4. Use other associated COCs as surrogates to determine the extent of contamination. In selecting the surrogate, confirm that the environmental mobility and toxicity of the original chemical(s) is equal to or less than the surrogate's mobility. Where multiple surrogates are possible, select the one with the mobility and toxicity most representative of the chemical with elevated detection limits. The use of surrogates must be approved by the authorities.

The above is not an exhaustive list of approaches. These and other reasonable approaches will be considered by the authorities and can be approved on a case-by-case basis.

6 Documentation of the IRBCA Process

The IRBCA process requires the collection and analysis of considerable amount of data. In addition, a variety of stakeholders – for example, government authorities, landowners, developers, lending agencies, local governments, and environmental groups – may be interested in the outcome of the IRBCA process. Therefore, the process by which data is collected and analyzed and by which decisions are made must be as transparent as possible through adequate and clear documentation. The IRBCA report must be unambiguous so that stakeholders can readily understand all the relevant data.

Typically, the following documents will have to be submitted to the authorities as a part of the IRBCA evaluation:

- Abatement of imminent threats report (when applicable),
- Work plan for site characterization and data collection,
- Site characterization report,
- Conceptual Site Model
- Risk Assessment Work plan including a summary of the problem formulation, identification of exposure areas, calculation of representative statistics for each exposure area that will be used in the subsequent risk assessment, and results of the ecological risk assessment checklists
- Tier 1 and/or Tier 2 risk assessment report (when applicable),
- Work plan for Tier 3 risk assessment (when applicable),
- Tier 3 risk assessment report (when applicable),
- Risk management plan, and risk management plan completion and performance monitoring report, including confirmatory sampling if applicable.

Depending on site conditions, some of the above may not be necessary at a site

or may be combined with the approval of the authorities.

6.1 Initial Site Characterization Report

The responsible party should document the results of the site characterization report, according to the MoEP and Water Authority guidance documents for conducting Initial Site Characterization (Phase II), and a comparison with VSLs. This report must be submitted to the authorities.

It is emphasized that any site investigation work plan for monitoring soil, soil gas, surface water, seawater, sediments, must be submitted to the MoEP. Additionally, if contamination is suspected to endanger groundwater, the work plans must be submitted to the IWA.

7 Development and Validation of a CSM

7.1 Introduction

This section discusses a systematic planning process for data collection activities for site characterization for Tier 1, 2, and 3 risk assessments. Environmental data used in the IRBCA process must be scientifically valid, defensible, of known quality and well documented. This can be achieved by the use of adequate QA/QC procedures from initial study planning through data usage. This section briefly discusses techniques used to collect the data. References are cited to provide more detailed information about methodologies for the collection of data.

It is extremely important that careful attention be paid to the preparation and implementation of the site characterization work plan to ensure that the nature and extent of contamination is accurately characterized and adequate quantity and quality of data is collected to make defensible risk based decisions.

7.2 Components of the CSM

Conceptual Site Models (CSM) identifies exposure pathways and determines the route a chemical takes (pathway) from the contaminated medium (source) to an exposed person, water source, animal, plant etc. (receptor). All items listed in this section may not apply to each site and depending upon the complexity of the site, there may be additional information required to complete the development of the conceptual site model.

If the maximum concentrations of COCs exceed the VSLs, IDWS or WQC and/or ecological VSLs and these levels are not selected as the cleanup levels, the RP would next develop and validate a CSM. A CSM describes all the relevant site-specific factors that affect the risk to human health and the environment.

The CSM is validated by collecting adequate quality and quantity of data and should be documented using narrative description, diagrams, and flow charts, as appropriate. It may include attachments such as well logs, geologic cross-sections and laboratory reports. If necessary, the CSM should be revised as new site-specific information is collected.

A CSM may be developed at the start of a project and refined and updated throughout the life of the site activities. A complete and detailed CSM is essential to making sound professional judgments related to the quality and quantity of data to be collected. Guidance documents such as *Guidance for the Data Quality Objectives Process, QA/G-4* (USEPA, 2000a) and *Data Quality Objectives Process for Hazardous Waste Site Investigations QA/G-4HW* (USEPA, 2000b) and other similar documents can help in the development of a robust CSM.

To adequately characterize a site to determine risks, the following categories of data may be required:

- Site information;
- Description and magnitude of the spill or release;
- Adjacent land use, activity use limitations (AULs), and receptor information;
- Analysis of current and future groundwater use;
- Vadose zone soil characteristics;
- Characteristics of saturated zones;
- Surface water body characteristics;
- Delineation of impacts;
- Chemicals of Concern;
- Ecological risk assessment;

Additionally, information about rainfall and other precipitation or any other watering of soil such as by irrigation and infiltration rate is also pertinent.

As part of the IRBCA evaluation, the responsible party must carefully review all the available data and identify any data gaps. A systematic planning process is required to develop a work plan to be approved by the authorities. To fill in data gaps, the Work Plan must include a sampling and analysis plan. The quality and quantity of data to be collected must ensure that:

- The intended use of the data is defined and understood to ensure that the collected data will be of adequate quality and quantity;
- All environmental data used to make risk assessment and risk management decisions are scientifically valid, defensible and of known quality; and
- The specific locations where samples will be collected, the sample handling requirements, and methods of analysis are clearly specified to avoid any confusion or ambiguity once the field work begins.

The work plan must follow a Quality Assurance Project Plan (QAPP) approved by the authorities. Examples include the guidelines of the USEPA such as *EPA Requirement for Quality Assurance Project Plans (EPA QA/R-5, 2001)* and *EPA Guidance for Quality Assurance Project Plan (EPA QA/G5, 2002a)* (QAPPs can be site specific or activity specific) and according to QA/QA required in the authorities guidelines. However, the authorities are free to decide on the QA/QC Project Plan they require.

The RP can calculate representative concentrations, prepare a tiered risk assessment, develop RBTLs, and prepare a RMP after all the necessary data have been collected.

7.3 Site Information

The term “site” refers to the areal extent of contamination where the spill or release occurred. Areas beyond the site that may be impacted by the site chemicals due to surface runoff or the migration of soil vapor or groundwater are referred to as the “off-site” areas.

The following site information is necessary to complete an IRBCA CSM. This information should be collected during the Phase I historical survey which must be approved by the MoEP/Water Authority prior to conducting a CSM:

- A site location map and site map;
- Ground surface conditions;
- Location of utilities on and adjacent to the site;
- Surface water bodies
- On-site and adjacent off-site groundwater use
- On site and adjacent off-site current and future land use;
- Local hydrogeology and aquifer characteristics;
- Sea water;
- Site history - Environmental site evaluation that will help create a complete picture of the site activities and identify COCs and data collection needs;
- All data obtained from site investigation such as soil, soil vapor, groundwater, surface water bodies and sediments sampling and monitoring;
- Site visits;
- Deed search;
- Historical records and aerial photographs;
- Interview of past site workers;
- Review of engineering drawings showing the layout of the site;
- Review of regional land use and groundwater use information;
- Review of files with the authorities related to the site or adjacent sites;

- Contact with the city, municipality or other authorities to identify any existing land use requirements, such as zoning; and
- Previous and current sampling and monitoring data of soil, soil vapor, groundwater, surface water bodies and sediments.

The following sections mention specific information relevant to the CSM that should be collected during the site information phase.

7.3.1 Site Location Map

A site location map must be prepared. The site location should be centered on the topographic map, with the site clearly marked. Contour lines on the topographic map must be legible.

7.3.2 Site Map

As appropriate, a detailed map(s) of the site should show:

- Property boundaries;
- Layout of past and current site features such as containment or storage systems; process areas; transportation and delivery distribution systems; waste handling and storage areas including associated components and piping runs; sumps; paved and unpaved areas; and buildings;
- Locations of area(s) of release;
- Locations of on-site monitoring wells (including those that have been abandoned, identified in some way but for which exact information is missing, or destroyed);
- Locations of water use wells (public and private);
- Location of surface water features;
- Location of sea and beaches;
- Ecological sensitive features; and
- Locations of soil borings, soil vapor extraction wells, and soil excavation areas.

Multiple maps showing these features may be necessary. Site maps must be drawn to scale, include a bar scale, and a north arrow. In addition to the site map(s), a land use map is also required.

7.3.3 Ground Surface Conditions

The following information should be included:

- Identify the portion of the site that is paved, unpaved or landscaped;
- Document the type, extent, date of installation, general condition of the pavement, and type of sealing material and compatibility of sealing materials with COCs present on the site;
- Describe the unpaved areas (for example, vegetated, gravel, or bare soil); and
- Determine the direction in which the surface is sloping and note relevant topographic features (for example, swales, drainage, or detention ponds).

7.3.4 Location of Utilities On and Adjacent to the Site

Contaminated groundwater and vapors can flow preferentially into and through underground utility lines and conduits and increase the probability of utility workers or other receptors being exposed. Therefore, a thorough assessment of potential and actual migration and impacts of COCs to underground utilities must be performed. Utilities include cable, electrical and telephone lines, sanitary and storm sewers, and water and natural gas lines. A combination of site observations, knowledge of buried utilities, and discussions with utility representatives and the site owner should be used to determine the location of site utilities. At a minimum, the following must be performed:

- If explosive conditions are encountered, immediately inform the local authorities, and the MoEP Information Center tel. *6911 or 08-9253321 or 1222-6911;
- Locate all underground utility lines and conduits within the area of known or suspected soil and groundwater impact, both on- and off-site, where the release may have migrated or may migrate in the future.

If utilities are located in the area of contamination, the following information may be useful:

- Direction of water flow in utility lines (potable water, storm water, and sewage);
- Location of the utility lines and conduits on a base map that shows the extent and thickness of non-aqueous phase liquid (NAPL), if any, and soil and groundwater contamination;
- Depth of the utility lines and conduits relative to the depth of groundwater. Seasonal fluctuations of groundwater levels (relative to the depth of utilities) must be carefully evaluated. A cross-sectional diagram that illustrates the depth to groundwater, the locations and depths of the utility lines, and conduits is recommended;
- Types of materials used for utility lines and conduits - for example, polyvinyl chloride (PVC), terra cotta, concrete or steel - and the type of backfill around the utilities; and
- Any historical work completed on any of the utilities and if any contamination-related issues identified at the time the work was performed.

7.3.5 Surface Water Bodies

The following information must be collected for surface water bodies, if impacted, to develop the CSM:

- Distance and direction to the surface water body;
- Likely location where COCs from the site would discharge into a surface water body;
- Flow direction and depth of any groundwater contamination plume(s) in relation to the water body;
- Lake or pond acreage or stream flow rate;
- Ecological habitats; and
- Relevant WQC for streams.

7.3.6 On-site and Adjacent Off-site Groundwater Use

An essential component of the CSM is to determine if the domestic use of groundwater is a complete pathway under current or future conditions. Domestic use of groundwater includes ingestion, dermal contact, and inhalation of vapors generated by indoor water use such as showering and washing.

Current and former site owners and operators should be interviewed to determine whether any water use well(s) is or was located on-site. Any and all wells must be identified based on a search of authority records and databases, drive by, or door-to-door surveys, as appropriate. The level of effort necessary will be especially critical for the authorities to make a determination whether the domestic use of groundwater pathway is complete or incomplete.

To the extent that such information is available, the RP must search for and provide well construction details for all wells identified including the total depth of the well, casing depth, screened or open interval, static and/or pumping level, and the use of water from the well. If available, average well pumping rates and drawdown information should also be provided.

If an identified well is not currently in use or likely to be used in the future, it

should be closed, or else it may act as a potential conduit for COCs to reach the groundwater.

7.3.7 Local Hydrogeology and Aquifer Characteristics

Local hydrogeology, soil types, and aquifer characteristics should be evaluated to determine the type and depth of aquifers in the area and whether they are confined, semi-confined or unconfined. This information may be found in published literature or reports for investigations conducted at adjacent or nearby sites. General aquifer characteristics such as yield and total dissolved solids will help determine whether the domestic consumption exposure pathway is a concern. The RP should use regional information to better understand site-specific soil and groundwater conditions.

The review discussed above should also identify surface water bodies (lakes, rivers, streams, and wetlands), seeps, caves, sinkholes, and springs located within a distance that is or could be affected by a release at the site. Water bodies must be identified on the area map.

7.3.8 Sea Water

The following information must be collected for sea water, if impacted, to develop the CSM:

- Distance and direction to beach and sea water;
- Likely location where COCs from the site would discharge or be released into the sea water or beaches;
- Flow direction and depth of any groundwater contamination plume(s) and/or adjacent surface water bodies that flow into the sea;
- Use of beaches and sea water (bathing, recreation, tourist, nature reserve etc.);

- Location of streams, wadis, canals, sewers in relation to the sea water;
- Open sea or closed bay;
- Flow rates as applicable;
- Ecological habitats; and
- Sea WQC.

7.4 Description and Magnitude of Spill Release

Knowledge about the nature, location and magnitude of a release(s) is necessary to identify the soil and groundwater source(s) at the site, horizontal and vertical extent of contamination, COCs and methods that will be used to collect and analyze the samples.

The RP must collect as much of the following information as is available for each release that has occurred at the site:

- History of site activities related to the release
- Location(s) and date(s) of spill(s) or release(s);
- Quantity of the release(s);
- Product(s) or chemical(s) released; and
- Any remedial actions and interim response actions taken with respect to each release.

Release-related information can be obtained from a variety of sources, including:

- Review of historical aerial photographs;
- Review of product or waste inventory records ;
- Interviews with past and current on-site employees; and
- Review of historic spill incident reports filed with the authorities.

7.4.1 History of Activities at the Site

A key step in the IRBCA process is to develop a comprehensive chronology of historical events related to any chemical impacts. A chronology will help create a complete picture of the site activities and identify COCs and data collection needs. The chronology should include information such as the dates, descriptions, and results of:

- Installation, removal or upgrade of containment, chemical processes, delivery or waste systems;
- Remedial activities such as excavation and disposal of contaminated soil;
- Drilling, sampling and gauging of monitoring wells; and
- Collection of environmental media samples.

Remedial actions or interim response may have removed all or part of the COCs released at a site. Soil and groundwater data collected prior to the completion of these activities may not be representative of current conditions and should not be used in the calculation of current exposure and risk. At such sites, the RP must collect additional soil, soil vapor (if volatile COCs are relevant), and groundwater concentration data representative of current conditions. However, data collected prior to the completion of interim action(s) may be used to guide decisions on additional data collection.

7.4.2 Location and Date of Spill or Release

The location of a release helps define the source area(s). Likely release locations at contaminated sites include:

- Corroded or damaged containment or process system components;
- Piping, especially at pipe bends and joints and floor drains;

- Dispenser and delivery systems;
- Deposition near smoke stacks or air discharge points;
- Accidental releases at areas for receiving, delivering, or handling chemicals and wastes;
- Waste water lagoons and run-off basins;
- Waste storage and disposal areas;
- Sewer pipes; and
- Hazardous product materials storage areas.

During collection of surficial soil samples where metals are a potential concern, it is important to collect data from the shallowest depth that can be practicably sampled, rather than choosing a random sampling interval in the 0 – 1 m zone or compositing samples across the entire zone. Random use of data from a 0 – 1 m interval can dilute and mask the actual distribution of the COCs' concentrations if contamination is not homogenous across the soil profile. These types of concerns should be addressed in the data collection work plan.

Based on the site chronology and operational history, the RP may be able to determine the location and date of the release(s). However, often the exact location and date of the release(s) cannot be known. In such cases, field screening, such as the use of a photoionization detector (PID), x-ray fluorescence (XRF) spectrophotometer, membrane interface probe (MIP), field bioassays, and/or collection of samples for laboratory analysis must be used to identify the likely location and extent (vertical and horizontal) of COCs in the soil and groundwater. All soil samples must be collected by a person or organization certified by the Israeli Laboratory Accreditation Authority and recognized by the MoEP. All sampling must follow the updated guidelines as published on the website of the MoEP and the work plan must be approved by the authorities. All soil analyses must be performed by a laboratory certified for the required tests by the Israeli Laboratory Accreditation Authority.

Decisions regarding the use and application of field screening technologies and collection of samples must be based on site-specific conditions and chemicals. For example, PIDs may not be accurate for soils above certain moisture content, and the PID does not detect all types of chemicals. Visual observations may be used to identify soil sample locations. This information is part of a sampling and analysis plan.

Field screening technologies such as PIDs, XRF, passive soil vapor sampling or other handheld field analyzers should <u>not</u> be used in the quantitative risk assessment as their detection limits may not meet the risk assessment requirements.

7.4.3 <u>Quantity of Spill or Release</u>

The IRBCA process does not require knowledge of the exact quantity of the historic releases of chemicals or wastes. Often this information is not known. However, having a general idea of the amount released can assist in assessing the potential extent and severity of a chemical impact. However, it should be noted that MoEP requires reporting of the exact amount spilled for current releases. This information is required, among other reasons, also in order to assess the efficiency of leak detection means required by law, the amount of contamination that remains in the environment that needs to be addressed, and is necessary for mass balance calculations required by MoEP.

7.5 Nuisance Conditions

In addition to HHRA and ERA, COC concentrations in the environment must not result in or cause nuisance conditions. The existence of such nuisance conditions must be considered and, as appropriate, risk management steps implemented to eliminate such conditions. In the context of petroleum impacted sites, the following are examples of nuisance conditions:

- A sheen on a water body;
- Gross discoloration and stains on the ground surface;
- Odors detected in the ambient air or inside a building that are noticeable and persist for several days;

Typically, nuisance conditions will be eliminated during remedial activities required to achieve the tiered human and ecological risk based standards. However, at sites where nuisance conditions need immediate abatement, or if nuisance conditions persist after risk management activities have been implemented or if risk management activities are not required due to health considerations, the authorities may require additional activities in order to eliminate nuisances.

7.6 Adjacent Land Use, Use Limitations, and Receptor Information

Land use information is used to identify the (i) location and type of potential receptors, (ii) exposure pathways by which the potential receptors may be exposed to the COCs, and (iii) presence of any AULs that may affect the completion of exposure pathways. This information is critical in developing a site EM. Specifically, the following information must be collected:

- Current land use and zoning;
- Potential future land use and zoning;
- Local ordinances, easements, and restrictions that affect land or groundwater use;
- Quality and availability of potable water supplies;
- Off-site groundwater use;
- Presence of ecological receptors, habitats and pathways; and
- Soil used for livestock and/or for agricultural crops and foods.

At a minimum, the authorities will require a land use and receptor survey

covering the entire impacted and potentially impacted area.

For the purposes of this document, land use is defined as:

Residential Land Use: The use of land for the primary purpose of (a) a residence by persons on a permanent, temporary or seasonal basis, including, without limitation, single family dwellings, cabins, apartments, condominiums or townhouses, or (b) institutional facilities, including, without limitation, schools, hospitals, daycare operations, prisons, community centers, places of worship (synagogues, mosques, churches).

Non-Residential "Commercial/Industrial Land Use": The use of land for the primary purpose of buying, selling or trading of merchandise or services including, without limitation, shopping malls, office complexes, restaurants, hotels, motels, grocery stores, automobile service stations, petroleum distribution operations, dry cleaning operations, municipal yards, warehouses, law courts, museums, golf courses, government offices, air and sea terminals, bus and railway stations, and storage associated with these uses.

In the event a site is located in a mixed residential and non-residential area, the residential land use should be considered by default.

Agricultural Land Use: Agricultural Land use should be considered "Residential" for the direct soil contact pathway (dermal contact, ingestion, and inhalation of vapors and particulates). The analysis of risks from consumption of food crops should be considered Tier 3.

7.6.1 Current Land Use

Knowledge of the uses of the site and nearby properties is necessary to define potential on-site and off-site receptors that may be exposed to the COCs. A visual, on-site land use reconnaissance survey within the area of impact must be

conducted to avoid ambiguity about site uses. The survey must clearly identify the following: schools, hospitals and other medical facilities, residences (apartments, condominiums, townhouses, and single-family homes), buildings with basements, day care centers, and synagogues, other houses of worship, nursing homes, and types of businesses. The survey must also identify surface water bodies, sea and beaches, parks, nature reserves, recreational areas, wildlife sanctuaries, wetlands, and agricultural areas. The survey must indicate whether impacted soil is used for livestock and/or for agricultural crops and foods. The results of the survey must be accurately documented on a land use map.

7.6.2 Future Land Use

Future land use and receptors must be established, which is more difficult to determine than current land use and receptors. Unless future land use is known and can be documented (for example, by development plans or building permits), predictions of reasonably anticipated future use must be presented, based on local zoning laws and surrounding land use patterns. As appropriate, zoning maps, aerial photographs, local planning offices, community master plans, changing land use patterns, and interviews with current property owners can provide information with which future land use can be predicted. Proximity to wetlands, sensitive habitats, and other environmentally sensitive areas must also be considered in predicting future land uses. Future land use for livestock and/or for agricultural crops and foods must be evaluated in the framework of Tier 3 risk assessment.

7.6.3 Analysis of Current and Future Groundwater Use

A water well survey must be conducted to locate all public and private water supply wells within a one kilometer radius of the site. (The radial distances referenced above are minimum requirements, the survey will be based upon IWA

database. Relevant authorities' requirements or differences in COC mobility and/or hydrogeology at the specific site may necessitate well surveys of greater areal extent.) A few of these wells may be known prior to the water well survey; others may be identified during the survey.

The effort to be invested in this task is especially critical if the authorities are to identify domestic consumption pathway during the RA process or if groundwater discharge into streams or sea is involved.

As for on-site wells, to the extent that such information is available, the RP must provide well construction details for all wells identified. Relevant construction details include the total depth of the well, casing depth, screened or open interval, static and/or pumping level, and the use of water from the well. If available, average well pumping rates and drawdown information also should be provided.

If an active groundwater supply well is located within a 500 m radius of the site, the point of exposure (POE) will zero (0), meaning no horizontal dilution attenuation will be allowed.

The IRBCA process can be used in cases where groundwater has been contaminated or is likely to be contaminated by a site-specific release. The process has the following objectives:

- To protect all current and reasonably anticipated future uses of groundwater and ecological systems from vapor intrusion under current and future conditions;
- To provide a rationale for incorporating site-specific characteristics into the determination of groundwater target levels; and
- To facilitate the development of properties based on reasonable expectations for groundwater cleanup.

The groundwater domestic consumption pathway is considered complete by default in the IRBCA process. If the RP determines that groundwater pathway is incomplete for drinking water use, e.g., that the groundwater for this pathway will not be impacted, or if the water is naturally saline and cannot be used for drinking water purposes, then justification for this determination should be provided in the tiered risk assessment report. Such justification must be approved by the IWA prior to risk assessment report submission. Other groundwater exposure pathways such as discharge to surface waters, including sea water, agriculture irrigation must be evaluated in Tier 2 and Tier 3 risk assessments as required by the IWA and the MoEP. Other relevant exposure pathways for ERA will be evaluated in Levels 1 – 3.

Whether a well may be impacted depends on factors such as:

- Characteristics of soil and rock formations;
- Groundwater flow direction;
- Hydraulic conductivity;
- Distance to the well;
- The zone where the well is screened;
- Depth of well casing;
- Zone(s) of influence and capture generated by well discharge; and
- Biodegradability and other physical and chemical properties of the COCs.

7.7 Ecological Receptor Survey

Ecological receptors include both specific species and general populations of flora and fauna, terrestrial organisms, and aquatic organisms and their habitats, including wetlands, surface water bodies, sea water, sediments, sensitive habitats. Protected, threatened and endangered species residing on the site and its vicinity may require special consideration. Protection of such ecological receptors is a key part of the IRBCA process.

The ERA Level 1, Checklists A and B are a screening tool that must be completed for any Tier 1, Tier 2, or Tier 3 risk assessment if deemed relevant as part of the risk assessment work plan. Accurate information for the above checklists will require that the area around the site be visually and otherwise surveyed for specific ecological receptors and habitat criteria by an ecologist.

Refer to the "Ecological Risk Assessment" section for further information regarding ERA.

A key determination in developing risk-based groundwater target levels is whether the groundwater domestic use pathway is complete under current or future conditions. The analysis of current and future groundwater domestic use must include all groundwater zones beneath or in the vicinity of the site that could potentially be (i) impacted by site-specific COCs, or (ii) targeted in the future for the installation of water use wells. For the purposes of this analysis, groundwater-bearing zones must be evaluated in a three dimensional context.

As a part of this step, other groundwater uses must also be identified and documented and risk must be evaluated.

7.8 Vadose Zone Soil Characteristics

The vadose zone is the uppermost layer of the earth and is conceptualized as a three-phase system consisting of solids, liquid, and vapors. Vadose zone soil is a medium through which COCs can migrate to groundwater and through which vapors can migrate in all directions to indoor and outdoor air. The following vadose zone parameters and their variability across the contaminated area affects the movement of chemicals:

- Dry bulk density, porosity, water content, and fractional organic carbon content – these four parameters are often collectively referred to as the

soil geophysical or geotechnical parameters. Consideration should be given to preferential pathways. For example, desiccation cracks may provide a preferential pathway at sites where the primary soil type is clay.

- Thickness of vadose zone, depth to groundwater, and thickness of capillary fringe.

For Tier 1 RA, the authorities have assigned conservative default values to these parameters for a generic vadose zone soil type representing soils in the Israeli coastal aquifer. For Tier 2 and Tier 3 RAs, site-specific values based on data collected from the site or justified default parameters must be used.

If circumstances at a site are such that the geophysical properties cannot be determined because of sampling limitations, the RP must use appropriate conservative, justifiable literature values or values from samples collected in the field at nearby sites having similar lithological and geologic characteristics. If values cannot be found or do not exist, the RP should contact the authorities for further guidance.

Generally, collection of geophysical soil samples will require more than one boring or probe, depending on site conditions and recovery volumes. Ultimately the number of borings or probes necessary to obtain representative values of these parameters will be a site-specific decision of the environmental consultant based on professional experience and judgment. The objective is to collect enough samples so that the results are representative of site-specific conditions. Fewer samples will be required at sites with relatively homogeneous vadose zone characteristics while more samples will be required if heterogeneous conditions exist.

In situations where undisturbed samples cannot practically be collected for the purposes of measuring dry bulk density, justified literature values may be used. However, samples must be collected and analyzed for fractional organic carbon,

gravimetric water content, and particle density. The table below summarizes various vadose zone characteristics used in the IRBCA model.

Parameter	Symbol	Unit	Calculation / Method of Determination	Description
Dry Bulk Density	ρ_s	[g/cm^3]	ASTM Method D2937.94 or Similar	Dry bulk density is the dry weight of a soil sample divided by its field volume. An accurate measurement of dry bulk density requires determination of the dry weight and volume of an undisturbed sample of soil.
Total Soil Porosity	θ_T	[c^3/c^3]	$\theta_T = 1 - \rho_\beta/\rho_\sigma$ Where, θ_T = Porosity [c^3/c^3], ρ_β = Dry bulk density (g/c^3), and ρ_σ = Specific gravity or particle density (g/c^3).	Total 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 of soil particles to calculate total porosity.
Volumetric Water Content	θ_{ws}	[cm^3/cm^3]	ASTM Method D2216-98, "*Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soils and Rock by Mass*,"	Volumetric water content is the ratio of the volume of water to the volume of field or undisturbed soil. When using ASTM Method D2216-98, proper conversion between the mass of the sample to the volume should be applied.

Parameter	Symbol	Unit	Calculation / Method of Determination	Description
Fractional Organic Carbon Content in the Soil	f_{ocv}	[g-c/ s-soil]	ASTM Method D2974 *(Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils). or* Walkley-Black Method in ASTM F1647-11	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. This parameter is used to estimate the pore water concentration and pore air concentration based on a total soil concentration.
Thickness of the Vadose Zone, Depth to Groundwater	H_v	[cm]	$H_V=L_{gw} - h_c$ Where: H_V = Thickness of the Vadose Zone L_{gw} = Depth to Groundwater from the Ground Surface h_c = Thickness of the Capillary Fringe	The thickness of the vadose zone can be determined based on information presented on boring logs and/or from measurements taken from monitoring wells or piezometers. It represents the distance from the ground surface to the depth at which the water table is encountered.

Parameter	Symbol	Unit	Calculation / Method of Determination	Description
Thickness of the Capillary Fringe	h_c	[cm]	Thickness or height of the capillary fringe can be measured or an appropriately justified value used, since accurate field measurement can be difficult.	The capillary fringe is the zone immediately above the saturated zone where capillary attraction causes upward movement of water molecules from the saturated zone into the soil above. This zone is distinct in that it has characteristics of both the vadose and saturated zones. Literature values based on the soil type immediately above the water table may be used to assign a site-specific value for the capillary fringe thickness.

7.9 Characteristics of the Saturated Zone

COCs may reach the water table by travelling vertically through the vadose zone. Vertical migration in the saturated zone can be expected in the following conditions:

- When the matrix porosity of the subsurface medium of interest is conducive to vertical migration;
- When a natural or induced downward vertical gradient exists between shallow and deeper saturated zones;
- When vertically oriented secondary porosity features are present; or
- When NAPLs are present. Typically, the vertical migration of LNAPLs will stop at the water table, whereas the dense NAPLs (DNAPLs) will continue to move vertically downwards through the saturated zone.

Saturated zone characteristics that determine the rate, magnitude and direction of migration of COCs in groundwater include:

- Horizontal and vertical hydraulic conductivity;
- Hydraulic gradients (magnitude in both horizontal and vertical direction);
- Residual mass in capillary fringe;
- Saturated zone soil geophysical characteristics (fractional organic carbon content, total and effective porosity, and bulk density);
- Groundwater parameters;
- Infiltration rate;
- Occurrence and rate of biodegradation;
- Retardation due to other factors, such as sorption due to soil mineral oxide content; and
- pH and redox potential especially at sites where the COCs include metals.

Of the characteristics mentioned above, the properties typically having the

greatest influence on COC migration are hydraulic conductivity and hydraulic gradient. Early in the IRBCA process, various groundwater zones and the hydraulic inter-connection among them must be identified. Qualitative and quantitative understanding of the above factors may be necessary for each of the zones.

When necessary, values of hydraulic conductivity, hydraulic gradient, effective porosity, and fractional organic carbon content must be used to estimate the advective migration for the COCs in groundwater. The calculated migration rate and extent of the groundwater plume should be compared with actual data to further validate the CSM. The table below summarizes the characteristics of the saturated zone used in the IRBCA model.

Parameter	Symbol	Unit	Calculation / Method of Determination	Description
Hydraulic Conductivity	K	[cm/yr]	Reliable estimates of site-specific hydraulic conductivity can be obtained by field tests such as pump tests or slug tests. 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.	Hydraulic conductivity is the discharge of water per unit area per unit hydraulic gradient in a subsurface formation.
Hydraulic Gradient in the Saturated Zone	i	[cm/yr]	The magnitude and direction of the hydraulic gradient is estimated by comparing water levels measured in monitoring wells across a site.	Hydraulic gradient is a vector gradient between two or more hydraulic head measurements over the length of the flow path.
Groundwater Darcy Velocity	U_{gw}	[cm/yr]	Ugw = K * i	The flow per unit cross sectional area of a porous medium.

7.10 Surface Water Body Characteristics

To develop soil and groundwater target levels that are protective of surface water beneficial uses, surface water standards are necessary.

7.11 Delineation of Impacts

IRBCA process requires the collection of sufficient data to delineate the impacts in various contaminated media, as discussed below.

7.11.1 Delineation of Impacts in Soil and Groundwater

Prior to the performance of a risk assessment, the RP must review the available data and determine if data of sufficient quality and quantity are available to delineate the extent of impacts in soil and groundwater. The horizontal and vertical extent of soil and groundwater contamination must be delineated on- and off-site to the extent necessary to assess potential exposures to receptors and impacts to surface water bodies, sediments, and sea.

A key issue related to the delineation of impacts is the concentration levels to which impacts are defined. Several alternatives are available. Examples include but are not limited to: background levels, IDWS, Tier 1 RBTLs, SSTLs, or non-detect levels. The IRBCA guidance does not explicitly specify one-size-fits-all delineation concentrations for environmental media; instead, it uses "performance based" delineation criteria, as explained below.

Lateral and vertical impacts in soil and groundwater must be delineated to the extent required to determine potentially complete exposure pathways to human and ecological receptors (including habitats) under current and reasonably anticipated future use conditions and the extent of impacts above target levels for corresponding potential exposure pathways.

For example,

- Delineation may be to non-residential levels on-site at non-residential facilities, but if the plume extends off-site and surrounding land uses are residential, then delineation would be to residential levels;
- Depending on the complete exposure pathways, delineate soil to lower of the concentrations protective of indoor inhalation or domestic use of groundwater target levels; or
- Delineate to vapor intrusion target levels if volatile compounds are beneath or adjacent to existing buildings or planned future buildings would be located over contaminated areas.

The above use of performance criteria presents a dilemma in that the contaminated media must be sufficiently delineated to evaluate the risk at a site; however, risks cannot be accurately estimated until the site has been delineated. If AULs or engineering controls are to be used as a component of the final remedy, delineation efforts will need to define areas over which these controls will be placed.

Thus, an iterative approach to delineation may be necessary unless the RP decides to delineate the site to background, VSLs, relevant WQC, or non-detectable levels. If these delineation levels are not used, the following iterative approach may be used. At sites where it is clear that active remediation is necessary, the RP may proceed with interim remedial measures and subsequently use confirmatory samples to delineate the extent of residual impacts. Thus, issues associated with contaminant delineation would not delay the implementation of remedial activities.

1. Prior to performing the site work, develop a preliminary CSM, including the EM. The EM must consider receptors on site and on adjacent properties that may be exposed to contamination. This will require a determination of

whether the domestic use of groundwater is or could be a complete pathway in the future.

2. Based on the complete exposure pathways for soil and groundwater, identify the applicable Tier 1 RBTLs. At sites where it is clear that a Tier 2 RA will be necessary and enough information is available about the site, it may be reasonable at this time for RP to develop preliminary Tier 2 SSTLs.

3. After the delineation level for each COC has been established, the following field activities should be conducted:

    - Groundwater data from a direct push investigation may be used to screen the extent of impact prior to the installation of permanent monitoring wells. The number and location of direct push screening points and monitoring wells is a very site-specific professional decision. Delineation will require multiple field mobilizations. For sites where sufficient groundwater data from monitoring wells indicates a shrinking plume, data from a direct push investigation could be used to delineate the down gradient extent of the plume. Direct push investigations should be continued down gradient of the site source/release area until data indicates levels at or below the delineation level.

    - For sites where the available data indicates that the plume may be migrating, the RP must conduct sufficient investigations to determine the extent and rate of migration. It may be more cost effective to conduct a direct push investigation followed by the installation of a permanent delineation monitoring well(s). Wells must be monitored at a frequency and for a period of time sufficient to clearly demonstrate plume trends (expanding, stable, or shrinking) and to demonstrate that the COC concentrations in the

down gradient wells are below the delineation levels.

- Upon preliminary completion of the site characterization, a check should be made to confirm that the assumptions used in the initial CSM were accurate and that the delineation levels are appropriate.

- In cases where the source of the pollution is still active (including a groundwater plume moving towards the site), the COC will be examined individually after consultation with the relevant regulator (MoEP, IWA, Ministry of Health) and will not automatically enter Tier 2 or set and expected future representative concentration value higher according to the IRBCA spreadsheet.

- For delineation of soil impacts, borings should be installed and soils sampled at increasing horizontal and vertical distances from the source area until the delineation levels are reached.

Chemical fate and transport modeling may be used as appropriate to aid in the placement of monitoring wells. Degradation or breakdown products must be taken into account.

7.11.2 Delineation of Impacts in Other Media

In addition to the delineation of soil and groundwater contamination, impacts to other media (for example, surface water, sea water, sediments, and air) must be evaluated. The number of samples, sample locations, delineation, and sampling methodologies will be based on site-specific considerations; hence, the RP must receive the MoEP's approval for the work plan prior to conducting fieldwork. For surface water and sediment sampling, the work plan must contain a strategy to determine background levels, location and concentration of site-related discharges to the surface water and/or sea, and the extent of COC impacts as

well as the impact of their degradation or breakdown products. If soil gas concentrations are to be measured, the work plan must contain a strategy to determine ambient background levels of the COCs.

Because the delineation process may be iterative, as part of the work plan, the authorities will require documentation supported by site-specific data to confirm that the impacts have been delineated to the final risk-based target levels in all media.

7.12 Ecological Risk Assessment

The IRBCA process requires protection of both human health and ecological systems. Ecological protection extends to all non-human organisms and their habitats (ecological receptors). Therefore, exposure to ecological receptors (including their habitats) must be considered and evaluated. For a more detailed discussion of ERA refer to the *Ecological Risk Assessment for Superfund (ERAGS): Process for Designing and Conducting Ecological Risk Assessments* (USEPA, 1997a).

An ERA is required as a part of all IRBCA evaluations even when cleanup to VSLs and WQC is executed. Within the IRBCA process, ERA has three levels:

- Level 1 is a qualitative screening evaluation comprised of Checklists A and B;

- Level 2 requires comparison of site specific concentrations with relevant published screening values protective of ecological receptors and Israeli threshold values protective of ecological receptors. If required by the results of Level 1, the RP must develop a work plan to conduct an ERA and submit to the MoEP for approval prior to its implementation, and

- Level 3 ERA that allows a site-specific evaluation.

A Level 2 and/or Level 3 ERA is necessary only if ecological concerns persist beyond the Level 1 ERA and must be performed by an ecologist, biologist, eco-toxicologist or equivalent.

7.12.1 Level 1 Ecological Risk Assessment

A Level 1 ERA must be performed at every site to identify whether any ecological receptors or habitat exist at, adjacent to, or near the site that may be affected. The evaluation, starts with Checklist A included as part of this guidance and consists of multiple questions. This checklist is a qualitative evaluation that can be completed by an experienced environmental professional who is a trained ecologist or biologist. The checklist is designed in such a way that if the answer to all the questions is negative, no further ecological evaluation is necessary.

Completion of this checklist requires a definition of environmentally sensitive areas. These areas are of special significance due to its flora or fauna, the sensitive nature of its natural features, historical considerations, or other reasons associated with the environment. Examples of environmentally sensitive areas include, but are not limited to the following:

- National parks;
- Designated and proposed national wilderness and natural areas, endangered, rare, and threatened species habitat as designated by the MoEP;
- National monuments, historic sites, lakeshore, river and rivers recreational areas;
- Designated scenic or wild rivers and streams;
- Habitat of designated or proposed endangered, rare, or threatened

species, and species under review as to their endangered, rare, or threatened status;

- National preserves and forests;
- Wildlife refuges;
- Critical fish spawning areas;
- Critical migratory pathways and feeding areas for fish species within river/streams reaches or areas in a lake where such species spend extended periods of time;
- Terrestrial areas used for breeding by large or dense aggregations of faunal species;
- State lands designated by Israel for wildlife or game management; and
- Wetlands as defined by the MoEP.

A positive answer to any one of the questions in Checklist A implies that a receptor or a habitat exists on or near the site and further evaluation is required. Therefore, a second checklist of questions, Checklist B must be completed. The second checklist determines if any pathways are complete or have a reasonable potential to be complete for any of the receptor(s) identified in Checklist A. If the answer to all questions is negative, the conclusion is that, even though a receptor exists on or near the site, a complete pathway to the receptor(s) does not exist and, therefore, there are no ecological concerns at the site and its vicinity. If the answer to one or more of the seven questions is positive, a Level 2 ERA may be necessary to determine whether contamination at the site poses an unacceptable risk to ecological receptors. A trained professional who is an ecologist, biologist or ecotoxicologist is necessary to make these determinations.

7.12.2 Level 2 Ecological Risk Assessment

In a Level 2 ERA, site-specific COC concentrations that may reach an environmental receptor are compared to the relevant ECO-VSLs presented in the

ECO VSL tables. If a chemical is not included in ECO VSL tables, a value may be obtained from literature. Examples of sources for ECO-SSLs include the following:

- Region 4 Ecological Risk Assessment Supplemental Guidance - Table 3 (USEPA, March 2018)
- Guidance for Developing Ecological Soil Screening Levels (Eco-SSL). OSWER directive 9285.7-55, November 2003, Revised February 2005;
- Environmental screening levels (ESLs): Screening for Environmental Concerns at Sites with Contaminated Soil and Groundwater, prepared by California Regional Water Quality Control Board, San Francisco Bay Region- Interim Final- November 2007 (Revised May 2008);
- National Oceanic and Atmospheric Administration (NOAA) criteria: Screening Quick Reference Table (SQuiRTS) (NOAA, 2008). Region 5 RCRA Corrective Action Branch;
- Ontario sediment criteria;
- USEPA online databases (examples include ECOTOX, AQUIRE);
- Ecotox Thresholds (ETs) update of ECO: Office of Solid Waste and Emergency Response. Publication 9354.0-12FSI, EPA 540/F-95/038, PB95-963324, January 1996a. Office of Emergency and Remedial Response Intermittent Bulletin Volume 3, Number 2;
- Oak Ridge National Laboratory (ORNL) benchmarks: ORNL Values as presented in Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision ES/T/Tm-96/R2. Sutter II and C.L. Tsao, (DOE 1996);
- TOXNET (National Institute of Health); and
- Ecological Screening Values for Surface Waters, Sediment and Soil. Friday G.P. Contract No. WSRC-TR-98-00110.

Since the above documents are periodically updated, it is important to use the most current values. If the comparison of representative, site-specific soil concentrations indicate that applicable screening concentrations, presented in

the IRBCA tables, are exceeded, the RP may perform a Level 3 ERA or choose these concentrations as cleanup standards.

The ratio of the site representative concentration to the ECO-SSL concentration is referred to as the hazard quotient (HQ). Thus a HQ greater than 1 implies that the site concentration exceeds the acceptable concentration. In this situation, if it is decided to clean the site to meet the ECO-SSLs, then at least one element of the RMP must address management of the ecological risk.

7.12.3 Level 3 Ecological Risk Assessment

A Level 3 ERA will include a detailed site-specific evaluation. Following are a few documents that present guidance for performing a site specific evaluation:

- Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments Interim Final EPA 540-R-97-006 June 1997 (USEPA, 1997a);
- Guidelines for Ecological Risk Assessment. USEPA/630/R-95/002F. April 1998 (USEPA, 1998);
- Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities- State of California- DTSC July 4 1996 (CalEPA, 1996);
- R.S. Wentsel, Tri-Service Procedural Guidelines for Ecological Risk Assessment. U.S. Army Edgewood Research, Development and Engineering Center (ERDEC), Aberdeen Proving Ground, MD, ADA29796, May 1996.

A Level 3 ERA will require the development of a site-specific, detailed work plan and approval by the MoEP prior to its implementation. As above, if a site-specific analysis determines that the risk to ecological species is still unacceptable, then at least one element of the RMP must address management of the ecological risk to protect the target species or habitat.

7.13 Chemicals of Concern

Chemicals identified by the RP prior to conducting the Tier 1 risk assessment screening evaluation are considered to be Chemicals of Potential Concern (COPC). Following the Tier 1 risk assessment, chemicals that do not meet acceptable risk levels are be designated as “Chemicals of Concern” (COCs).

Chemicals of potential concern (COPCs) must be evaluated for potential impacts to public health and the environment. COPCs are screened on the basis of frequency of detection, background concentrations, and chemical concentrations relative to risk-based screening levels. For this guidance, a chemical can be identified as a COPC if it follows in one of the following categories:

- A regulated substance identified during the historical survey utilized currently or previously by the site.
- A regulated substance that was detected in a medium (soil, air, groundwater) during the site investigation.

Important considerations when evaluating COPCs and COCs:

- Analytical Methods - MoEP and Water Authority guidelines should be followed when performing an analysis of chemicals. For chemicals that are not identified in the guideline documents, approved analytical methods must be used.

- Limits of Detection - Analytical limits of detection must be reported by the laboratory to determine if detection limits were low enough to evaluate both human health and ecological risk.

- Background Concentrations - In some cases it may be required to determine if the measured concentration of a chemical discovered at a site

is from anthropogenic sources (human caused) or from natural background concentrations found at the site.

In some cases, screening values for certain metals in soil have been set to typical background concentrations in Israel (Arsenic for example).

7.13.1 Petroleum Hydrocarbons

The MoEP requires that all the chemicals analyzed by USEPA Methods 8260 (VOC) and 8270 (SVOC) will be reported in a table, including the analytical procedure used. Laboratories should be asked to report the concentrations in Excel™ spreadsheet format and also provide the reports of laboratory results.

At sites where multiple products may have been released, the COCs for the relevant products, as listed in in the IRBCA spreadsheet model, have to be analyzed and reported. For example, if gasoline and diesel have been released, the COCs for both gasoline and diesel must be considered.

Table 11 is a list of all the chemicals, in accordance with the petroleum products, for which Tier 1 RBTLs could be calculated based on the availability of toxicological and physical-chemical properties. Other non-petroleum COCs may be relevant at a site, if non-petroleum products e.g., solvents have also been released. Such additional COCs will be determined based on site-specific conditions.

Tier 1

The following Tier 1 TPH soil target level concentrations have been established for each of the TPH mixtures for residential and industrial / commercial land use. The risk assessor is required to perform the Tier 1 analysis of VOC concentrations in soil only in place of TPH - Gasoline Range Organics (GRO).

Land Use	TPH-Gasoline Range Organics (GRO) C6-C10 [mg/kg]	TPH-Diesel Range Organics (DRO) & Oil Range Organics (ORO) C10-C40 [mg/kg]
Residential	NA	350
Commercial / Industrial & Construction Worker	NA	1,280

Tier 2

The IRBCA model was developed using the USEPA chemical and toxicity parameters for TPH carbon fractions defined in the generic tables published in the regional screening levels (USEPA RSL 2018). The TPH Fractions used for the Tier 2 analysis are defined as:

- TPH Aliphatic \ (Low) C5-C8
- TPH Aliphatic (Medium) C9-C18
- TPH Aliphatic (High) C19-C32
- TPH Aromatic (Low): C6-C8
- TPH Aromatic (Medium): C9-C16
- TPH Aromatic (High) C17-C32

In order to calculate Tier 2 site specific target levels for each TPH mixture (TPH-GRO, DRO, ORO) in the IRBCA model, it was necessary to determine the typical carbon composition of each TPH mixture. Information from the Hawaii Department of Health (Hawaii, 2017) was used which is based on estimates of carbon range makeup of each TPH mixture as outlined below:

Summary of Aliphatic/Aromatic Composition in TPH Mixtures (Hawaii 2017)

TPH Mixture	TPH Sub-Fraction	Composition of TPH Sub-Fractions (Hawaii, 2017)
TPH - GRO	Aliphatic low (C5-C8)	45%
	Aliphatic medium (C9-C18)	12%
	Aromatic medium (C9-C16)	43%
	Sum	**100%**
TPH - DRO	Aliphatic low (C5-C8)	<1%
	Aliphatic medium (C9-C18)	35%
	Aromatic medium (C9-C16)	22%
	Aliphatic high (C19-C32)	43%
	Sum	**100%**
TPH - ORO	Aliphatic high (C19-C32)	75%
	Aromatic high (C17-C32)	25%
	Sum	**100%**

Users of the IRBCA model can adjust site specific parameters at Tier 2 (such as exposure time for outdoor inhalation) to calculate site-specific target values for the TPH mixtures. The calculations and results can be viewed on the "TPH Calculator" page of the model.

It is important to note that the regulator has defined a ceiling level for the Aliphatic High (C19-C32) and Aromatic high (C17-C32) to prevent nuisances and other gross contamination concern. A maximum concentration of 2,000 mg/kg and 5,000 mg/kg was established for residential receptors and commercial/industrial/construction worker receptors.

Users of the Tier 2 model are required to analyze at least 20% samples for TPH-GRO analysis.

7.13.2 Chemicals of Concern in Soil

The objective of soil characterization is to (i) delineate the vertical and horizontal extent of site-related COCs to identify the exposure areas for each combination of receptor-pathway-complete exposure pathway, and (ii) estimate maximum and representative concentrations for each exposure area.

Data collected in areas that are clean (either because the samples were collected beyond the extent of impact or the remedial activities eliminated the COCs) are not appropriate for use in the calculation of representative concentrations. Use of such data may incorrectly underestimate the representative concentrations. Because of the significance of accurately estimating the representative concentrations for each exposure area in the overall risk management decision, this concept is further discussed in Appendix D.

The IRBCA evaluation requires that a thorough assessment of source areas be performed to ensure that representative concentrations of chemicals can be estimated within each exposure area. Sufficient data should be collected to define the horizontal and vertical extent of impacts up to VSLs and for the calculation of the 95% UCL for each COC in each exposure area (see Appendix D). Soil data should continue to be collected and analyzed until it can be demonstrated that the boundary soil samples contain concentrations below the VSLs. To determine the vertical extent of the contamination, soil borings should be extended down and Sections samples collected from surface and subsurface soil zones. Depending on the characteristics of the COC released, the vertical extent, and the presence of vertical gradients, sampling of soils beneath the water table in multiple deep saturated zones may be required.

The sampling plan for subsurface soil is pathway-specific. 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.

Each soil boring must be logged to indicate depths correlating with changes in lithology (with lithological descriptions), occurrence of groundwater, total depth, visual and olfactory observations, and other pertinent data such as a soil vapor screening reading. Soil and soil gas sampling and monitoring must be conducted per the approved work plan. When a monitoring well is installed, as-built diagrams with depth to groundwater indicated must be submitted for each well. A continuous soil profile from soil borings should be developed with detailed lithological descriptions. Particular emphasis should be placed on characteristics that may control chemical migration and distribution such as zones of higher or lower permeability, changes in lithology, correlation between soil vapor concentrations and different lithological zones, obvious areas of soil discoloration, organic content, fractures, and other lithological characteristics. All boreholes must be drilled according to updated MoEP guidelines.

If it becomes apparent during the site investigation that the VSLs will be met, then no additional information may be needed at the site. However, if the concentrations exceed the VSLs on- or off-site, the site investigation should be performed such that all data necessary to perform a Tier 1,Tier 2, or Tier 3 RA and Level 1, 2, or 3 ERA are obtained as expeditiously as possible. The field investigation to collect the soil data should follow most current version of the MoEP guidance.

The IRBCA program does not make a distinction between surficial soil and subsurface soil. In some cases, surficial soil data is necessary where there was a surface spill or overfill, or where it is likely that surficial soils have been impacted. However, the exposure pathways associated with soil include:

- Direct dermal contact,
- Ingestion of soil particulates,
- Outdoor inhalation of vapors and particulates,
- Leaching to groundwater, and
- Release to surface fresh waters and marine waters.

For all receptor scenarios, the direct soil contact with soil pathway cannot be considered incomplete regardless of the depth of the contaminated soil to protect for future unknown land use. Nevertheless, in cases where the industrial site is operating with an active business license, the regulator may allow for managing risk for this pathway with the condition written as part of the No Further Action (NFA) letter issued to the site and as part of the site's business license.

The construction worker may have direct exposure to the subsurface soil when involved in excavation activities. The commercial worker may limited direct contact with soil and also have indirect exposure through indoor and outdoor inhalation of vapors. Representative concentrations in subsurface soil depend on the pathway and the exposure area of the receptor.

7.13.3 Chemicals of Concern in Groundwater

The field investigation to collect the groundwater data should follow most current version of the Water Authority's guidance. The groundwater investigation should focus on collection of the following data/information:

1. Delineation of the horizontal and vertical extent of dissolved groundwater plumes and NAPLs, and identification of exposure area for each receptor, pathway and exposure pathway combination.

2. Calculation of representative COC concentrations for each exposure area

3. Determine the status of the plume (increasing, stable or shrinking), determine boundaries of plume by transects across plume, characterization of dissolved contaminant plume by collection of groundwater samples from spatially distributed (at least in 2-D) sampling points and multilevel groundwater monitoring (such as: nested wells or well cluster).

7.13.4 Non-Aqueous Phase Liquids (NAPL)

The presence of dense or light NAPL may serve as a long-term source of contaminants which will continue to migrate to surrounding soils, groundwater, surface water, and sea. Therefore, the authorities will require that all NAPL be removed to the maximum extent practicable.

The delineation criteria for groundwater depends on whether the current and potential future domestic use of groundwater (or ecological receptors if applicable), will involve a complete or incomplete pathway. Where the domestic use of groundwater pathway is complete, delineation criteria will be the lower of the following criteria:

1. Drinking water standard,
2. Concentrations for the protection of ecological receptors (when present)
3. Land use-dependent concentrations protective of indoor inhalation, or
4. Non-domestic uses of groundwater, when present.

Where the domestic use of groundwater pathway is determined to be incomplete, the delineation criteria will be based on other potentially complete pathways. Examples are: protection of indoor air due to volatilization of contaminants from the groundwater, exposures that may be encountered by subsurface construction workers, or the discharge of contaminated groundwater to surface water or sea.

7.13.5 Chemicals of Concern in Soil Gas

At sites where volatile chemicals of concern exist and the potential of indoor or outdoor vapor migration exists, it is required to measure soil vapor concentrations. For risk assessment purposes, it is necessary to collect a representative soil gas samples according to MoEP Soil Gas sampling guidance and have it analyzed at a certified laboratory for the volatile chemicals of concern using To-15 method with maximal sensitivity of 1 ppbv or a lower less. A sample is typically collected in a Summa canister and analyzed in the laboratory. To determine the integrity of the sample, it is necessary to employ a leak detection technique. Such techniques have been adequately discussed in the literature, including ITRC (2007), and NJDEP (2005) and MoEP Soil Gas sampling guidance.

Note: The representative concentration for soil vapor will be the maximum concentration of three (3) active soil vapor samples taken over a period of six (6) months at the same sampling location.

7.13.6 Chemicals of Concern in Surface Waters including Marine Water

When site investigation data or modeling shows or suggests that COCs and/or their breakdown products may have migrated (discharged/seeped/ surface runoff) to a surface water body or sea water and/or sediments, representative surface water or sea water samples (and sediments) should be collected. If surface drainage or runoff pathways are suspected of having been impacted by any site contaminants surface water/sea water should also be sampled. Sampling must consider the representativeness of the samples with regard to the flow conditions. Water samples may have to be collected both upstream and downstream of each area where a discharge of contaminated groundwater is suspected. A surface water sample for determination of hardness be required if the target surface water value for the COC is hardness or pH dependent.

Both total and dissolved COCs concentrations must be determined. Toxic pollutant criteria applicable to aquatic receptors in surface waters are based on dissolved surface water concentrations and those for people are based on total surface water concentrations.

Sampling should be conducted in accordance with the most current version of MoEP guidance and based on the approved work plan. Depending on the results of the surface water investigation, a Level 2 or 3 ERA and Tier 2 and 3 RA may be required. Environmental water quality standards for surface water are provided in the VSL table for surface and marine waters. Standards for substances not included in the VSL table can be selected from international literature and require approval by the MoEP.

7.13.7 Chemicals of Concern in Sediments

The RP must compare the sediment sample data with sediment standards that are protective of human health and ecological receptors and habitats that can be obtained from the Eco-VSL for sediment or develop site-specific site-specific sediment standards (which would be considered a Level 3 ERA and would require a pre-approved work plan).

7.13.8 Chemicals of Concern with Special Considerations

The equations listed in the Appendix E can be applied to calculate target levels and forward mode risks for most of the chemicals of concern (COCs) in the IRBCA list. The USEPA Regional Screening Level (RSL) guidance has included many special considerations for several COCs which the IRBCA references. There are some cases where the standard equations do not apply and/or external adjustments to the chemical parameters are recommended (USEPA

RSL, November 2019). Users of the IRBCA Excel™ spreadsheet should refer to the complete list of special considerations on the USEPA RSL user guide website:

https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide#special

Below is a list of some chemicals with special considerations

Cadmium

Cadmium (CAS# 7440-43-9) appears in the IRBCA list of chemicals as "Cadmium (Diet)" and "Cadmium (Water)". The IRBCA references the USEPA Integrated Risk Information System (IRIS) for toxicity parameters for Cadmium. The IRIS presents two different toxicity parameters, "Cadmium (Diet)" used to assess risks to exposure to sources in soil and biota and "Cadmium (Water)" used to assess risks to sources in water and air.

Lead and Compounds

To date, there are no published toxicity values by the USEPA for lead (CAS# 7439-92-1), so it is not possible to calculate target levels and risks using the IRBCA equations for exposure to contaminants in soil. The IRBCA methodology follows the USEPA approach to assessing exposure to lead using the Integrated Exposure-Update Biokenetic Model (IEUBK). Details regarding the predefined target values for Lead are address in section E.10 of the IRBCA methodology.

Manganese

Manganese (CAS # 7439-96-5) appears in the IRBCA list of chemicals as "Manganese (Diet)" and "Manganese (Non-Diet)". The IRBCA methodology references published toxicity values according to an IRIS study which concluded that two separate toxicity factors should be used for manganese. "Manganese (Non-Diet)" is used to assess exposure to non-food sources such drinking water and soil. The toxicity values for non-diet sources (soil, water) were adjusted by IRIS to account for dietary contribution of manganese from a normal diet.

"Manganese (Diet)" toxicity factors should be used to asses exposure to dietary sources such as fish, plants, etc… The IRBCA recommends assessing risk for dietary sources as a Tier 3 assessment.

Arsenic

The target screening values for Arsenic (CAS#7440-38-2) in soil have been set by the MoEP based on natural background concentration representative of Israel.

8 Problem Formulation / Hazard Identification

The risk assessment framework provides a structured approach for evaluating potential adverse effects to receptors (e.g., people) from environmental stressors (e.g., chemicals in soil vapor). The framework for risk assessment typically involves four stages: problem formulation, exposure assessment, toxicity assessment and risk characterization which are described in greater detail below.

The problem formulation / hazard identification is part of the IRBCA process which identifies the major factors to be considered in the risk assessment. This section uses regulatory and decision-making policy and describes the technical approach to perform the risk assessment.

The problem formulation identifies the sources of contamination and exposed media (soil, groundwater, soil vapor), exposure pathways (direct soil contact, domestic use of groundwater, indoor vapor intrusion) and exposed receptors (residents, recreational users, construction workers, ecological receptors). A conceptual exposure model should be created to illustrate and explain how the contaminant sources, exposure pathways and receptors are linked together to form the potential for health risk.

8.1 Receptors

The IRBCA guidance defines the potential receptors to include human, structures, utilities, surface waters, seawater, sediments and ecological risk receptors (flora and fauna and their habitats) which may be adversely affected by a release and potentially be subject to damage by exposure to COCs and/or their by-products via ingestion, inhalation, absorption or dermal contact. This definition also specifically includes water-supply wells because it must be assumed that humans will be ingesting the water from these wells.

In IRBCA, four receptor scenarios are considered: Residential, Commercial/Industrial, Construction Worker and Recreational. The IRBCA model has the option to include a site-specific receptor which does not fall in one of the four categories. The model evaluates both current and future scenarios.

8.1.1 Residential Receptor

A residential receptor (current or future) would be considered if the primary purpose of the land use is (a) a residence by persons on a permanent, temporary or seasonal basis, including, without limitation, single family dwellings, cabins, apartments, condominiums or townhouses, or (b) institutional facilities, including, without limitation, schools, hospitals, daycare operations, prisons, community centers, places of worship (synagogues, mosques, churches).

Under the residential land use scenario, future residents are expected to be in frequent contact with contaminated. Exposure is calculated for a lifetime, and includes both child and adult life stages. Human health risks and the risk based target values (RBTLs) value for a residential receptor are calculated for a resident child (age 0-6), adult, and age-adjusted value (weighted average).

8.1.2 Non-Residential/Commercial/Industrial Worker Receptor

The use of land for a non-residential/commercial/industrial worker's primary purpose is buying, selling or trading of merchandise or services including, without limitation, shopping malls, office complexes, restaurants, hotels, motels, grocery stores, automobile service stations, petroleum distribution operations, dry cleaning operations, municipal yards, warehouses, law courts, museums, golf courses, government offices, air and sea terminals, bus and railway stations, and storage associated with these uses.

Workers who fall under the commercial/industrial scenario are expected to be routinely exposed to contaminated media within a commercial or industrial site. Exposure can be based on the potential for soil disturbances due to the use of heavy equipment producing particulate emissions which could be inhaled by the industrial worker. Assumptions and default parameters do not reflect the use of protective clothing or other safety precautions.

The use of groundwater as potable water (ingestion, dermal contact, and inhalation of vapors from groundwater) for a commercial/industrial scenario will be evaluated as domestic water use.

8.1.3 Construction Worker

Construction Worker is a generic term identifying workers who are employed in the physical building of infrastructure or other structure at a site. A construction worker may be exposed to chemicals released from shallow groundwater, exposed to VOCs released from working in a trench, exposed to subsurface soil through digging for a relatively short period of time relative to a commercial or industrial worker. A construction worker is expected to be exposed to chemicals outside only.

8.1.4 Recreational Receptor

In 2018, the IRBCA guidance was updated include the recreational receptor, also encompassing the "trespasser" or "site visitor" scenario. The IRBCA spreadsheet includes the option to evaluate exposures to soil, surface water, and sediments typically associated with hiking, canoeing, fishing, kayaking, boating, rowing, wading, and splashing. The IRBCA considers full-body contact with surface water scenarios (i.e. swimming and immersion) as well as incidental contact.

8.2 Exposure Pathways

Estimation of exposure involves the identification of exposure scenarios, pathways and routes of exposure. An exposure pathway is how a receptor comes in contact with the impacted media or COCs. Exposure pathways include fate and transport processes by which chemicals move from the point of release through the environment and the interaction(s) through which populations or individuals ore exposed. For example, a chemical in soil might migrate into groundwater or volatize into air. A person may then be exposed to the chemical through consumption of drinking water and inhalation of air (indoor or outdoor).

8.3 Development of the Conceptual Exposure Model

The Conceptual Exposure Model is used to identify complete exposure pathways under current and reasonably likely future land use conditions. The presence of exposure pathways and receptors is dependent on current and reasonably anticipated future use of the site and adjacent areas. If COCs could potentially migrate off-site, all affected properties must also be considered when developing the conceptual site exposure model.

A conceptual exposure model at a minimum consists of:

1. Identification of COCs in each applicable exposure media (soil, groundwater, surface water, soil vapor and sediment)
2. Identification of receptors
3. Identification of complete and potentially complete exposure pathways for current and reasonably anticipated future land use on- and off- the site;
4. Exposure pathways are considered "complete" when they contain the following elements:
    a. A source of contamination including the chemical release

scenario, location of source(s), COCs and the method it was released to the environment;

b. An environmental medium (air, soil, groundwater etc.) and a description of site stratigraphy, determination of the predominant vadose zone soil type, hydrogeology, and surface water bodies that may potentially be affected by site COCs;
c. A means where a receptor may come in contact with the impacted environmental medium;
d. A means for a chemical to come in contact with the receptor, distribution of COCs in the various affected media on-site and off-site.

8.4 Exposure Areas

In addition, for each complete or potentially complete pathway, identification of the exposure area is required by MoEP for evaluating risks for current and future conditions. In many instances, exposure areas are based on historic use of the site in terms of industrial activities. An exposure area should be selected based on known or anticipated uses and will require an understanding of differing activity patterns of different receptors at a site. Establishing exposure areas (and understanding their limitations) that are designed to evaluate potential exposures are critical to the scoping stage of the risk assessment.

In some cases, the exposure area cannot be reasonably established due to lack of information regarding the redevelopment of the site and information on the location and type of activity is not available. In these cases, exposure assessments might evaluate receptors by assuming equal likelihood of exposure across the entire site. Identification of the exposure area is necessary because the data collected within an exposure area is used to determine representative concentration for exposure assessment calculations (see Appendix D).

8.5 Work Plan

MoEP requires the submission of a work plan that summarizes the results of the problem formulation, identification of exposure areas and calculation of representative statistics for each exposure area that will be used in the subsequent risk assessment.

Specifically, the risk assessor must:

1. Document the pathways that are complete under current and reasonably anticipated future conditions;
2. Explain the rationale for pathway decisions, both complete and incomplete.
3. Identify the sampling locations within the exposure area that will be used to estimate representative concentrations for each pathway.
4. Calculation of summary statistics for each exposure area (e.g., representative statistics).
5. Users should submit as part of the work plan results of the ecologic risk assessment checklist.

As part of the work plan, the risk assessor must submit the name and professional qualifications of the risk assessor(s) who will perform the risk assessment. These include the specific academic and professional (e.g., toxicologist, biologist, chemist, engineer, geologist etc.) qualifications and details of their experience performing risk assessment.

8.6 Quantitative Risk Assessment

Following the completion of the problem formulation, a quantitative risk assessment is undertaken (e.g., Tier 1, 2 or 3 HHRA) which includes the following phases: toxicity assessment, exposure assessment and risk

characterization. The following sections describe the phases of the quantitative risk assessment.

8.6.1 Toxicity Assessment

The purpose of the toxicity assessment is to identify the toxic potential of the identified chemicals of potential concern (COPCs). The Toxicity Assessment involves the selection of a toxicity reference value (i.e., the acceptable dose that people can be exposed to without risk of adverse health effects over a lifetime). For human health, both the type of health effect (e.g., cancer) and the pathway by which a receptor is exposed to the contaminant (e.g., ingestion) are considered when selecting appropriate toxicity reference values (TRVs).

US EPA IRIS (2018) and IARC (2017) have developed classification systems on the carcinogenic properties of chemicals and these resources are used to determine whether each COC is considered to be a carcinogen or not based on classification. For threshold acting chemicals (e.g., non-carcinogens) a reference dose (oral/dermal pathways) represents an estimated daily intake to which people can be exposed to every day over a lifetime without experiencing a significant or adverse health impact. Reference doses are expressed as milligram of contaminant per kg of body weight per day (mg/kg bw/day) and reference concentrations (used for the inhalation pathway) are expressed in units of mg contaminant per cubic meter of air (mg/m^3). For non-threshold acting chemicals (e.g., carcinogens), the TRV is expressed as a slope factor (oral/dermal pathways) or an inhalation unit risk (inhalation pathways). Slope factors and inhalation unit risks are defined as a plausible upper bound probability of an individual developing cancer as a result of a lifetime exposure to a potential carcinogen.

8.6.2 Exposure Assessment

The Exposure Assessment involves estimating the exposure dose of the contaminant received by the receptors for each pathway identified in the problem

formulation. The dose of a chemical depends on the concentration in various media (e.g., water, soil, sediment and food), the amount of time that people might be in contact with these media and the physiological characteristics of the person (e.g., ingestion rates, inhalation rates, body weights and dietary preferences).

8.6.3 Risk Characterization

In the Risk Characterization, the results of the exposure assessment are compared with the findings of the toxicity assessment to determine whether there is potential for chemicals from the site to pose adverse human or ecological health effects. The predicted risks will be compared to negligible risk levels as determined by MoEP. The risk characterization is completed for the chemicals, receptors and exposure scenarios of concern identified in the problem formulation. Potential sources of uncertainty and conservative assumptions used in the assessment are described in an uncertainty assessment.

9 Tier 1 Risk Assessment

If any of the maximum soil, soil vapor, groundwater, surface water, or sediment concentrations exceeds the VSLs or relevant WQC, the RP may choose to either clean the site to the VSLs, or perform a Tier 1 RA.

A Tier 1 RA uses non-site specific (generic), conservative target levels for each complete and potentially complete human exposure pathway. These target levels are based on conservative assumptions, representative of Israeli conditions per the IRBCA Task Force, representative exposure factors; fate and transport parameters; and the analytical fate and transport models. If the relevant site conditions differ significantly from the site-specific factors, or include complete exposure pathways for which Tier 1 target levels have not been developed, a Tier 2 RA may be required by the MoEP.

The acceptable risk used to develop the Tier 1 RBTLs are:

(1) For carcinogenic risk, incremental excess lifetime cancer risk (IELCR) of 1×10^{-6}, and
(2) For non-carcinogenic risk, a hazard quotient (HQ) of 1.0.

A Tier 1 risk assessment involves determination of site COCs, selection of relevant Tier 1 RBTLs from generic lookup tables, and comparison of relevant RBTLs with representative COC concentrations.

Tier 1 RBTLs will be derived for each COC, each complete exposure pathway, and each medium of concern identified in the problem formulation.

Tier 1 RA requires the following steps:

1. Compilation of available data and identification of any data gaps,
2. Development of conceptual model and problem formulation,
3. Collection of data to fill any data gaps and design of sampling and analytical methods to match the required COCs, for example TPH fractions and individual constituents (including identification of sources),
4. Calculation of media and pathway-specific representative concentrations for COCs,
5. Selection of relevant Tier 1 RBTLs from lookup tables and comparison with representative concentrations, and
6. Determination of the next course of action and documentation of Tier 1 RA including recommendations.

Details of each step are presented below.

9.1 Step 1: Compilation of Data and Identification of Data Gaps

The objective of this step is to compile and evaluate all available relevant data, and identify any data gaps. Specifically the data required has been identified in the previous sections.

9.2 Step 2: Calculation of Representative Concentrations

The RP must calculate representative chemical concentrations for each complete exposure pathway using data from the exposure area. Depending on the exposure pathways, multiple representative concentrations (one for each exposure area) have to be calculated. The calculation of each representative concentration is further discussed in Appendix D.

At certain sites, multiple representative concentrations may be necessary for the same media. For example, if a groundwater plume has migrated below a non-residential building and a residential building, representative groundwater concentrations for the residential and non-residential receptors would be different.

The need to calculate representative concentrations may be avoided by initially using the maximum site-wide concentrations in the medium of interest for each pathway as the representative concentration. If the Tier 1 RBTLs are higher than the maximum concentrations, then the calculation of the representative concentrations is not necessary.

9.3 Step 3: Selection of Relevant Tier 1 RBTLs

Tier 1 RBTLs must be selected from Tier 1 RBTL tables for each chemical, each receptor, and each exposure pathway. Soil vapor concentrations are to be used to assess the indoor vapor inhalation pathway. If the soil to groundwater or soil to surface water pathway is complete, the soil concentrations presented in Tier 1 Tables will be used for soil concentrations. If for an exposure area and a media, multiple pathways are complete, the minimum concentration of all the complete pathways will apply.

At sites where there are no complete human exposure pathways, target levels protective of groundwater will apply. Further in such areas the soil target levels protective of ecological receptors presented in ECO-VSL will be applicable. If there is a spill that may directly impact a spring or a surface water body, the ecological target levels for soils and sediments will apply.

The Tier 1 soil vapor concentrations protective of indoor inhalation were calculated using an attenuation factor (alpha or α) of 0.01. Thus the soil vapor concentrations were calculated as the indoor air concentrations divided by 0.01.

These soil vapor concentrations were used to estimate risk-based soil concentrations using USEPA equilibrium conversion.

The Tier 1 RBTLs are compared with the representative concentrations calculated. Based on the comparison, the next course of action is determined.

9.3.1 Groundwater Resource Protection Evaluation (Tier 1 Calculation)

The Tier 1 RBTLs have been developed using a number of conservative assumptions. The RBTLs for groundwater source and the soil source have to be multiplied by the relevant distance dependent saturated zone and unsaturated zone dilution attenuation factors (DAF).

IF the groundwater use pathway is deemed to be complete under current or future conditions, the soil concentration protective of groundwater sources must be evaluated. The maximum allowable Tier 1 distance to the point of exposure is set to be 150 m which calculates a horizontal DAF to be 40.8 using the Domenico model. The vertical (unsaturated zone) DAF is calculated based on the depth of the groundwater from the bottom of the contamination.

For Tier 1, the depth dependent unsaturated zone DAF is calculated based on the distance from bottom of the contaminated zone to the groundwater. The Tier 1 default is considered to be 0 – 6 m which calculates a vertical DAF of 3 or > 6 m which calculates a vertical DAF of 8. Appendix E1 describes how the Tier 1 soil concentrations protective of groundwater sources are calculated.

9.3.2 Protection of Indoor Inhalation from Groundwater Sources

Groundwater concentrations protective of indoor inhalation are typically estimated using a model such as the Johnson and Ettinger (Johnson et al., 2001) model as incorporated in the IRBCA software and includes both diffusive and

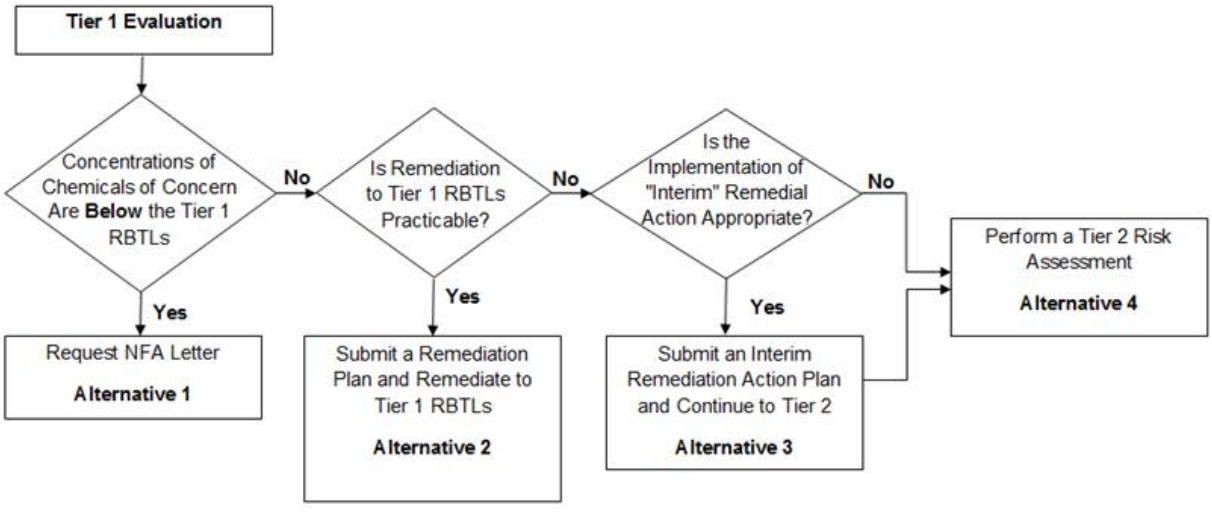
advective transport mechanisms. Unless otherwise noted, the advective transport component will be used to evaluate vapor intrusion from groundwater.

In certain situations, the advective vapor transport mechanism may not contribute to chemical flux into a building. Examples include when the source of the COCs is beyond the zone of pressure influence of the building. Other examples include the absence of a pressure gradient or a negative pressure gradient i.e. higher pressure within the building compared to the pressure at the source.

For Tier 1 Evaluation, GW RBTLs protective of indoor inhalation were calculated using Indoor air concentrations based on new Israeli's annual air standards and when absent, IRBCA- risk based calculated indoor air concentrations. The attenuation factor (α) is calculated using the J&E model.

9.4 Step 4: Determination of the Next Course of Action

Depending on the results of the comparison, the following alternatives are possible:



Alternative 1: Request NFA Letter

In the event that all the representative concentrations are <u>below</u> the Tier 1 RBTLs, the RP may request a NFA letter from the regulatory authorities. The RP should

refer to the MoEP and Water Authority guidance documents for submitting an NFA request.

Alternative 2: Submit a Remediation Plan (and remediate to Tier 1 values)
If one or more representative concentrations exceed the Tier 1 RBTLs, the RP can decide to remediate to Tier 1 values. The RP is required to submit a remediation plan describing corrective actions that will be taken.
The RP has the option to remediate the site to Tier 1 RBTLs, acceptable levels for ecological receptors and habitats, and request a NFA letter when remediation is complete. The cleanup levels selected will be the lowest of the risk based criteria protective of human health and ecological receptors. The selection of this alternative will require the development of a remediation plan and approval by the relevant authorities of the remediation plan and according to the following steps:

- During on-going remediation, a monitoring program is required to confirm the occurrence, the effectiveness and the impact of the remediation technology and a report must be submitted periodically to the authorities.

- In cases where representative site concentrations minimally exceed acceptable risk levels or when non-permanent technologies are used, the RP must conduct a compliance/long-term monitoring program to confirm site concentrations are not increasing.

- After completion of remediation by permanent technologies (such as excavation and disposal), confirmatory sampling is required, after approval of the relevant authorities of the confirmatory sampling plan, to ensure that the risk levels within each exposure area meet acceptable levels. In case non-permanent remediation technologies are selected (such as: capping, solidification/stabilization), a long term on- and off-site monitoring plan is necessary and must be developed and approved.

- After remediation to target levels is completed, implementation of activity use limitations (AULs) and enforceable long-term stewardship activities may be required. Further a monitoring plan may be necessary and will have to be developed by the RP and approved by the authorities.

The responsible party also has the option to perform the necessary actions to eliminate that pathway for which representative concentrations exceed the Tier 1 RBTLs and request a NFA letter.

Alternative 3: If meeting the Tier 1 RBTL is impracticable due to technology or resource limitations, an interim remediation action plan can be submitted to the regulator. This may include removal or treatment of "hot spots" and/or addressing the most significant concerns at the site. A Tier 2 risk assessment will still be required for the Site and should be conducted in parallel to carrying out interim remediation action. The Tier 2 risk assessment should be performed using confirmatory samples after interim remediation is completed.

Alternative 4: Decide to perform a Tier 2 risk assessment, as discussed below.

10 Tier 2 Risk Assessment

Tier 2 risk assessment allows for the use of site-specific fate and transport parameters to calculate site-specific risk, and if necessary, site-specific target levels (SSTLs). A Tier 2 RA may be conducted under any of the following conditions:

- It is not feasible or cost effective to meet Tier 1 RBTLs,
- Tier 1 assumptions are significantly different from site-specific conditions, so that the Tier 1 RBTLs may not be protective of site-specific conditions and hence unacceptable. Examples include, volumetric water content in the vadose zone soil is significantly less than the default value and the indoor vapor inhalation pathway is complete, the fractional organic carbon content is significantly less than its default value, or the site is characterized by karst or soil very different than default soil used for Tier 1 RBTLs calculations.
- The COCs are not listed in the RBTLs or VSL tables.

Due to the inherent difference between Tier 1 and Tier 2 RAs, the Tier 2 work plan will vary in the amount of details. Specifically, information regarding all required site-specific parameters will be discussed in the Tier 2 work plan. Detailed work plan has to be submitted to the authorities for approval. Such approval is necessary prior to proceeding with the Tier 2 RA.

Unlike a Tier 1 RA, a Tier 2 RA uses site-specific exposure and fate and transport parameters or appropriate literature values if they can be justified. A Tier 2 RA includes the following steps:

1. Development of a work plan;
2. Calculation of carcinogenic and non-carcinogenic Tier 2 risks;

3. Comparison of calculated risks with acceptable risks and, if necessary, development of Tier 2 SSTLs;
4. Recommendation for the next course of action;

10.1 Documentation of the Tier 2 RA Including Major Assumptions

Details of each of these steps are presented below. Authorities must approve the Tier 2 work plan.

In preparation for a Tier 2 risk assessment, additional data may be required and the CSM revised, if necessary. The RP must submit a work plan for approval of the authorities prior to performing the risk assessment and prior to carrying out any additional site characterization. The risks are calculated based on site-specific data such as land use, soil and groundwater characteristics, and physical characteristics of the site.

The Tier 2 risks are compared with allowable risk levels at the site. Depending on the comparison, the RP may make one of the following decisions:

- The residual chemicals are protective of human health and the environment and request a NFA for the land use conditions assumed in the risk assessment;
- Calculate Tier 2 SSTLs for use as cleanup levels, and/or develop a RMP;
- Or develop a work plan for a Tier 3 risk assessment.

Upon completion of the Tier 2 risk assessment, the RP must provide a Tier 2 RA Report to the authorities.

10.2 Step 1: Development of a Work Plan

The Tier 2 work plan to be submitted to the authorities for their approval should

include an overall project schedule, milestones and any deliverables. Upon receipt of approval of the work plan, the RP should implement the work plan as per the schedule in the work plan. This implementation may include the collection of additional data that may be necessary and the compilation of site-specific fate and transport and building parameters. In cases where delays occur, it is the RP's obligation to inform the authorities of the delay and submit a revised schedule.

Upon completion of the work, the RP should document the results and submit the report to the authorities. The report must include recommendations and the future course of action as discussed below.

A Tier 2 RA allows for the application of site-specific fate and transport parameters based on:

- Correctly measured site-specific parameters at the appropriate locations using approved methods; or
- Literature values that can be justified as being representative of the site conditions.

At a minimum, site-specific measured values (see Appendix C) including soil source dimensions, depth to subsurface soil sources, thickness of vadose zone, depth to groundwater, hydraulic gradient, hydraulic conductivity, and the distances to the POE and POD wells located between the COC source area and the POE) must be used. Where site-specific values are not available for parameters and professional judgment has to be used (with the approval of the authorities), to determine whether to perform additional assessment or to use appropriate literature values. If additional data are necessary, a data acquisition work plan should be developed and approved by authorities prior to performing the Tier 2 risk assessment.

10.3 Step 2: Calculation of Tier 2 Risks

Step 2 estimates the carcinogenic and non-carcinogenic risks for all COCs, receptors, and exposure pathways using the IRBCA software. For a Tier 2 RA, carcinogenic and non-carcinogenic risks must be calculated for each COC and each complete and potentially complete exposure pathway as per the problem formulation. Then, the total risk for each COC and the cumulative risk must be calculated.

In calculating the Tier 2 risks, the models, physical-chemical properties, and toxicological properties will be the same as used in the Tier 1 RBTL calculations presented in Appendix E. For chemicals that do not have toxicity values but are COCs at a site, it may be necessary to develop the necessary toxicity values based on literature review, available guidance from USEPA, WHO, California EPA or to use a surrogate chemical. Such values have to be approved by the MoEP and the Ministry of the Health.

The RP must also identify appropriate levels protective of ecological receptors and habitats if needed. The representative soil and groundwater concentrations (and other relevant media concentrations) are calculated the same as for the Tier 1 RA and as discussed in Appendix D. These representative concentrations are used to estimate the site risk. If the site risk exceeds the acceptable risk level, a RMP will have to be developed which may include the development of Tier 2 SSTLs. The work plan should include a discussion of how the representative concentrations will be calculated.

10.3.1 Groundwater Resource Protection (Tier 2 Calculation)

For contaminated groundwater the following pathways have to be evaluated:

- The use of groundwater as a current and a future drinking water supply;
- Potential for volatilization from groundwater that may cause vapor intrusion; and
- Groundwater discharge into surface waters and/or sea.

A determination of allowable soil and groundwater contaminant levels must be made when there are water supply wells on-site or off-site. At sites where there are no water supply wells, the cleanup levels for soil and groundwater are required to be protective of the other pathways listed above.

For Tier 2 RA, target levels will be developed that will be compared to the source soil and groundwater representative concentrations. The POE for domestic use is located at a distance that is lesser of the property boundary and 200 m from COC source or at a distance set by the IWA.

10.3.2 Surface Water Evaluation

At sites where surface water bodies may be impacted by site contaminants, a Tier 2 or 3 risk assessment may be necessary.

10.4 Step 3: Comparison of Tier 2 Risks with Acceptable Risk Levels

The Tier 2 risks will be compared with the following acceptable risk criteria for each individual receptor:

- The sum of IELCRs for each COC across all exposure pathways must be equal to or less than 1×10^{-5}.

- The sum of IELCRs for all the COCs evaluated across each exposure pathway must be equal to or less than 1×10^{-5}.

- The cumulative IELCR, i.e., sum of risk for all COCs and all exposure pathways must not exceed 1×10^{-5}.

- The hazard index (HI) for each chemical, which is the sum of hazard quotient (HQs) for all exposure pathways for each chemical (the total risk), must not exceed 1.0.

- The hazard index (HI) for each exposure pathway, which is the sum of HQs for all COCs for each exposure pathway (the total risk), must not exceed 1.0.

- The cumulative HI (the sum of the hazard quotients for all chemicals for all exposure pathways) must be equal or less than 1.0.

The above comparison will result in the following possibilities:

- The sum of IELCRs for all exposure pathways and for every COC is less than 1×10^{-5} and the cumulative IELCR is below 1×10^{-5}. In this case, it will still be necessary to develop Tier 2 SSTLs for carcinogenic effects. However, for specific cases where it is there are technical issues, the regulator will consider the forward mode results.

- Either the IELCR for one or more of COCs or the IELCR for one or more of exposure pathways exceeds 1×10^{-5} and/or the cumulative IELCR exceeds 1×10^{-5} In this case, Tier 2 SSTLs must be developed. As explained in Appendix E, considerable flexibility is available in the calculation of SSTLs. Therefore, the RP must carefully explain the method and the assumptions used to calculate the SSTLs.

- The calculated HIs for every COC and for every exposure pathway and the cumulative non-cancer risk HI are less than 1.0. In this case, it will still

be necessary to develop Tier 2 SSTLs for carcinogenic effects. However, for specific cases where it is there are technical issues, the regulator will consider the forward mode results.

- The HI for one or more COCs or the HI for one or more exposure pathways and/or the cumulative HI is greater than 1.0. In this case, Tier 2 SSTLs must be developed.

The risk estimates for each COC and all exposure pathways is acceptable, but the cumulative risk estimates are unacceptable. In this case, it may be appropriate to develop adverse health risk estimates specific to target organs or mode of action. This will require the segregation of the COCs by target organ, system or mode of action and derive risk estimates for each adverse effect with prior approval of the toxicologist of the Ministry of Health – the Environmental Health Division. As an example, if there are 10 non-carcinogenic COCs at a site, four of which affect the kidney only, three affect the central nervous system only, and three affect the liver only. In this case, the COCs may be grouped into three categories, those that affect the (i) kidney, (ii) central nervous system, and (iii) liver. A cumulative HI for each of the three organs may be developed. If each of these cumulative HIs is less than one, it will not be necessary to develop Tier 2 SSTLs for these COCs for non-carcinogenic effects. If not acceptable, it will be necessary to develop the target levels for the COCs in the group that exceed the HI of unity. A target organ specific risk assessment can only be conducted as part of a Tier 3 risk assessment.

10.5 Step 4: Recommendations for the Next Course of Action

Depending on the results of the above comparison, one of the following alternatives is available:

Alternative 1: The RP may request the regulatory authority to issue a NFA letter if the following are met:

1. The total risk for each chemical (all exposure pathways) for all receptors is acceptable;
2. The total risk for each exposure pathway (all chemicals) for all receptors is acceptable; and
3. The cumulative risk (all chemicals and all complete pathways) for all receptors is acceptable.
4. Alternatively, the representative concentrations for all COCs and all the exposure pathways are below the Tier 2 SSTLs.

Additionally, the following conditions must be met.

Condition 1: The plume, if one exists, is stable or shrinking. If this condition is not satisfied, the RP must continue groundwater monitoring until the plume is demonstrably stable. Actions may be taken to increase plume stability. This recommendation must include a sampling plan with specifics such as:

- Wells to be sampled,
- Frequency of sampling,
- Laboratory analysis method,
- Method to be used to demonstrate that the plume is stable or shrinking, and
- The format and frequency of reporting requirements.

Condition 2: Prior to issuance of a NFA letter, adequate assurance is provided that remediation, has been performed according to a pre-approved remediation plan by the relevant authorities and is complete, the land use assumptions used in the IRBCA evaluation are not violated for current or future conditions. This condition may require that one or more legally binding AULs are placed on the site, the AULs can be enforced, and plans are in place to maintain and enforce LTS for as long as necessary to protect human health and the environment.
Confirmatory sampling after remediation is completed is required. Pre-approval of the sampling work plan by the authorities is required.

Condition 3: There are no ecological concerns on-site and off-site, as determined by confirmation that the representative concentrations are below levels protective of ecological receptors or by completion of the ERA. If this condition is not met, the RP must provide recommendations to the MoEP to manage the ecological risk. If the MoEP approves the recommendations, these must be implemented and demonstrated to be effective.

Condition 4: The RP was not required by the authorities to perform subsequent tier risk assessment.

Condition 5: No nuisance conditions exist at the site

Condition 6: LNAPL has been removed to the maximum extent practicable.

Alternative 2: The calculated risks <u>exceed</u> the acceptable risk levels:

1. The total risk for <u>any</u> chemical (all exposure pathways*)* for any human or

ecological receptors and/or habitats exceeds acceptable levels;

2. The total risk for any exposure pathway (all COCs) for any human or ecological receptors and/or habitats exceeds acceptable levels;
3. The cumulative risks (all chemicals and all complete pathways) exceeds acceptable levels; or

4. The representative concentrations exceed the calculated Tier 2 SSTLs.

Based on this decision, the RP must recommend one of the following:

1. Remediation to Tier 2 SSTLs (if the RP decides to remediate the site to Tier 2 SSTLs, the cleanup levels will be the lower of concentrations protective of human health, both carcinogenic and non-carcinogenic, and ecological receptors and/or habitats). Selection of this alternative will require the development of a RMP and approval by the relevant authorities according to the following steps:

    - During on-going remediation, a monitoring program is required in order to confirm the occurrence, the effectiveness and the impact of the remediation technology, and a report must be submitted periodically to the authorities.

    - In case representative site concentrations minimally exceed acceptable risk levels or natural attenuation was selected or when non-permanent technologies are used, the RP must conduct compliance/ long-term monitoring program to confirm site concentrations are not increasing and/or in order to confirm the occurrence, the effectiveness and the impact of the natural attenuation.

- After completion of remediation e.g., excavation and disposal, confirmatory sampling is required to ensure that the risk levels within each exposure area meet acceptable levels. The confirmatory sampling plan will be submitted to approval of the relevant authorities. In case non-permanent remediation technologies are selected (such as: capping, solidification/stabilization), a long term on-site and off-site monitoring plan is necessary and must be developed and approved.

- After remediation to target levels is completed, implementation of AULs or LTS may be required and a monitoring plan may be necessary. Such a plan will have to be approved by the authorities prior to its implementation.

2. Performance of a Tier 3 RA. If the risks exceed the acceptable risk levels, the RP may decide to perform a Tier 3 RA for the receptors for which the Tier 2 risk is exceeded. Note all the COCs have to be included in the Tier 3 evaluation.

A NFA granted with restrictions (e.g., with AULs, LTS, long-term monitoring) is valid only so long as the restrictions are maintained.

10.6 Step 5: Documentation of the Tier 2 RA and Recommendations

To facilitate the review of the Tier 2 RA by the authorities and other interested parties, the risk assessment must be clearly documented in report format. If a Tier 1 risk assessment is also conducted, both evaluations may be submitted as a single report. The final report must be submitted in electronic and printed formats for each government office. The authorities may request Excel™ spreadsheets with the raw data used in the RA report.

At a minimum, the Tier 2 RA report must include the following:

- Site background and chronology of events;
- Current and past and future land use;
- Site stratigraphy and hydrogeology;
- Data used to perform the evaluation;
- Assumptions used to perform the evaluation;
- Documentation of the exposure model and its assumptions;
- Documentation and justification of all fate and transport parameters;
- Estimated risk for each COC, each exposure pathway, each receptor, and the cumulative risk for each receptor and media; and
- Recommendations based on the Tier 2 RA.

Additionally, the report must include the following:

- All the inputs files (as well as screen printouts if requested), intermediate calculations and output files from the software and models used to perform the calculations for at least three COCs for each pathway.
- The exact source of all parameters, models, equations must be detailed and if not per the IRBCA guidance-should be clearly discussed as such. The MoEP may request copies of such references.
- The RP must submit in advance the name of the risk assessor(s) who will perform the risk assessment and model calculations and their (their specific academic and professional (geologist, toxicologist, modeler, engineer, etc.) qualifications and details of their experience to perform the risk assessment.

If a NFA letter is requested, documentation that all of the conditions have been met is necessary.

11 Tier 3 Risk Assessment

A Tier 3 risk assessment allows considerable flexibility in managing risk at a contaminated site. The authorities require that a work plan be submitted and approved prior to the performance of a Tier 3 risk assessment and prior to carrying out any additional site characterization.

Tier 3 RA is a detailed, site-specific evaluation that the RP may choose to conduct. Although not a requirement, typically, Tier 3 RA would be performed after completing Tier 1 and/or Tier 2 RAs. A Tier 3 RA is beyond the scope of the IRBCA spreadsheet model and therefore will require site specific modeling.

As shown in Table 2-1, compared to a Tier 2 RA, a Tier 3 RA may use the most recent toxicity factors, physical and chemical properties, site-specific exposure factors, and alternative fate and transport models. Thus, Tier 3 RA provides the most flexibility to the RP. A Tier 3 RA may include a Level 1, Level 2, or Level 3 ERA.

The Tier 3 RA requires the following steps:

1. Development of a Tier 3 work plan approved by the authorities;
2. If necessary, collection of additional data;
3. Calculation of Tier 3 risks;
4. Comparison of calculated risks with acceptable risk levels and if necessary, development of clean-up levels;
5. Recommendation of the next course of action; and
6. Completion of a Tier 3 risk assessment report.

Each of the steps is discussed below.

11.1 Step 1: Development of a Tier 3 Work Plan

Tier 3 RA provides considerable flexibility to the RP. Examples include, but are not limited to:

- Evaluation of additional site-specific receptors (other than residential and non-residential considered in Tier 1 and Tier 2 risk assessments) such as recreational users or trespassers;
- Use of site-specific exposure factors;
- Use of toxicity values different than the values used in Tier 1 and Tier 2 risk assessments, and may include the use of sub-chronic toxicity values for non-carcinogenic effects when the exposure duration is less than seven years (Note that sub-chronic toxicity values are not as widely available as chronic values. The Agency for Toxic Substances and Disease Registry (ATSDR) publishes Minimal Risk Levels (MRLs) that may be suitable for use as sub-chronic toxicity values);
- Use of alternative fate and transport models;
- Alternative definition of surficial soils based on site-specific considerations; and
- The integrated exposure update biokinetic (IEUBK) model may be used to develop SSTLs for lead.

In each case, the specific choice must be technically justified. Because of this flexibility and the very site-specific nature of Tier 3 RA, the authorities must approve a Tier 3 work plan prior to implementation.

In Tier 3 RA, the only receptors that need to be considered are those for which the risk in Tier 2 RA exceeds acceptable levels and any additional receptors not considered in Tier 2 evaluation. Receptors for which the Tier 2 risk is not exceeded need not be evaluated. However, none of the COCs considered in the

Tier 2 RA can be eliminated for the Tier 3 RA. Thus, the COCs considered in Tier 2 and Tier 3 risk assessments would be identical, unless new data collected subsequent to the Tier 2 risk assessment indicates otherwise.

The work plan must, at a minimum, include the following:

- Identification of the receptors that will be evaluated in Tier 3.
- Identification of the COCs for which Tier 3 risk will be calculated. Typically, these would be the same as for a Tier 2 RA.
- Complete and potentially complete exposure pathways for which Tier 3 risk will be calculated. Typically, these would be the same as for a Tier 2 RA.
- An explanation of the fate and transport models to be used for the calculation of risk for the complete and potentially complete exposure pathways. The RP may propose the use of a model(s) different than that used in Tier 1 or Tier 2 RA. At a minimum, the models to be used must:
  - Be peer reviewed,
  - Be publicly available or a copy provided to the authorities at no cost,
  - Preferably have a history of use on similar projects, and
  - Be technically defensible.
- A tabulation of the input parameters required to compute the Tier 3 risk. For each of these parameters, the RP must justify the use of the selected values and methodology.
- Examples of input parameters that may be specific to Tier 3 RA are:
  - Chemical-specific physical properties,
  - Chemical-specific toxicological properties,
  - Site-specific or other alternate exposure factors, and
  - Media and site-specific parameters required by the selected fate and transport models.
- A discussion of the data and the methodology that will be used to calculate the representative concentrations (see Appendix D for further information).

- An explanation of data gaps, if any, that requires additional fieldwork. A scope of work for the collection of this data must be included in the Tier 3 RA work plan.
- A discussion of the variability and uncertainty in the input parameters and the manner in which the impact of this variability on the final risk will be evaluated. Uncertainty analysis techniques range from sensitivity analysis to detailed Monte Carlo simulations.
- An evaluation of ecological risk. ERAs previously completed at any tier are also acceptable in Tier 3 RA and need not be re-done.

After receiving approval of the Tier 3 work plan, the RP can perform a Tier 3 risk assessment. Any changes to the methodology, schedule or input parameters during the course of Tier 3 work must also be approved by the authorities and documented by the RP.

Implementation of the work plan will require comparison of (i) Tier 3 risks with acceptable risks, and/or (ii) Tier 3 SSTLs with representative COC concentrations. Depending on the comparison, the RP can make one of the following two decisions:

11.2 Step 2: Collection of Additional Data, if Necessary

Upon approval of the Tier 3 work plan, the RP must perform the necessary fieldwork to collect the data. Any deviations from the work plan due to field conditions or logistics of fieldwork must be discussed with the authorities prior to completion of the field effort. Depending on the nature and type of field work and data gaps, it may not be necessary to submit a separate data report to the authorities; instead it may be included as a part of the Tier 3 RA. Documentation of the data collection efforts may be included as an appendix to the Tier 3 Risk Assessment Report.

11.3 Step 3: Calculation of Tier 3 Risks

Step 3 estimates the carcinogenic and non-carcinogenic risks for all COCs, receptors, and complete exposure pathways, using the models and data in accordance with the approved work plan. For Tier 3 RA, the risk must be calculated for each COC (sum of risk for all the complete exposure pathways for a chemical) and the cumulative risk for each receptor (sum of risk for all COCs and all complete exposure pathways). If needed, ecological risk should also be considered as per the work plan.

11.4 Step 4: Comparison of Calculated Risks with Acceptable Risk Levels

In Step 4, total risks for each COC as well as cumulative risk for each receptor are compared with their respective acceptable risk levels. The cumulative IELCR, i.e., sum of risk for all COCs and all exposure pathways must not exceed 1×10^{-5}. The acceptable HI for each COC and all exposure pathways and the cumulative HI is 1.0, which are identical to those used for Tier 2 RA.

The comparison will result in the following possibilities.

- The calculated total IECLR for each COC, the total IELCR for each exposure pathway, and the cumulative IECLR are <u>below</u> the acceptable risk levels. In this case, it will not be necessary to develop Tier 3 SSTLs for carcinogenic COCs.

- Any of the total IELCR for each COC, the total IELCR for each exposure pathway, or the cumulative IECLR <u>exceeds</u> the acceptable risk level. In this case, Tier 3 SSTLs must be developed. As explained in Appendix E considerable flexibility is allowed in the calculation of the SSTLs. Therefore, the RP must carefully explain the method and the assumptions used to calculate the target levels.

- The calculated cumulative HI (sum of the HQs for all chemicals for all exposure pathways) is acceptable (less than 1.0). In this case, the non-carcinogenic risk is deemed acceptable and it will not be necessary to develop Tier 3 SSTLs for non-carcinogenic effects.

- The HI for each COC is acceptable (less than 1.0), but the cumulative HI is unacceptable (greater than 1.0) and it will be necessary to develop the target levels for the COCs.

- The HI for each exposure pathway is acceptable (less than 1.0), but the cumulative HI is unacceptable (greater than 1.0) and it will be necessary to develop the target levels for the COCs.

In addition to the HHRA, ecological risks or levels protective of ecological receptors and habitats must be considered.

11.5 Step 5: Determination of the Next Course of Action

After completion of the Tier 3 risk assessment, one of the following two alternatives is available:

Alternative 1: The RP may request the regulatory authority to issue a NFA letter if the following are met:

5. The total risk for each chemical (all exposure pathways) for all receptors is acceptable;
6. The total risk for each exposure pathway (all chemicals) for all receptors is acceptable;
7. The cumulative risk (all chemicals and all complete pathways) for all

receptors is acceptable; and

8. Alternatively, the representative concentrations for all COCs and all the exposure pathways are below the Tier 3 SSTLs.

Additionally, the following conditions must be met.

Condition 1: The plume, if one exists, is stable or decreasing. If this condition is not satisfied, the RP must continue groundwater monitoring until the plume is demonstrably stable. Actions may be taken to increase plume stability. This recommendation must include a sampling plan with specifics such as:

- Wells to be sampled,
- Frequency of sampling,
- Laboratory analysis method,
- Proposed method to demonstrate that the plume is stable or shrinking, and
- The format and frequency of reporting requirements.

Condition 2: Prior to issuance of a NFA letter, adequate assurance is provided that the land use assumptions used in the IRBCA evaluation are not violated for current or reasonably anticipated future use. This condition may require that one or more AULs are placed on the site and can be enforced and plans are in place to maintain and enforce LTS for as long as needed to protect human health and the environment, and that the LTS is legally binding.

Condition 3: There are no ecological concerns at the site, as determined by confirmation that the maximum or representative concentrations are below levels protective of ecological receptors or completion of the ERA. If this condition is not met, the RP must provide recommendations to the

MoEP to manage the ecological risk. If the MoEP approves the recommendations, their implementation and effectiveness, then this condition would be met.

Alternative 2: If the calculated risks are exceeded, the RP must develop SSTLs and propose remedial actions to achieve these levels if the analysis finds that either:

1. The total risk for each COC (all pathways) is unacceptable for any of the human or ecological receptors and/or habitats;

2. The total risk for each exposure pathway (all COCs) is unacceptable for any of the human or ecological receptors and/or habitats; or

3. The cumulative (all COCs and all complete pathways, $IELCR_T$ and HI_T) is unacceptable for any of the human or ecological receptors and/or habitats.

The SSTLs and the methodologies used to achieve these levels must be included in the RMP.

11.5.1 Surface Water Evaluation

Sampling for COCs in surface water bodies and/or sea water may be required when COC migration is known or suspected to affect surface water body and/or sea water. Target levels represent the lesser of the suggested surface (and/or sea) water quality criteria values being utilized for (i) freshwater (and/or sea water) acute exposure, (ii) freshwater (and/or sea water) chronic exposure, and (iii) human consumption of fish and water, (iv) recreational water (such as contact during swimming). Soil and groundwater concentrations protective of surface water are calculated using the same process as the calculation of concentration

protective of groundwater ingestion.

A surface water sample for determination of hardness or pH may have to be to collected if the target surface water concentration for the COC is hardness or pH dependent.

The values determined should not be exceeded in the groundwater discharging/seeping into a stream. For all tier evaluations, target levels must be met at the discharge point since mixing within the stream is not allowed under any tier evaluation (DAF equals 1).

At contaminated sites where surface runoff to surface waters occurs, the runoff must meet the freshwater standards at the point of discharge to the surface water body. Further, the surficial soil and sub-surface soil must meet soil target levels protective of ecological receptors. If there is a spill or surface runoff that may directly impact a spring or a surface water body, the target levels for soils and sediments must meet soil target levels protective of ecological receptors and human receptors.

11.5.2 Evaluation of Other Pathways

Other complete exposure pathways such as ingestion of food crops for human consumption grown in impacted media, ingestion of fish, or use of groundwater for irrigation purposes should be evaluated under the Tier 3 risk assessment. Refer to the *Risk Assessment Guidance for Superfund, Volume I* (USEPA, 1989) for guidance on evaluation of risk due to food intake.

11.6 Step 6: Documentation of the Tier 3 Risk Assessment and Recommendations

Because a Tier 3 risk assessment is very site-specific, the RP must submit a report that clearly describes the data used, methodology and key assumptions, results, and recommendations regarding the path forward.

Any deviation from the approved scope of work, the rationale for the deviation, and the date when the deviation was approved by the authorities must be clearly documented in the report. At a minimum the report must include:

- Site background and chronology of events;
- Data used to perform the evaluation;
- Documentation of the exposure model and its assumptions;
- Documentation and justification of all input parameters used;
- Estimated risk for each COC, each exposure pathway, each receptor, and the risk for each receptor and media;
- Recommendations based on the Tier 3 risk assessment; and
- If a NFA letter is requested, documentation that all the conditions in Section 9.6, Alternative 1, have been met.

Additionally, the report must include the following:

- All the inputs, intermediate calculations and output from the software and models used to perform the calculations for at least three COCs,
- The exact source of all parameters, models, equations that are not per the IRBCA guidance, The MoEP may request copies of such references.
- The RP must submit the name of the risk assessor who performed the calculations and his specific academic and professional (geologist, toxicologist, modeler, engineer, etc.) qualifications to perform the risk assessment.

The effort required to prepare the final report can be significantly reduced by preparing a detailed work plan prior to the start of work.

12 Risk Management Plan

The objective of a RMP is to protect human health and the environment under current and reasonable future conditions. Typically, a RMP will be developed after the authorities approve media-specific cleanup levels under any of the tiers (VSLs, Tier 1, Tier 2, or Tier 3 levels). The RMP may include a combination of active and passive remedial options, a description of and schedule for all remedial activities, AULs, and other relevant reports. To the extent needed to protect human health and the environment, the plan may include:

1. Remedial technology(ies);
2. Long Term Stewardship (LTS) plan, including any proposed Activity Use Limitations (AULs) and justification for their use;
3. Estimate of the time needed to implement the RMP;
4. Monitoring plan to verify the effectiveness of the RMP;
5. Manner in which the monitoring data will be evaluated;
6. Monitoring action levels that would require re-evaluation of the effectiveness of the RMP; and
7. Steps that will be taken if the RMP is not effective.

The RMP must be implemented as written and approved by the authorities. During implementation, sufficient data must be collected and analyzed to evaluate the performance of the plan and, if needed, to implement modifications. The data and the evaluation must be submitted to the authorities. If the RMP is not progressing as planned and changes are needed, a proposal for modifying the plan must be submitted to the authorities for approval. Modifications cannot be implemented without prior approval of the authorities.

RMP must continue until the authorities determine, based on site-specific data, that cleanup goals (VSLs, IDWS, WQC and ECO-SSLs if relevant, Tier 1 RBTLs,

Tier 2 SSTLs, or Tier 3 SSTLs) have been met; specified AULs are in place and can be enforced for the period necessary; and risks have been appropriately managed. The RMP must include a commitment to maintain the AULs for as long as is necessary to ensure protection of human health and the environment - that is, as long as residual concentrations exceed unrestricted use levels. The authorities will issue a NFA if based on (i) information available to the authorities at the time, (ii) the IRBCA evaluation, and (iii) assumptions inherent in the IRBCA risk assessment, the site conditions are protective of human health and the environment. The authorities may require that the NFA letter be part of a deed notice.

If in the future, additional information becomes available that indicates that (i) the site poses an unacceptable risk to human health and the environment, or (ii) the site conditions have changed so that they are no longer compatible with RMP, the authorities may rescind the NFA and require further action at the site.

A RMP encompasses all activities necessary to manage a site's risk to human health and the environment so that they do not exceed the acceptable risk levels under either current or reasonably anticipated future land use conditions. RMP activities may also include monitoring to demonstrate plume stability. RMP activities may include, but are not limited to (i) corrective action plans for cleanup, that may include AULs, and (ii) monitoring to confirm that the assumptions made in the risk assessment are correct.

12.1 Need for a Risk Management Plan

A site-specific RMP is required if any of the following conditions is met:

- Representative COC concentrations for at least one complete exposure pathway exceed the appropriate tier-specific target levels;
- Representative COC concentrations for none of the complete exposure

pathways exceed the appropriate tier-specific target levels, but the risk assessment was based on certain site-specific assumptions that must be preserved via an AUL;

- The carcinogenic risk for any COC exceeds 1×10^{-6} (Tier 1 risk assessment);
- The total (sum of all exposure pathways) carcinogenic risk for any COC exceeds
  1×10^{-5} (for Tier 2 or Tier 3 risk assessment);
- The HQ for any COC exceeds 1.0 (Tier 1 risk assessment);
- The HI (sum of all exposure pathways) for any COC exceeds 1.0 (for Tier 2 or Tier 3 risk assessment); ;
- The cumulative carcinogenic risk (sum of COCs and all exposure pathways) exceeds 1×10^{-5} (for Tier 2 or 3 risk assessment); Although neither the carcinogenic or non-carcinogenic risk for any COC nor the cumulative risk exceeds acceptable levels, the risk assessment was based on site-specific assumptions that require an AUL;
- Although neither the carcinogenic nor non-carcinogenic risk for any COC or risk exceeds acceptable levels, the groundwater plume is expanding; or
- Ecological risk does not meet the acceptable criteria.

The overall objective of a RMP is to ensure that:

- Site conditions are protective of human health and the environment (i.e. ecological receptors and their habitats) under current and reasonably anticipated future conditions, based on achieving acceptable risk levels at any one of the three tiers.
- Acceptable ecological protection is based on the process identified in the ERA.
- Assumptions made in the estimation of risk and developments of cleanup levels are not violated in the future.
- Sufficient data has been collected to confirm that the groundwater plume

is stable.

- LNAPL and DNAPL present in soil and/or groundwater were removed as much as allowable by best available technology (BAT). Further, recoverable LNAPLs are not present in the soil or groundwater in volumes that will result in any of the following conditions: (i) an expanding LNAPL plume in soil or groundwater, (ii) an expanding dissolved plume, or (iii) explosive or fire hazard (iv) nuisance (odor, visual), and (v) endangering ecological receptors and their habitats.
- Recoverable DNAPLs are not present in soil or groundwater in volumes that will result in an expanding DNAPL plume, or (ii) an expanding dissolved plume, (iii) nuisance (odor, visual) and (iv) endangering ecological receptors and their habitats.
- The site is free of nuisance conditions, e.g., odors or debris (aesthetics) or noise (resulting from risk management activities), etc.

Successful implementation of the RMP will result in the issuance of a NFA letter, by the authorities, if requested. The following sections provide general information regarding the preparation of a RMP.

12.2 Contents of Risk Management Plan

Once it is determined that a RMP is necessary for a site, the RP should prepare and submit a RMP to the authorities that should include at a minimum:

- The reasons why a RMP is being prepared and the specific objectives of the plan. As mentioned above, reasons for preparing the plan include:
  - Exceedance of target levels. The RMP should very clearly indicate the pathway, COC, and media that exceed the target level.
  - General description of cleanup program.
  - Need for AULs. The RMP should very clearly identify the specific

reasons why AULs are necessary and the area to which they apply.

- Presence of recoverable NAPL. The RMP should very clearly indicate the wells where this condition exists and the extent of the LNAPL or DNAPL.

- Active remedial actions to reduce COC mass and concentrations to meet applicable human health and ecological target levels. Examples include, but are not limited to, soil excavation and off-site treatment or disposal, groundwater pump and treat, soil or groundwater vapor extraction, and enhanced MNA in groundwater. A RMP must include cleanup to actively reduce COC mass and concentrations to meet applicable target levels and/or a combination of cleanup and certain AULs to eliminate certain exposure pathways. A description of the specific activities that will be conducted as a part of the RMP. Note that, for active remedial actions, a corrective action plan must be prepared for submittal to and approval by, the authorities. Examples include soil vapor extraction until the representative soil concentrations achieve a specified numerical value, or semi-annual monitoring of specified wells until concentrations show a clear decreasing trend. For the latter, the RMP shall indicate the method used to confirm plume stability (plots, contour maps or statistical evaluation of data).

- The use of institutional controls or AULs must be in accordance with the laws and regulations. AULs may be approved only if a warning remark is registered in the land registry office, e.g., if AULs are a part of the RMP, sufficient documentation must be provided to demonstrate the existence, execution, and long term viability of the AULs. Note that a work plan is required when AULs are proposed to address a specific risk or risks. Examples of AULs include:

  (i) Restrictions on use of building underground structures, e.g.,

basements

(ii) Installation and maintenance of a fence to limit property access.

Depending on the site specific conditions, institutional controls are an integral part of risk management activities at a site and may involve multiple authorities**.** Compared to remediation vs. use of institutional controls to manage risk, it is the authorities' preference to eliminate or remove the contamination as opposed to imposing institutional controls.

- An explanation of the data that will be collected and the manner in which it will be analyzed during implementation of the RMP. An example of data that might be collected would be confirmatory soil or groundwater sampling data to demonstrate the effectiveness of the remedial measures.

- Details of how and when data will be evaluated and presented to the authorities. Examples include trend maps, concentration contours, concentration vs. distance plots, calculations related to mass removal rates, and application of specific statistical techniques.

- If needed, monitoring to demonstrate plume stability or the effectiveness of reduction of COC concentrations during enhanced natural attenuation in groundwater.

- A schedule for implementation of the plan. If the duration of the planned activities exceeds a few months, a detailed project time line must be developed. It must include all major milestones and all deliverables to the authorities.

- The RMP shall include specific criteria that will be used to demonstrate that the risk management activities have been successfully completed. Generally, this demonstration will require the collection of samples from

the medium or media of concern. Note that a RMP must include performance monitoring plan.

- As appropriate, the RMP shall also include contingency plans that will be implemented should the selected remedy fail to meet the overall objectives of the RMP in a timely and reasonable manner or the remedy is not as effective as anticipated.

- A schedule for implementation of the plan. Where the duration of the proposed activities is expected to exceed a few months, a detailed project time line shall be developed. This should include all major milestones and the deliverables.

Prior to implementation of the RMP, the RP must submit for approval a RMP tailored to meet site-specific conditions. The RMP may have to be presented to the public for review, comment and response. The authorities will examine all comments and either approve the plan as submitted, approve the plan with comments, disapprove the plan, or disapprove the plan with comments. The person who prepared the plan shall then revise the RMP and resubmit the plan for approval. Upon receipt of approval, the RP should begin implementing the plan as per the approved schedule.

12.3 Completion of Risk Management Activities

Upon successful completion of the approved RMP, the RP will submit a RMP Completion and Performance Monitoring Report that will include (i) documentation of completion of all risk management activities, and confirmation of the successful completion of all elements of the RMP, (ii) a request for NFA letter, and (iii) a request to plug and abandon monitoring wells related to the environmental activities at the site.

Upon review of the final report, the authorities will either issue a NFA letter for the site or provide comments back to the RP explaining why a NFA letter cannot be issued and what additional activities are necessary. RMP activities must continue until the authorities issue a NFA letter or provide written authorization to terminate RMP activities. However, the authorities may require interim or additional reports once the final remedy is operational but before remediation performance standards have been met**.**

12.4 No Further Action Procedure

When the IRBCA process has been performed, the evaluation has been approved, and the approved RMP has been successfully implemented, the RP may submit a request for issuance of a NFA letter. The NFA request should be a part of the RMP Completion and Performance Monitoring Report. An NFA letter issued that includes AULs must also be submitted as "a warning remark" to the land registry office. The "warning remark" must be updated according to the RMP status of the site.

Typically, the RMP Completion and Performance Monitoring Report, including the NFA request, would be the last report submitted to the authorities prior to receiving a NFA letter. The authorities will review the report and issue a NFA letter if all applicable requirements have been met. Section 11.0 contains more detailed guidance on the NFA letter.

13 Long-Term Stewardship for Risk-Based Remedial Action Sites

13.1 Background

The purpose of LTS is to ensure the productive and safe use of properties if residual COCs remain in place above the unrestricted land use levels. LTS requires the MoEP's prior written approval.

The implementation of LTS may be considered by the MoEP only in municipalities that adopt site investigation, site cleanup and relevant MoEP guidelines. Further, these municipalities have to implement zoning and mapping of the suspected contaminated zones as part of their planning processes and procedures and allow a consent remark be included for the specific property as part of the planning process according to the Planning and Building Law, 1965. The local authorities and municipalities must prove to the MoEP that all information regarding the residual COC concentrations left on the site is properly documented in the "City Building File" in the Department of Engineering for the relevant property.

The local authority must provide the MoEP with evidence that this information will be included in a computerized database that is available to the MoEP and the public according to the Freedom of Information Act and any other Law. LTS may only be considered if a proven methodology was established by the local authority to monitor, control and document the presence of residual COCs and LTS and only if ecological receptors and habitats will not be affected. In addition, the MoEP may require a warning notice to be registered in the land registry office or in case of a new plan a consent remark is written as part of planning process for that site according to the Planning and Building Law, 1965.

Various terms have been used to refer to land use controls, including institutional controls, AULs, and LTS. Risk-based remedies may sometimes rely on these

tools, provided that relevant active remediation activities were implemented, leaving behind residual COCs whose cleanup and removal was proven to be infeasible and /or acceptable to the MoEP. Under the above circumstances, LTS may be also included as additional measures to ensure that people do not disturb residual contamination, will not be in contact with it or engineered control measures or otherwise violate the assumptions used in developing site-specific RMPs.

Examples of LTS tools include:

- Engineering or physical controls;
- Prohibition of soil digging and soil piling;
- Building restrictions (no basement/no use of basement);
- Soil vapor mitigation measures (passive and active control),
- Commercial/industrial use allowed only (instead of residential);
- Prohibition of storm runoff infiltration for recharge;
- Restrictions to protect ecological resources in the surroundings;
- Government controls such as the implementation of zoning and well drilling restrictions;
- Informational devices such as deed notices and databases;
- AULs; and
- Long term monitoring program (water/soil gas) in purpose to take action if the conditions of the contamination are changing

Within the IRBCA process, preventing unacceptable exposures to COCs may be achieved by removing the contamination entirely and if it is not possible to remove it entirely by managing exposure pathways from contamination to a “receptor” (such as a person or the natural environment). AULs might be necessary under certain cases for ensuring redevelopment and reuse of formerly contaminated properties or if residual COCs remain above unrestricted use levels.

This section provides guidance for establishing AULs necessary to ensure sustainable protection for risk-based remedies. This guidance provides the minimum level of AULs necessary. Any specific controls that are required by the authority supervising a cleanup must be met.

The MoEP may approve a RMP where the proposed controls and limitations are consistent with this guidance and any other controls or limitations that are required by the specific legal authority governing the cleanup.

13.2 Long-Term Stewardship Principles

The following principles offer a broad approach and direction for LTS functions and activities in risk-based corrective action. LTS is the system of activities required to protect human health and the environment from hazards remaining after cleanup is complete and provided that the MoEP has approved the cleanup plan and its goals and has agreed to include untreatable residual contamination.

Stewardship tools must ensure ongoing protection of human health and the environment for site with contamination remaining above unrestricted use levels and in cases where cleanup was infeasible and approved by MoEP. In such cases, LTS will be included as a part of the NFA letter. The tools must facilitate monitoring, maintenance, and, if necessary, replacing engineered controls where they fail. Institutional controls cannot be the sole remedy if an exposure to any COC poses an unacceptable risk.

Stewardship can be used only if it can be incorporated into existing systems that already have a proven track record of durability, function and acceptance among likely customers. LTS must be registered as a letter including maps in the "Building file" of the site in the local authority department of Engineering filing system and its database together with a letter from the MoEP which provides details as to the nature and extent of the residual COCs and a warning notice

registered in the Land Registry Office as required by the MoEP or a consent remark that will be written as part of the planning process for that site according to the Planning and Building Law, 1965. If the relevant local authority cannot demonstrate to the MoEP its ability to register LTS, monitor, control and notify the relevant public (purchaser, neighbors etc.), LTS will not be considered an option.

Stewardship tools should:

1. Facilitates Safe Reuse of Sites. The appropriate application of LTS can and should facilitate the beneficial reuse and redevelopment of property at sites that have existing infrastructure and an available work force.

2. Reliable. Each stewardship tool should be evaluated for uncertainties and include contingency plans for addressing possible failures.

3. Transparent. Information on sites should be readily available and accessible to the public as long as it is legally permissible.

4. Durable. The effectiveness of LTS tools must extend over the lifetime of the contamination risk. Given the potential duration of some remaining risks, current assumptions may require periodic re-evaluation on a specific schedule and modification as needed.

5. Termination. Stewardship controls can and should be altered when risk levels change and terminated when controls are no longer needed to protect human health and the environment. Any such change must be notified to the MoEP, local authority. The local authority should prove to the MoEP that such an update mechanism exists.

6. Roles and Responsibilities. Stewardship management and implementation responsibilities must be clearly articulated, accepted by all

appropriate parties, and documented through legal and other means. Responsibilities regarding the determination and apportionment of stewardship activities among the MoEP, local authority and private entities (including the site owner) must also be defined and stated at the outset. The parties responsible for enforcing stewardship requirements must be clearly identified and capable of taking appropriate actions.

7. Funding. The life-cycle costs of LTS must be assessed and incorporated into the remedial decision-making process prior to final remedy action decisions. Accurate cost estimates are critical to identifying the financial resources needed to ensure the long-term protection of human health and the environment. Any financial assurance instrument used must ensure that adequate funding is available to support the activities in the RMP. At sites where comparable costs are incurred for remediating a site to unrestricted use levels and remediating a site to a lesser level plus the lifetime costs of LTS, the preference is the former.

8. Documentation. Any document regarding site clean up including LTS must be filed and stored in local authorities and MoEP for 60 years from the discovery of site contamination.

9. Application of New Science and Technology. The RPs will be required, to include in RMPs a mechanism for future examination and re-evaluation of new technologies for remediation and monitoring that may develop over time. The objective of this re-evaluation would be to determine whether the application of new science or technology would provide more cost-effective means of assuring or enhancing protection of human health or the environment in on-going or future remedial actions than the measures adopted in the RMP. The MoEP will require a review every 3 years and will be documented in "City building file" in the local authority and MoEP databases. Any specific reviews should be noted in the RMP.

13.3 Activity and Use Limitations

If needed, AULs must be fully developed and proposed as part of the RMP and may be included in the NFA letter. A thorough discussion of AULs can be found in EPA documents (USEPA, September 2000 and USEPA, December 2002). The RMP can use the following AULs or a combination:

1. Engineered controls;
2. Well location and construction restrictions; and
3. Land use and/or institutional control mechanisms for governmental facilities (such as army, defense industries, energy companies, governmental companies): Environmental Covenants, Letters of Completion, and the recording requirements of the MoEP under which remediation is being performed apply to the property and must be transferred with the property (that is, run with the land).

13.3.1 Engineered Controls

Engineered controls may not be used as AULs to prevent direct human or environmental exposure to contaminants unless complete cleanup is not feasible and after proper justification. Assurance of long-term monitoring and maintenance must be provided to the MoEP (at least 30 years).

An engineered control is a barrier designed or verified using engineering practices that limits exposure to or controls migration of COCs. Access controls may be considered engineered controls. Natural attenuation and point-of-use treatment are not engineered controls. Asphalt and untreated concrete surfaces cannot be considered as a proper barrier. High density polyethylene (HDPE) lining must be properly installed (double layer with drainage, collection and treatment of liquid system and when HDPE or other barriers are used as mitigation against vapor intrusion - they should be installed according to MoEP

guidelines). HDPE lining must be monitored for tears and leaks every 3 years and repaired or replaced if necessary. Indoor air monitoring might be required in case of vapor intrusion risk.

Effective inspection and maintenance of the engineered control is required. In case effective inspection and maintenance is not feasible, for example as a result of lack of sufficient or skilled professional manpower in the municipality, or lack of cooperation of the local authority which is vital for long-term control and enforcement, then LTS cannot be implemented.

Such inspection and maintenance provisions must be in place before the authorities will issue a NFA letter for the subject site. The inspection, maintenance, and integrity certification requirements will be included in the RMP. The RMP should include contingencies to address temporary breaches of an engineered control. Absent such a provision, temporary breaches of the control, including those caused by a Force Majeure event, must be repaired in a timely manner.

13.3.2 Well Location and Construction Restrictions

Israeli law prescribes specific requirements for well construction. These can be used as AULs to the extent that they restrict access to certain groundwater and thus limit the pathway for contaminants. Rules delineating special areas and setting out requirements for wells in those areas are contained in the protective zone of wells.

13.4 NFA Letter: Issuance and Voidance

Issuance: A NFA letter according to MoEP guidelines is issued by the authorities after the satisfactory completion of the RMP and after all applicable AULs are in place and their existence has been documented. Its issuance may be contingent

upon the continued application of controls to manage activities. The letter attests to the successful completion of the RMP and indicates the on-going activities (monitoring, property use restriction, etc.) that must be maintained.

- NFA letter must be documented in "city building file" and the engineer of the local authority must provide the MoEP with a letter of confirmation that the letter was included.

- Restrictions in the NFA letter determining the need for application of certain technologies might be modified or cancelled by the MoEP upon the RP request if site conditions have been changed and new risk assessment was carried out as approved by the MoEP or new proven cleanup technologies have emerged that enable the RP to remove residual contamination that could not be removed when NFA conditions were given.

The letter may also include or be subject to administrative reporting, public participation, and long-term site review requirements of specific regulations under which authority a RMP is completed. The MoEP may include all of the following in a NFA letter:

1. An acknowledgement that the requirements of the RMP were satisfied, including reference to the administrative record supporting completion of the site work;

2. The use level of remediation objectives (residential or non-residential use) specifying any AULs imposed as part of the remediation efforts; if the Environmental Unit of local authority has adopted an appropriate ordinance and entered into a memorandum of agreement (MOA) with the MoEP;

3. A statement that the MoEP issuance of the NFA letter signifies a release

from further responsibilities under applicable laws and regulations in implementing the approved RMP and that the site does not present unacceptable risks to human health and the environment based upon currently known information. If the remediation site is part of a larger parcel of property or if the remediating party decided to limit the cleanup to specific environmental conditions and related COCs, or both, the NFA letter should include this information;

4. The prohibition against the use of any remediation site in a manner inconsistent with any land use limitation imposed as a result of the remediation efforts without additional appropriate remedial activities;

5. A description of any preventive, engineered or institutional controls or monitoring, including long-term monitoring of wells, required in the approved RMP or a reference that specifies where in the RMP this information can be found;

6. The obligation to record the NFA letter in the chain of title for the site;

7. Notification that further information regarding the remediation site can be obtained from the MoEP;

8. A standard agency reservation of rights clause for previously unknown or changing site conditions. This wording will vary depending upon the authority overseeing the remediation;

9. Notification that the NFA letter may be voided under special circumstances;

10. A description of the remediation site by legal description, by reference to a plan showing the boundaries, or by other means sufficient to identify site location, any of which may be an attachment to the letter;

11. Any change in site conditions that might affect the residual contamination or conditions included in NFA letter must be notified to the MoEP and relevant local authority.

If only a portion of the site or only selected contaminants at a site were remediated, the NFA letter may contain any other provisions agreed to by the MoEP and the RP, such as the limitation of the letter to the specific area or contaminants.

Voidance: The MoEP may void the Letter of Completion if the remediation site activities are not managed in full compliance with the approved RMP upon which the issuance of the NFA letter was based. The RMP must also contain the specific details of any LTS requirements that are relied upon to reach the conclusion. Specific acts or omissions that may result in voiding of the NFA letter include:

1. Failure to adhere to any other applicable institutional controls, land use restrictions, or other AUL(s);

2. Failure of the owner, operator, remediating party, or any subsequent transferee to operate and maintain preventive or engineered controls, to comply with any monitoring plan, or any disturbance of the site contrary to the established AULs;

3. Disturbance or removal of contamination that has been left in place that is not in accordance with the RMP. Disturbance of soil contamination may be allowed if, during and after any activity, human health, and the environment are protected consistent with the RMP or other health and safety requirements;

4. Failure to comply with the recording requirements or to complete them in a timely manner;

5. Obtaining the NFA letter by fraud or misrepresentation;

6. Subsequent discovery of contaminants, releases, or other site specific conditions that were not identified as part of the investigative or remedial activities and which pose a threat to human health, public welfare or the environment; and

7. If the MoEP decides to void a NFA letter, it must provide notice to the current titleholder of the remediation site and to the RP at his or her last known address, specifying the cause for the voiding and the facts in support of that cause.

The MoEP may give the RP a specified time to come into compliance with the terms of the letter. The RP or current titleholder may appeal or seek dispute resolution on the MoEP's final decision after the receipt of the notice of voiding.

If the MoEP voids a NFA letter, it may place a notice to that effect in the chain of title, pursue enforcement action, declare an environmental emergency, or take other action(s) to protect human health or the environment, as appropriate.

13.5 Information and Tracking

Effective site information storage and timely retrieval are essential to redeveloping properties and managing site uses. Information about NFA letters, and the recording requirements of the authority under which remediation is being performed will be recorded in MoEP databases.

The MoEP might not allow LTS implementation if proper databases do not exist or are not satisfactory in local authority zoning and planning department and business licensing department or if a warning remark or consent remark was not registered.

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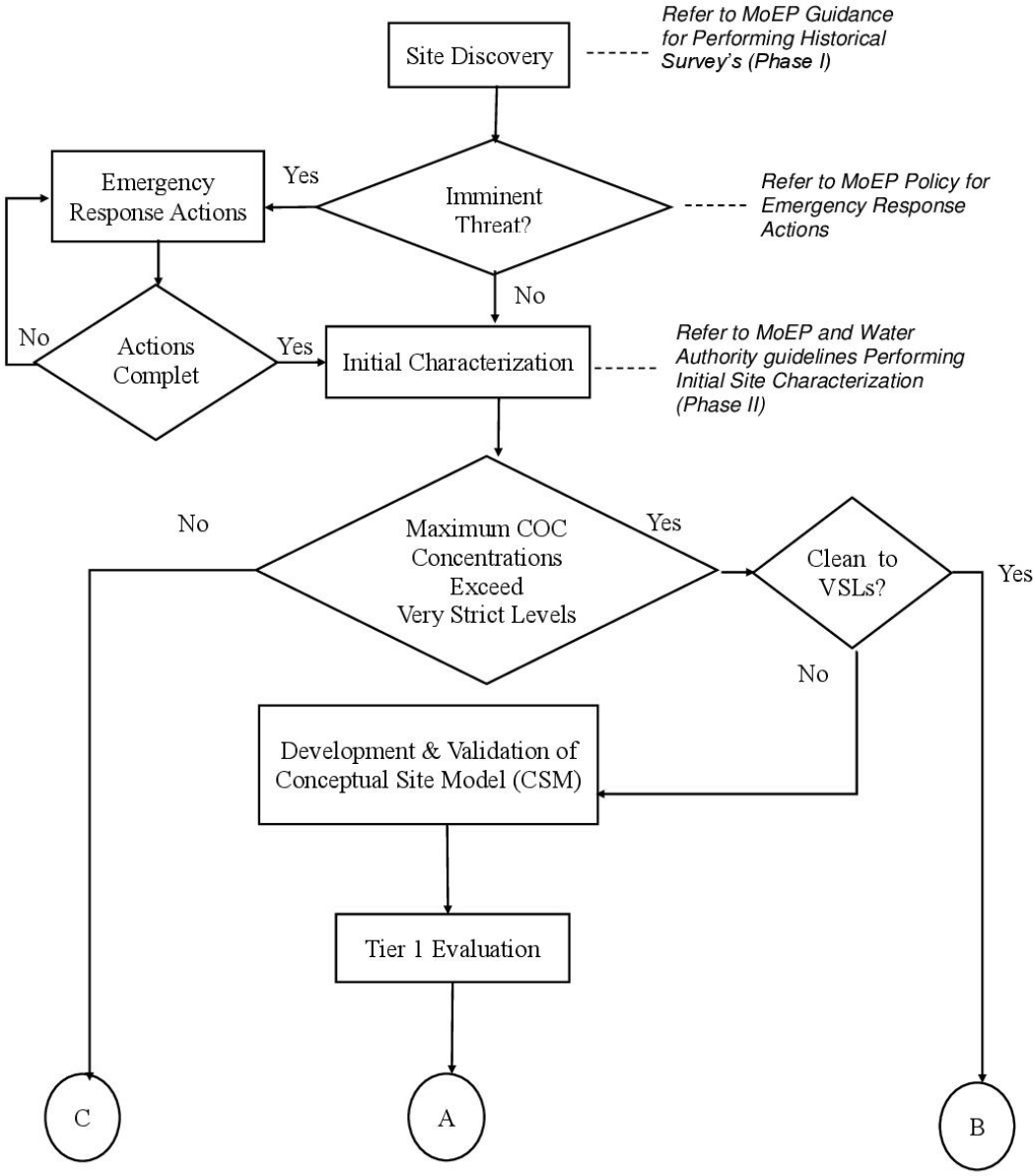
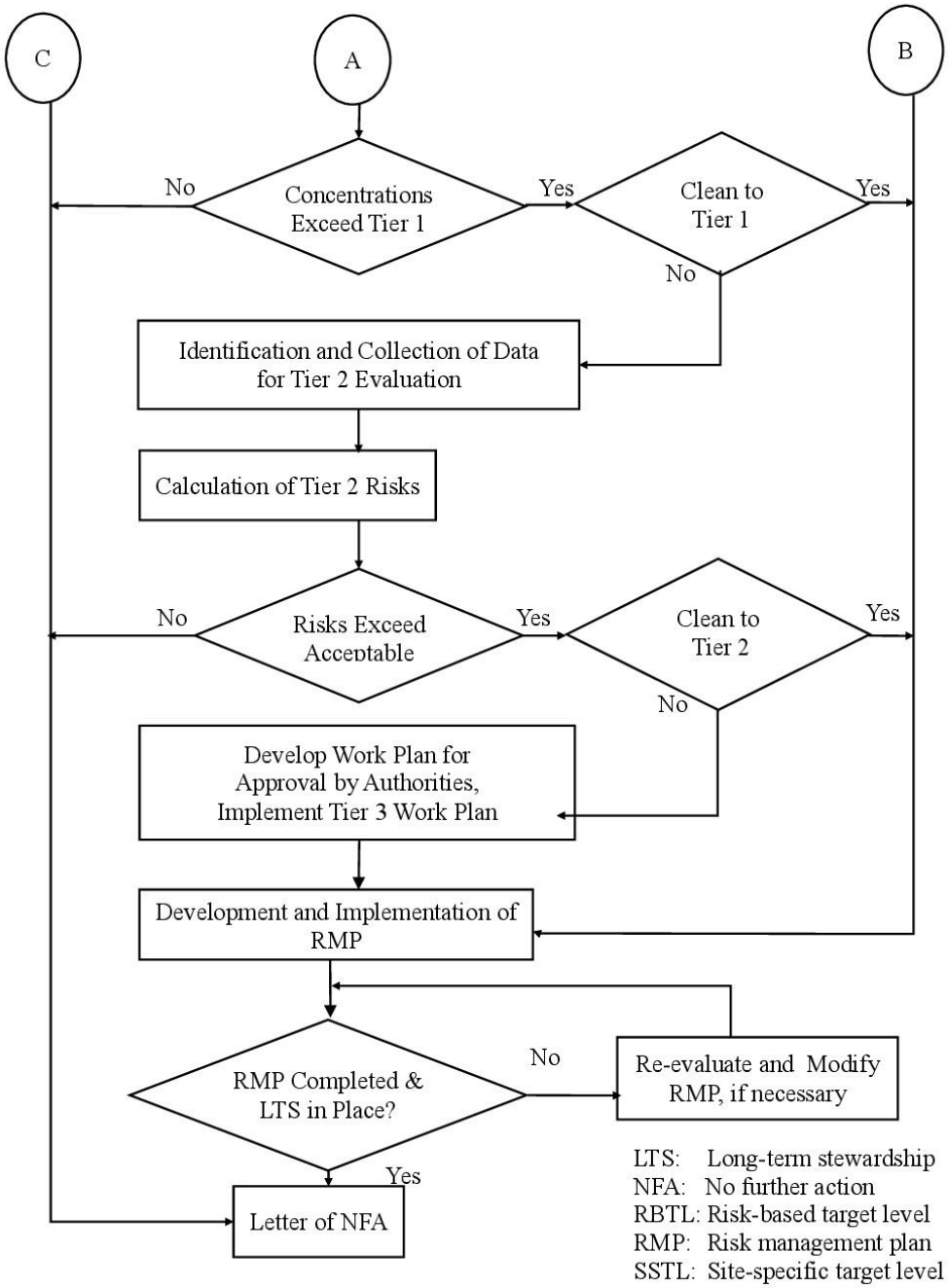


Figure 1. Israel Risk-Based Corrective Action Flow Chart



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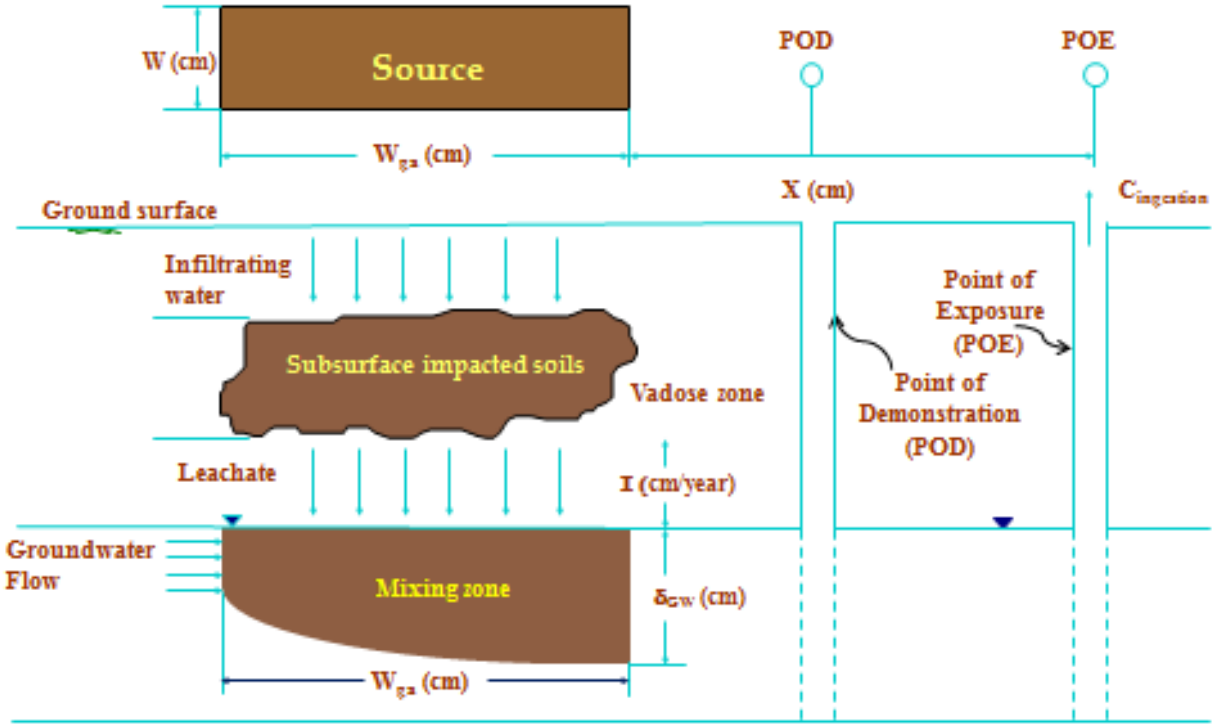
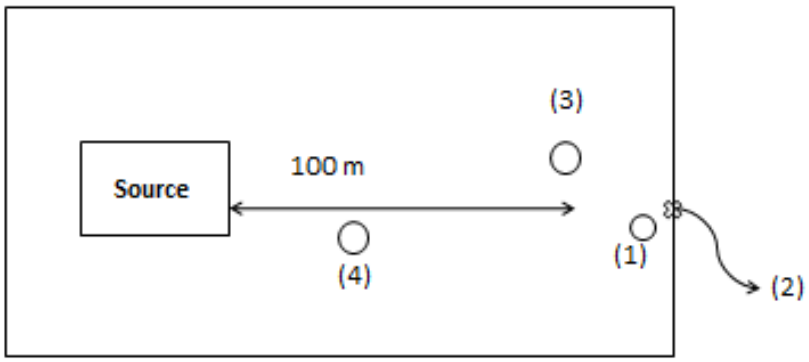
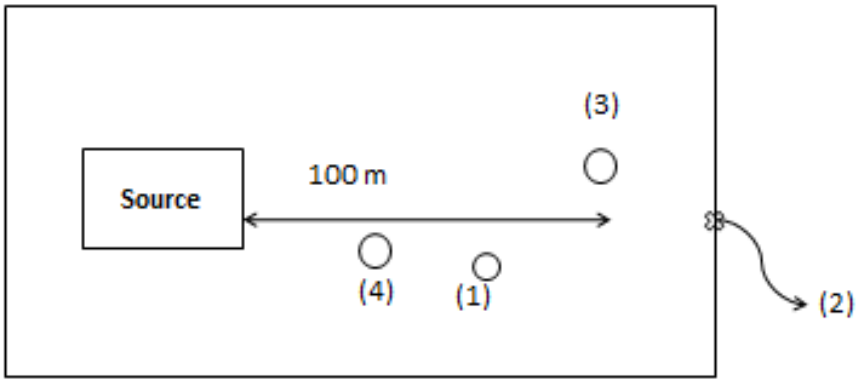


Figure 2: Schematic of Leaching to Groundwater

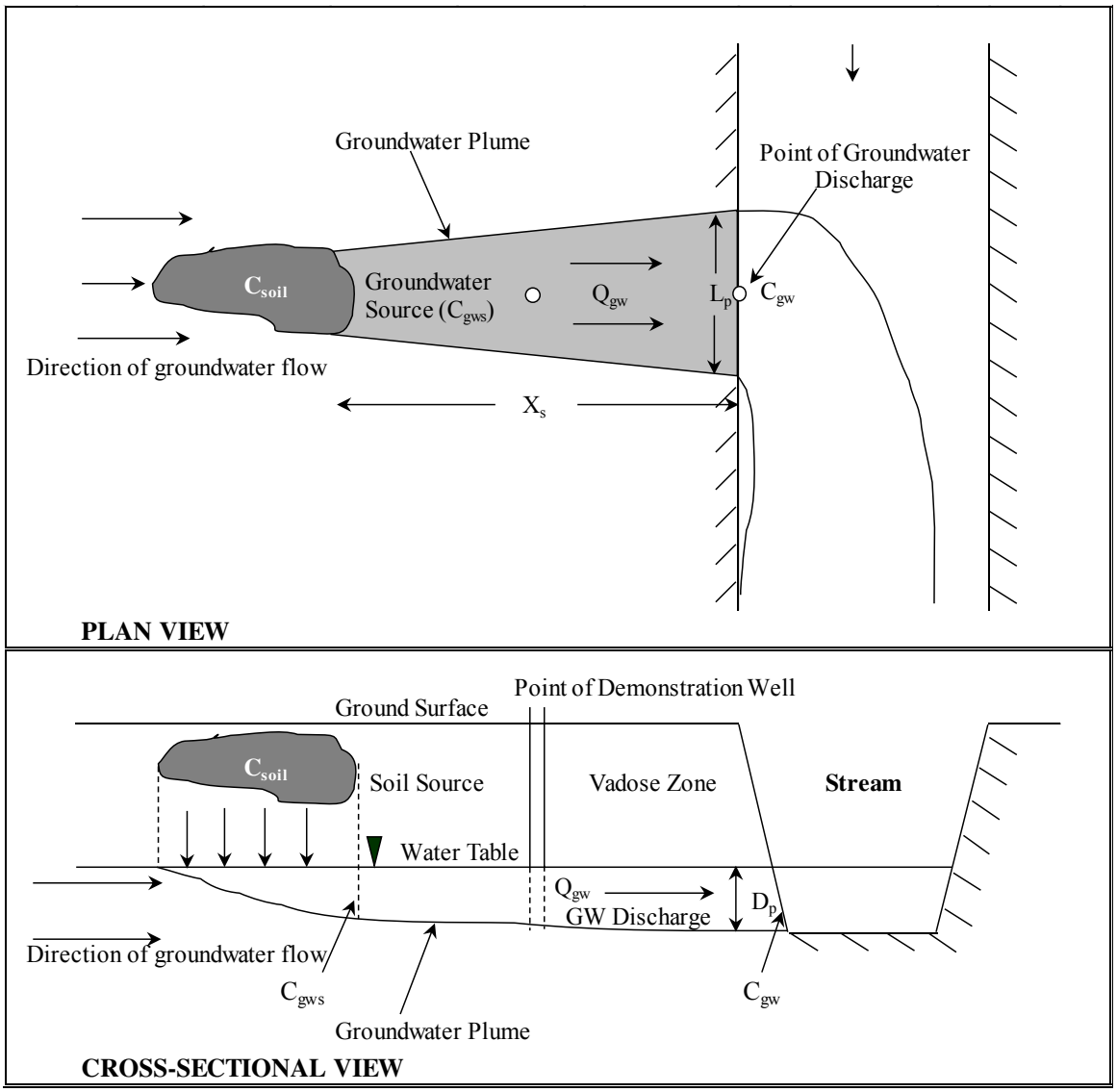


1. Existing well
2. Property boundary
3. Point of exposure (POE)
4. Point of demonstration (POD)



1. Existing well, Point of Exposure (POE)
2. Property boundary
3. Point at 100m from the source
4. Point of demonstration (POD)

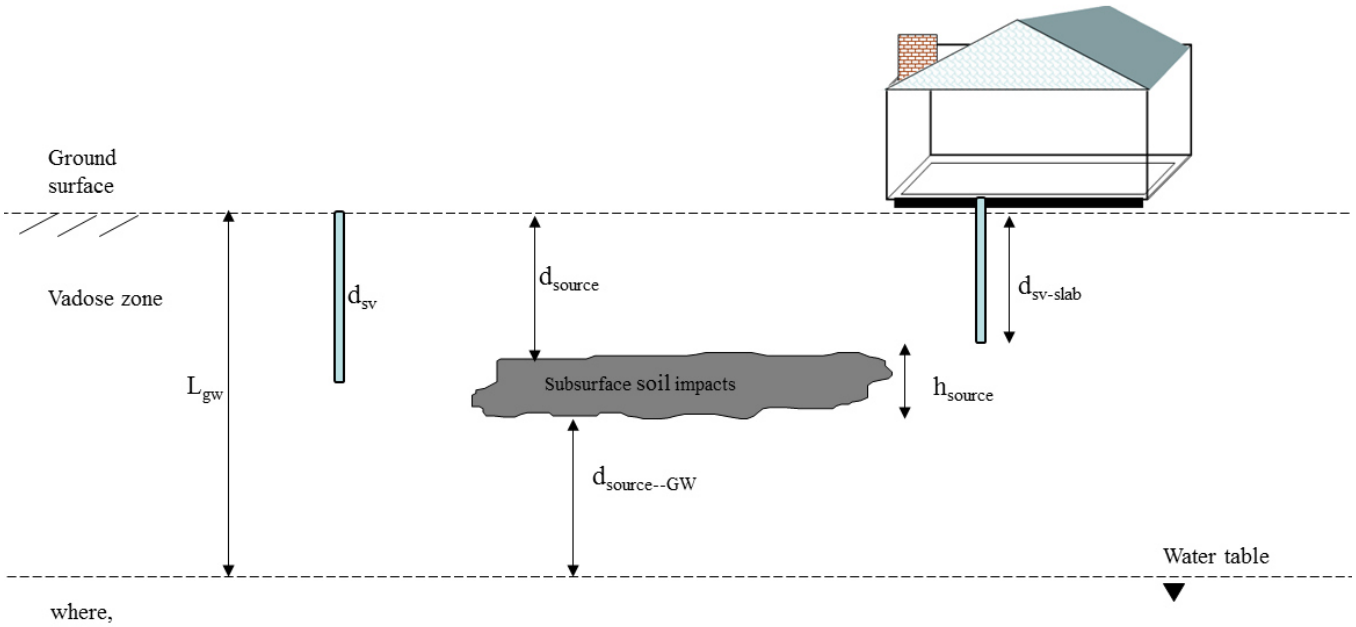
Figure 3: Example for Determining the Location of the POE



Explanation of Symbols

Q_{gw} = Impacted groundwater discharge into the stream [m^3/day]
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 [m]
D_p = Thickness of groundwater plume discharging to the stream [m]
X_s = Distance from the downgradient edge of the groundwater source to the stream [m]

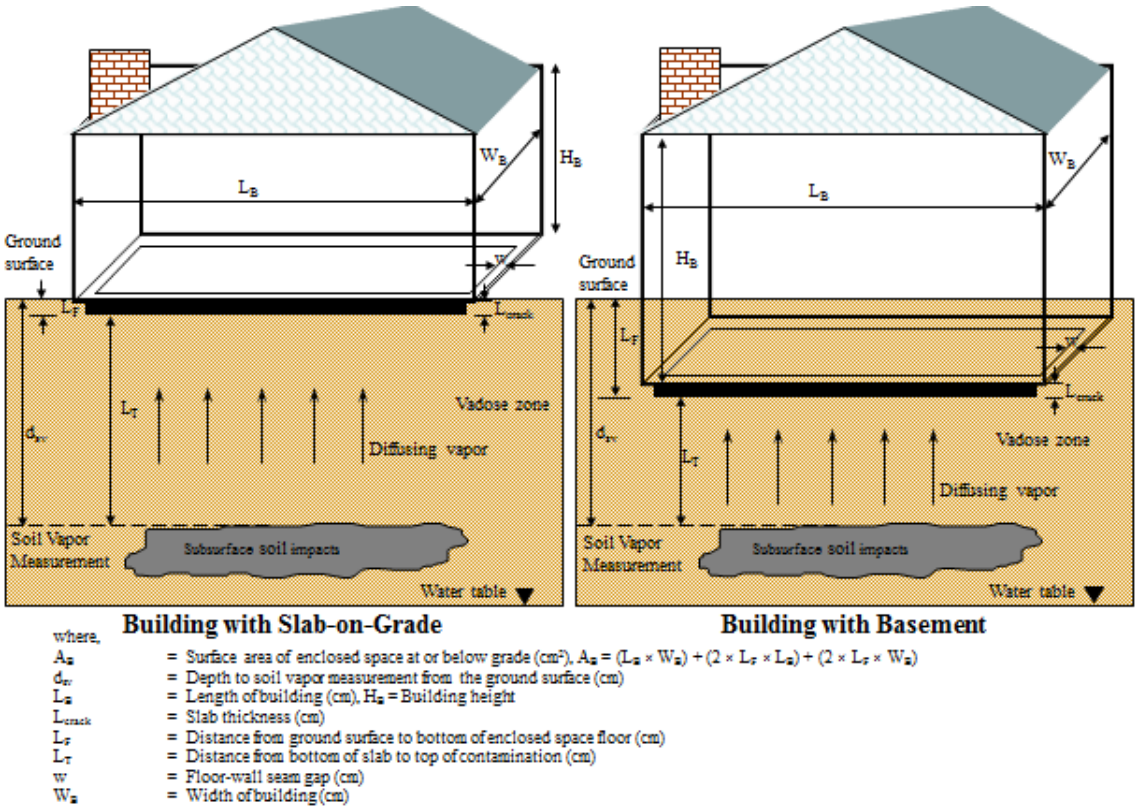
Figure 4: Schematic of Leachate Migration from the Soil to a Stream



where,

d_s	=	Depth to soil vapor measurement from the ground surface (cm)
d_{sv}	=	Depth to soil vapor measurement from the ground surface (cm)
$d_{sv-slab}$	=	Depth to soil vapor measurement from the ground surface below the building foundation slab (cm)
d_{source}	=	Depth to top of soil contamination source (cm)
h_{source}	=	Thickness of the soil contamination source (cm)
$d_{source-GW}$	=	Depth from the bottom of the soil contamination to groundwater (cm) $d_{source-GW} = L_{gw} - d_{source} - h_{source}$
L_{gw}	=	Depth to groundwater from the ground surface (cm)

Figure 5: Contaminant Parameters in the Soil



where,

A_B = Surface area of enclosed space at or below grade (cm^2), $A_B = (L_B \times W_B) + (2 \times L_F \times L_B) + (2 \times L_F \times W_B)$

d_{sv} = Depth to soil vapor measurement from the ground surface (cm)

L_B = Length of building (cm), H_B = Building height

L_{crack} = Slab thickness (cm)

L_F = Distance from ground surface to bottom of enclosed space floor (cm)

L_T = Distance from bottom of slab to top of contamination (cm)

w = Floor-wall seam gap (cm)

W_B = Width of building (cm)

Figure 6: Schematic Diagrams for the J&E Model

Chemical	CAS No.
Acenaphthene	83-32-9
Acephate	30560-19-1
Acetaldehyde	75-07-0
Acetochlor	34256-82-1
Acetone	67-64-1
Acetone Cyanohydrin	75-86-5
Acetonitrile	75-05-8
Acetophenone	98-86-2
Acetylaminofluorene, 2-	53-96-3
Acrolein	107-02-8
Acrylamide	79-06-1
Acrylic Acid	79-10-7
Acrylonitrile	107-13-1
Adiponitrile	111-69-3
Alachlor	15972-60-8
Aldicarb	116-06-3
Aldicarb Sulfone	1646-88-4
Aldicarb sulfoxide	1646-87-3
Aldrin	309-00-2
Allyl Alcohol	107-18-6
Allyl Chloride	107-05-1
Aluminum	7429-90-5
Aluminum metaphosphate	13776-88-0
Aluminum Phosphide	20859-73-8
Ametryn	834-12-8
Aminobiphenyl, 4-	92-67-1
Aminophenol, m-	591-27-5
Aminophenol, p-	123-30-8
Amitraz	33089-61-1
Ammonia	7664-41-7
Ammonium Perchlorate	7790-98-9
Ammonium polyphosphate	68333-79-9
Ammonium Sulfamate	7773-06-0
Amyl Alcohol, tert-	75-85-4
Aniline	62-53-3
Anthracene	120-12-7
Anthraquinone, 9,10-	84-65-1
Antimony (metallic)	7440-36-0
Antimony Pentoxide	1314-60-9
Antimony Tetroxide	1332-81-6
Antimony Trioxide	1309-64-4
Aroclor 1016	12674-11-2
Aroclor 1221	11104-28-2
Aroclor 1232	11141-16-5
Aroclor 1242	53469-21-9
Aroclor 1248	12672-29-6
Aroclor 1254	11097-69-1
Aroclor 1260	11096-82-5
Aroclor 5460	11126-42-4
Arsenic, Inorganic	7440-38-2
Arsine	7784-42-1
Asulam	3337-71-1
Atrazine	1912-24-9
Auramine	492-80-8
Avermectin B1	65195-55-3
Azinphos-methyl	86-50-0
Azobenzene	103-33-3
Azodicarbonamide	123-77-3
Barium	7440-39-3
Benfluralin	1861-40-1
Benomyl	17804-35-2
Bensulfuron-methyl	83055-99-6
Bentazon	25057-89-0
Benz[a]anthracene	56-55-3
Benzaldehyde	100-52-7
Benzene	71-43-2
Benzenediamine-2-methyl sulfate, 1,4-	6369-59-1
Benzenethiol	108-98-5
Benzidine	92-87-5
Benzo(j)fluoranthene	205-82-3
Benzo(a)pyrene	50-32-8
Benzo(b)fluoranthene	205-99-2
Benzo(k)fluoranthene	207-08-9
Benzoic Acid	65-85-0
Benzotrichloride	98-07-7
Benzyl Alcohol	100-51-6
Benzyl Chloride	100-44-7
Beryllium and compounds	7440-41-7
Bifenox	42576-02-3
Biphenthrin	82657-04-3
Biphenyl, 1,1-	92-52-4
Bis(2-chloro-1-methylethyl) ether	108-60-1
Bis(2-chloroethoxy)methane	111-91-1
Bis(2-chloroethyl)ether	111-44-4
Bis(2-ethylhexyl)phthalate	117-81-7
Bis(chloromethyl)ether	542-88-1
Bisphenol A	80-05-7
Boron And Borates Only	7440-42-8
Boron Trichloride	10294-34-5

Chemical	CAS No.
Boron Trifluoride	7637-07-2
Bromate	15541-45-4
Bromo-2-chloroethane, 1-	107-04-0
Bromobenzene	108-86-1
Bromochloromethane	74-97-5
Bromodichloromethane	75-27-4
Bromoform	75-25-2
Bromomethane	74-83-9
Bromophos	2104-96-3
Bromoxynil	1689-84-5
Bromoxynil Octanoate	1689-99-2
Butadiene, 1,3-	106-99-0
Butanol, N-	71-36-3
Butyl alcohol, sec-	78-92-2
Butyl Benzyl Phthalate	85-68-7
Butylate	2008-41-5
Butylated hydroxyanisole	25013-16-5
Butylated hydroxytoluene	128-37-0
Butylbenzene, n-	104-51-8
Butylbenzene, sec-	135-98-8
Butylbenzene, tert-	98-06-6
Butylphthalyl Butylglycolate	85-70-1
Cacodylic Acid	75-60-5
Cadmium (Diet) Source: Soil	7440-43-9
Cadmium (Water) Source: Water and Air	7440-43-9
Calcium Cyanide	592-01-8
Calcium pyrophosphate	7790-76-3
Caprolactam	105-60-2
Captafol	2425-06-1
Captan	133-06-2
Carbaryl	63-25-2
Carbofuran	1563-66-2
Carbon Disulfide	75-15-0
Carbon Tetrachloride	56-23-5
Carbonyl Sulfide	463-58-1
Carbosulfan	55285-14-8
Carboxin	5234-68-4
Ceric oxide	1306-38-3
Chloral Hydrate	302-17-0
Chloramben	133-90-4
Chloranil	118-75-2
Chlordane	12789-03-6
Chlordecone (Kepone)	143-50-0
Chlorfenvinphos	470-90-6

Chemical	CAS No.
Chlorimuron, Ethyl-	90982-32-4
Chlorine	7782-50-5
Chlorine Dioxide	10049-04-4
Chlorite (Sodium Salt)	7758-19-2
Chloro-1,1-difluoroethane, 1-	75-68-3
Chloro-1,3-butadiene, 2-	126-99-8
Chloro-2-methylaniline HCl, 4-	3165-93-3
Chloro-2-methylaniline, 4-	95-69-2
Chloroacetaldehyde, 2-	107-20-0
Chloroacetic Acid	79-11-8
Chloroacetophenone, 2-	532-27-4
Chloroaniline, p-	106-47-8
Chlorobenzene	108-90-7
Chlorobenzilate	510-15-6
Chlorobenzoic Acid, p-	74-11-3
Chlorobenzotrifluoride, 4-	98-56-6
Chlorobutane, 1-	109-69-3
Chlorodifluoromethane	75-45-6
Chloroethanol, 2-	107-07-3
Chloroform	67-66-3
Chloromethane	74-87-3
Chloromethyl Methyl Ether	107-30-2
Chloronaphthalene, Beta-	91-58-7
Chloronitrobenzene, o-	88-73-3
Chloronitrobenzene, p-	100-00-5
Chlorophenol, 2-	95-57-8
Chloropicrin	76-06-2
Chlorothalonil	1897-45-6
Chlorotoluene, o-	95-49-8
Chlorotoluene, p-	106-43-4
Chlorozotocin	54749-90-5
Chlorpropham	101-21-3
Chlorpyrifos	2921-88-2
Chlorpyrifos Methyl	5598-13-0
Chlorsulfuron	64902-72-3
Chlorthal-dimethyl	1861-32-1
Chlorthiophos	60238-56-4
Chromium (III) Cr+3	16065-83-1
Chromium (VI) Cr+6	18540-29-9
Chromium, Total	7440-47-3
Chrysene	218-01-9
Clofentezine	74115-24-5
Cobalt	7440-48-4
Coke Oven Emissions	8007-45-2
Copper	7440-50-8

Chemical	CAS No.
Copper Cyanide	544-92-3
Cresol, m-	108-39-4
Cresol, o-	95-48-7
Cresol, p-	106-44-5
Cresol, p-chloro-m-	59-50-7
Cresols	1319-77-3
Crotonaldehyde, trans-	123-73-9
Cumene (Isopropylbenzene)	98-82-8
Cupferron	135-20-6
Cyanazine	21725-46-2
Cyanide (CN-)	57-12-5
Cyanogen	460-19-5
Cyanogen Bromide	506-68-3
Cyanogen Chloride	506-77-4
Cyclohexane	110-82-7
Cyclohexane, 1,2,3,4,5-pentabromo-6-chloro-	87-84-3
Cyclohexanone	108-94-1
Cyclohexene	110-83-8
Cyclohexylamine	108-91-8
Cyfluthrin	68359-37-5
Cyhalothrin	68085-85-8
Cyromazine	66215-27-8
Dalapon	75-99-0
Daminozide	1596-84-5
DDD	72-54-8
DDE, p,p'-	72-55-9
DDT	50-29-3
Decabromodiphenyl ether, 2,2',3,3',4,4',5,5',6,6'- (BDE-209)	1163-19-5
Demeton	8065-48-3
Di(2-ethylhexyl)adipate	103-23-1
Diallate	2303-16-4
Diammonium phosphate	7783-28-0
Diazinon	333-41-5
Dibenz[a,h]anthracene	53-70-3
Dibenzo(a,e)pyrene	192-65-4
Dibenzofuran	132-64-9
Dibenzothiophene	132-65-0
Dibromo-3-chloropropane, 1,2-	96-12-8
Dibromobenzene, 1,3-	108-36-1
Dibromobenzene, 1,4-	106-37-6
Dibromochloromethane	124-48-1
Dibromoethane, 1,2- (EDB)	106-93-4
Dibromomethane (Methylene Bromide)	74-95-3
Dibutyl Phthalate	84-74-2
Dibutyltin Compounds	E1790660
Dicalcium phosphate	7757-93-9
Dicamba	1918-00-9
Dichloro-2-butene, 1,4-	764-41-0
Dichloro-2-butene, cis-1,4-	1476-11-5
Dichloro-2-butene, trans-1,4-	110-57-6
Dichloroacetic Acid	79-43-6
Dichlorobenzene, 1,2-	95-50-1
Dichlorobenzene, 1,4-	106-46-7
Dichlorobenzidine, 3,3'-	91-94-1
Dichlorobenzophenone, 4,4'-	90-98-2
Dichlorodifluoromethane	75-71-8
Dichloroethane, 1,1-	75-34-3
Dichloroethane, 1,2- (EDC)	107-06-2
Dichloroethylene, 1,1-	75-35-4
Dichloroethylene, 1,2-cis-	156-59-2
Dichloroethylene, 1,2-trans-	156-60-5
Dichlorophenol, 2,4-	120-83-2
Dichlorophenoxy Acetic Acid, 2,4-	94-75-7
Butanoic acid, 4-(2,4-dichlorophenoxy)-	94-82-6
Dichloropropane, 1,2-	78-87-5
Dichloropropane, 1,3-	142-28-9
Dichloropropanol, 2,3-	616-23-9
Dichloropropene, 1,3-	542-75-6
Dichlorvos	62-73-7
Dicrotophos	141-66-2
Dicyclopentadiene	77-73-6
Dieldrin	60-57-1
Diesel Engine Exhaust	E17136615
Diethanolamine	111-42-2
Diethyl Phthalate	84-66-2
Diethylene Glycol Monobutyl Ether	112-34-5
Diethylene Glycol Monoethyl Ether	111-90-0
Diethylformamide	617-84-5
Diethylstilbestrol	56-53-1
Difenzoquat	43222-48-6
Diflubenzuron	35367-38-5
Difluoroethane, 1,1-	75-37-6
Dihydrosafrole	94-58-6

Chemical	CAS No.
Diisopropyl Ether	108-20-3
Diisopropyl Methylphosphonate	1445-75-6
Dimagnesium phosphate	7782-75-4
Dimethipin	55290-64-7
Dimethoate	60-51-5
Dimethoxybenzidine, 3,3'-	119-90-4
Dimethyl methylphosphonate	756-79-6
Dimethylamino azobenzene [p-]	60-11-7
Dimethylaniline HCl, 2,4-	21436-96-4
Dimethylaniline, 2,4-	95-68-1
Dimethylaniline, N,N-	121-69-7
Dimethylbenz(a)anthracene, 7,12-	57-97-6
Dimethylbenzidine, 3,3'-	119-93-7
Dimethylformamide	68-12-2
Dimethylhydrazine, 1,1-	57-14-7
Dimethylhydrazine, 1,2-	540-73-8
Dimethylphenol, 2,4-	105-67-9
Dimethylphenol, 2,6-	576-26-1
Dimethylphenol, 3,4-	95-65-8
Dimethylterephthalate	120-61-6
Dimethylvinylchloride	513-37-1
Dinitrobenzene, 1,2-	528-29-0
Dinitrobenzene, 1,3-	99-65-0
Dinitrobenzene, 1,4-	100-25-4
Dinitro-o-cresol, 4,6-	534-52-1
Dinitro-o-cyclohexyl Phenol, 4,6-	131-89-5
Dinitrophenol, 2,4-	51-28-5
Dinitrotoluene, 2,4-	121-14-2
Dinitrotoluene, 2,6-	606-20-2
Dinitrotoluene, 2-Amino-4,6-	35572-78-2
Dinitrotoluene, 4-Amino-2,6-	19406-51-0
Dinitrotoluene, 2,4/2,6 Mixture (DNT)	25321-14-6
Dinoseb	88-85-7
Dioxane, 1,4-	123-91-1
Diphenamid	957-51-7
Diphenyl Sulfone	127-63-9
Diphenylamine	122-39-4
Diphenylhydrazine, 1,2-	122-66-7
Dipotassium phosphate	7758-11-4
Diquat	85-00-7
Direct Black 38	1937-37-7
Direct Blue 6	2602-46-2
Direct Brown 95	16071-86-6

Chemical	CAS No.
Disodium phosphate	7558-79-4
Disulfoton	298-04-4
Dithiane, 1,4-	505-29-3
Diuron	330-54-1
Dodine	2439-10-3
Endosulfan	115-29-7
Endothall	145-73-3
Endrin	72-20-8
Epichlorohydrin	106-89-8
Epoxybutane, 1,2-	106-88-7
EPTC	759-94-4
Ethanol, 2-(2-methoxyethoxy)-	111-77-3
Ethephon	16672-87-0
Ethion	563-12-2
Ethoxyethanol Acetate, 2-	111-15-9
Ethoxyethanol, 2-	110-80-5
Ethyl Acetate	141-78-6
Ethyl Acrylate	140-88-5
Ethyl Chloride (Chloroethane)	75-00-3
Ethyl Ether	60-29-7
Ethyl Methacrylate	97-63-2
Ethylbenzene	100-41-4
Ethylene Cyanohydrin	109-78-4
Ethylene Diamine	107-15-3
Ethylene Glycol	107-21-1
Ethylene Glycol Monobutyl Ether	111-76-2
Ethylene Oxide	75-21-8
Ethylene Thiourea	96-45-7
Ethyleneimine	151-56-4
Ethylphthalyl Ethyl Glycolate	84-72-0
Ethyl-p-nitrophenyl Phosphonate	2104-64-5
Fenamiphos	22224-92-6
Fenpropathrin	39515-41-8
Fenvalerate	51630-58-1
Fluometuron	2164-17-2
Fluoranthene	206-44-0
Fluorene	86-73-7
Fluoride	16984-48-8
Fluorine (Soluble Fluoride)	7782-41-4
Fluridone	59756-60-4
Flurprimidol	56425-91-3
Flusilazole	85509-19-9
Flutolanil	66332-96-5
Fluvalinate	69409-94-5
Folpet	133-07-3

Chemical	CAS No.
Fomesafen	72178-02-0
Fonofos	944-22-9
Formaldehyde	50-00-0
Formic Acid	64-18-6
Fosetyl-AL	39148-24-8
Furan	110-00-9
Furazolidone	67-45-8
Furfural	98-01-1
Furium	531-82-8
Furmecyclox	60568-05-0
Glufosinate, Ammonium	77182-82-2
Glutaraldehyde	111-30-8
Glycidyl	765-34-4
Glyphosate	1071-83-6
Guanidine	113-00-8
Guanidine Chloride	50-01-1
Haloxyfop, Methyl	69806-40-2
Heptachlor	76-44-8
Heptachlor Epoxide	1024-57-3
Heptachlorobiphenyl, 2,3,3',4,4',5,5'- (PCB 189)	39635-31-9
Hexabromobenzene	87-82-1
Hexabromodiphenyl ether, 2,2',4,4',5,5'- (BDE-153)	68631-49-2
Hexachlorobenzene	118-74-1
Hexachlorobiphenyl, 2,3,3',4,4',5- (PCB 156)	38380-08-4
Hexachlorobiphenyl, 2,3,3',4,4',5'- (PCB 157)	69782-90-7
Hexachlorobiphenyl, 2,3',4,4',5,5'- (PCB 167)	52663-72-6
Hexachlorobiphenyl, 3,3',4,4',5,5'- (PCB 169)	32774-16-6
Hexachlorobutadiene	87-68-3
Hexachlorocyclohexane, Alpha-	319-84-6
Hexachlorocyclohexane, Beta-	319-85-7
Hexachlorocyclohexane, Gamma- (Lindane)	58-89-9
Hexachlorocyclohexane, Technical	608-73-1
Hexachlorocyclopentadiene	77-47-4
Hexachlorodibenzo-p-dioxin, Mixture	HxCDD
Hexachloroethane	67-72-1
Hexachlorophene	70-30-4

Chemical	CAS No.
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	121-82-4
Hexamethylene Diisocyanate, 1,6-	822-06-0
Hexamethylphosphoramide	680-31-9
Hexane, N-	110-54-3
Hexanedioic Acid	124-04-9
Hexanone, 2-	591-78-6
Hexazinone	51235-04-2
Hexythiazox	78587-05-0
Hydramethylnon	67485-29-4
Hydrazine	302-01-2
Hydrazine Sulfate	10034-93-2
Hydrogen Chloride	7647-01-0
Hydrogen Cyanide	74-90-8
Hydrogen Fluoride	7664-39-3
Hydrogen Sulfide	7783-06-4
Hydroquinone	123-31-9
Imazalil	35554-44-0
Imazaquin	81335-37-7
Imazethapyr	81335-77-5
Indeno[1,2,3-cd]pyrene	193-39-5
Iodine	7553-56-2
Iprodione	36734-19-7
Iron	7439-89-6
Isobutyl Alcohol	78-83-1
Isophorone	78-59-1
Isopropalin	33820-53-0
Isopropanol	67-63-0
Isopropyl Methyl Phosphonic Acid	1832-54-8
Isoxaben	82558-50-7
JP-7	E1737665
Lactofen	77501-63-4
Lead acetate	301-04-2
Lead and Compounds	7439-92-1
Lead Phosphate	7446-27-7
Lead subacetate	1335-32-6
Lewisite	541-25-3
Linuron	330-55-2
Lithium	7439-93-2
Lithium Perchlorate	7791-03-9
Malathion	121-75-5
Maleic Anhydride	108-31-6
Maleic Hydrazide	123-33-1

Chemical	CAS No.
Malononitrile	109-77-3
Mancozeb	8018-01-7
Maneb	12427-38-2
Manganese (Diet) / Tier 3	7439-96-5
Manganese (Non-diet)	7439-96-5
MCPA	94-74-6
MCPB	94-81-5
MCPP	93-65-2
Mephosfolan	950-10-7
Mepiquat Chloride	24307-26-4
Mercuric Chloride (and other Mercury salts)	7487-94-7
Mercury (elemental)	7439-97-6
Merphos	150-50-5
Merphos Oxide	78-48-8
Metalaxyl	57837-19-1
Methacrylonitrile	126-98-7
Methamidophos	10265-92-6
Methanol	67-56-1
Methidathion	950-37-8
Methomyl	16752-77-5
Methoxy-5-nitroaniline, 2-	99-59-2
Methoxychlor	72-43-5
Methoxyethanol Acetate, 2-	110-49-6
Methoxyethanol, 2-	109-86-4
Methyl Acetate	79-20-9
Methyl Acrylate	96-33-3
Methyl Ethyl Ketone - MEK (2-Butanone)	78-93-3
Methyl Hydrazine	60-34-4
Methyl Isobutyl Ketone - MIBK (4-methyl-2-pentanone)	108-10-1
Methyl Isocyanate	624-83-9
Methyl Mercury	22967-92-6
Methyl Methacrylate	80-62-6
Methyl methanesulfonate	66-27-3
Methyl Parathion	298-00-0
Methyl Phosphonic Acid	993-13-5
Methyl Styrene (Mixed Isomers)	25013-15-4
Methyl tert-Butyl Ether (MTBE)	1634-04-4
Methyl-1,4-benzenediamine dihydrochloride, 2-	615-45-2
Methyl-5-Nitroaniline, 2-	99-55-8
Methylaniline Hydrochloride, 2-	636-21-5
Methylarsonic acid	124-58-3

Chemical	CAS No.
Methylbenzene,1-4-diamine monohydrochloride, 2-	74612-12-7
Methylbenzene-1,4-diamine sulfate, 2-	615-50-9
Methylcholanthrene, 3-	56-49-5
Methylene Chloride	75-09-2
Methylene-bis(2-chloroaniline), 4,4'-	101-14-4
Methylene-bis(N,N-dimethyl) Aniline, 4,4'-	101-61-1
Methylenebisbenzenamine, 4,4'-	101-77-9
Methylenediphenyl Diisocyanate	101-68-8
Methylnaphthalene, 1-	90-12-0
Methylnaphthalene, 2-	91-57-6
Methyl-N-nitro-N-nitrosoguanidine, N-	70-25-7
Methylstyrene, Alpha-	98-83-9
Metolachlor	51218-45-2
Metribuzin	21087-64-9
Metsulfuron-methyl	74223-64-6
Mineral oils	8012-95-1
Mirex	2385-85-5
Molinate	2212-67-1
Molybdenum	7439-98-7
Monoaluminum phosphate	13530-50-2
Monoammonium phosphate	7722-76-1
Monocalcium phosphate	7758-23-8
Monochloramine	10599-90-3
Monomagnesium phosphate	7757-86-0
Monomethylaniline	100-61-8
Monopotassium phosphate	7778-77-0
Monosodium phosphate	7558-80-7
Myclobutanil	88671-89-0
N,N'-Diphenyl-1,4-benzenediamine	74-31-7
Naled	300-76-5
Naphtha, High Flash Aromatic (HFAN)	64742-95-6
Naphthalene	91-20-3
Naphthylamine, 2-	91-59-8
Napropamide	15299-99-7
Nickel Acetate	373-02-4
Nickel Carbonate	3333-67-3
Nickel Carbonyl	13463-39-3
Nickel Hydroxide	12054-48-7

Chemical	CAS No.
Nickel Oxide	1313-99-1
Nickel Refinery Dust	E715532
Nickel Soluble Salts	7440-02-0
Nickel Subsulfide	12035-72-2
Nickelocene	1271-28-9
Nitrate	14797-55-8
Nitrate + Nitrite (as N)	E701177
Nitrite	14797-65-0
Nitroaniline, 2-	88-74-4
Nitroaniline, 4-	100-01-6
Nitrobenzene	98-95-3
Nitrocellulose	9004-70-0
Nitrofurantoin	67-20-9
Nitrofurazone	59-87-0
Nitroglycerin	55-63-0
Nitroguanidine (Pricrite)	556-88-7
Nitromethane	75-52-5
Nitropropane, 2-	79-46-9
Nitropyrene, 4-	57835-92-4
Nitrosodiethanolamine, N-	1116-54-7
Nitrosodiethylamine, N-	55-18-5
Nitrosodimethylamine, N-	62-75-9
Nitroso-di-N-butylamine, N-	924-16-3
Nitroso-di-N-propylamine, N-	621-64-7
Nitrosodiphenylamine, N-	86-30-6
Nitrosomethylethylamine, N-	10595-95-6
Nitrosomorpholine [N-]	59-89-2
Nitroso-N-ethylurea, N-	759-73-9
Nitroso-N-methylurea, N-	684-93-5
Nitrosopiperidine [N-]	100-75-4
Nitrosopyrrolidine, N-	930-55-2
Nitrotoluene, m-	99-08-1
Nitrotoluene, o-	88-72-2
Nitrotoluene, p-	99-99-0
Nonane, n-	111-84-2
Norflurazon	27314-13-2
Octabromodiphenyl Ether	32536-52-0
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX)	2691-41-0
Octamethylpyrophosphoramide	152-16-9
Octyl Phthalate, di-N-	117-84-0
Oryzalin	19044-88-3
Oxadiazon	19666-30-9
Oxamyl	23135-22-0
Oxyfluorfen	42874-03-3

Chemical	CAS No.
Paclobutrazol	76738-62-0
Paraquat Dichloride	1910-42-5
Parathion	56-38-2
Pebulate	1114-71-2
Pendimethalin	40487-42-1
Pentabromodiphenyl Ether	32534-81-9
Pentabromodiphenyl ether, 2,2',4,4',5- (BDE-99)	60348-60-9
Pentachlorobenzene	608-93-5
Pentachlorobiphenyl, 2,3,3',4,4'- (PCB 105)	32598-14-4
Pentachlorobiphenyl, 2,3,4,4',5- (PCB 114)	74472-37-0
Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	31508-00-6
Pentachlorobiphenyl, 2',3,4,4',5- (PCB 123)	65510-44-3
Pentachlorobiphenyl, 3,3',4,4',5- (PCB 126)	57465-28-8
Pentachloroethane	76-01-7
Pentachloronitrobenzene	82-68-8
Pentachlorophenol	87-86-5
Pentaerythritol tetranitrate (PETN)	78-11-5
Pentane, n-	109-66-0
Perchlorate and Perchlorate Salts	14797-73-0
Perfluorobutane sulfonic acid (PFBS)	375-73-5
Permethrin	52645-53-1
Phenacetin	62-44-2
Phenmedipham	13684-63-4
Phenol	108-95-2
Phenol, 2-(1-methylethoxy)-, methylcarbamate	114-26-1
Phenothiazine	92-84-2
Phenylenediamine, m-	108-45-2
Phenylenediamine, o-	95-54-5
Phenylenediamine, p-	106-50-3
Phenylmercuric Acetate	62-38-4
Phenylphenol, 2-	90-43-7
Phorate	298-02-2
Phosgene	75-44-5
Phosmet	732-11-6
Phosphine	7803-51-2

Chemical	CAS No.
Phosphoric Acid	7664-38-2
Phosphorus, White	7723-14-0
Phthalic Acid, P-	100-21-0
Phthalic Anhydride	85-44-9
Picloram	1918-02-1
Picramic Acid (2-Amino-4,6-dinitrophenol)	96-91-3
Picric Acid (2,4,6-Trinitrophenol)	88-89-1
Pirimiphos, Methyl	29232-93-7
Polybrominated Biphenyls	59536-65-1
Polychlorinated Biphenyls (high risk)	1336-36-3
Polychlorinated Biphenyls (low risk)	1336-36-3
Polychlorinated Biphenyls (lowest risk)	1336-36-3
Polymeric Methylene Diphenyl Diisocyanate (PMDI)	9016-87-9
Polyphosphoric acid	8017-16-1
Potassium Cyanide	151-50-8
Potassium Perchlorate	7778-74-7
Potassium Perfluorobutane Sulfonate	29420-49-3
Potassium Silver Cyanide	506-61-6
Potassium tripolyphosphate	13845-36-8
Prochloraz	67747-09-5
Profluralin	26399-36-0
Prometon	1610-18-0
Prometryn	7287-19-6
Propachlor	1918-16-7
Propanil	709-98-8
Propargite	2312-35-8
Propargyl Alcohol	107-19-7
Propazine	139-40-2
Propham	122-42-9
Propiconazole	60207-90-1
Propionaldehyde	123-38-6
Propyl benzene	103-65-1
Propylene	115-07-1
Propylene Glycol	57-55-6
Propylene Glycol Dinitrate	6423-43-4
Propylene Glycol Monomethyl Ether	107-98-2
Propylene Oxide	75-56-9
Propyzamide	23950-58-5

Chemical	CAS No.
Pyrene	129-00-0
Pyridine	110-86-1
Quinalphos	13593-03-8
Quinoline	91-22-5
Quizalofop-ethyl	76578-14-8
Refractory Ceramic Fibers	E715557
Resmethrin	10453-86-8
Ronnel	299-84-3
Rotenone	83-79-4
Safrole	94-59-7
Selenious Acid	7783-00-8
Selenium	7782-49-2
Selenium Sulfide	7446-34-6
Sethoxydim	74051-80-2
Silica (crystalline, respirable)	7631-86-9
Silver	7440-22-4
Silver Cyanide	506-64-9
Simazine	122-34-9
Sodium acid pyrophosphate	7758-16-9
Sodium Acifluorfen	62476-59-9
Sodium aluminum phosphate (acidic)	7785-88-8
Sodium aluminum phosphate (anhydrous)	10279-59-1
Sodium aluminum phosphate (tetrahydrate)	10305-76-7
Sodium Azide	26628-22-8
Sodium Cyanide	143-33-9
Sodium Diethyldithiocarbamate	148-18-5
Sodium Fluoride	7681-49-4
Sodium Fluoroacetate	62-74-8
Sodium hexametaphosphate	10124-56-8
Sodium Metavanadate	13718-26-8
Sodium Perchlorate	7601-89-0
Sodium polyphosphate	68915-31-1
Sodium trimetaphosphate	7785-84-4
Sodium tripolyphosphate	7758-29-4
Sodium Tungstate	13472-45-2
Sodium Tungstate Dihydrate	10213-10-2
Stirofos (Tetrachlorovinphos)	961-11-5
Strontium, Stable	7440-24-6
Strychnine	57-24-9
Styrene	100-42-5
Styrene-Acrylonitrile	(SAN) Trimer

Chemical	CAS No.
Sulfolane	126-33-0
Sulfonylbis(4-chlorobenzene), 1,1'-	80-07-9
Sulfur Trioxide	7446-11-9
Sulfuric Acid	7664-93-9
Sulfurous acid, 2-chloroethyl 2-[4-(1,1-dimethylethyl)phenoxy]-1-methylethyl ester	140-57-8
TCDD, 2,3,7,8-	1746-01-6
TCMTB	21564-17-0
Tebuthiuron	34014-18-1
Temephos	3383-96-8
Terbacil	5902-51-2
Terbufos	13071-79-9
Terbutryn	886-50-0
Tetrabromodiphenyl ether, 2,2',4,4'- (BDE-47)	5436-43-1
Tetrachlorobenzene, 1,2,4,5-	95-94-3
Tetrachlorobiphenyl, 3,3',4,4'- (PCB 77)	32598-13-3
Tetrachlorobiphenyl, 3,4,4',5- (PCB 81)	70362-50-4
Tetrachloroethane, 1,1,1,2-	630-20-6
Tetrachloroethane, 1,1,2,2-	79-34-5
Tetrachloroethylene (PCE)	127-18-4
Tetrachlorophenol, 2,3,4,6-	58-90-2
Tetrachlorotoluene, p- alpha, alpha, alpha-	5216-25-1
Tetraethyl Dithiopyrophosphate	3689-24-5
Tetraethyl Lead	78-00-2
Tetrafluoroethane, 1,1,1,2-	811-97-2
Tetrahydrofuran	109-99-9
Tetrapotassium phosphate	7320-34-5
Tetrasodium pyrophosphate	7722-88-5
Tetryl (Trinitrophenylmethylnitramine)	479-45-8
Thallic Oxide	1314-32-5
Thallium (I) Nitrate	10102-45-1
Thallium (Soluble Salts)	7440-28-0
Thallium Acetate	563-68-8
Thallium Carbonate	6533-73-9
Thallium Chloride	7791-12-0
Thallium Selenite	12039-52-0
Thallium Sulfate	7446-18-6
Thifensulfuron-methyl	79277-27-3

Chemical	CAS No.
Thiobencarb	28249-77-6
Thiocyanates	E1790664
Thiocyanic Acid	463-56-9
Thiodiglycol	111-48-8
Thiofanox	39196-18-4
Thiophanate, Methyl	23564-05-8
Thiram	137-26-8
Tin	7440-31-5
Titanium Tetrachloride	7550-45-0
Toluene	108-88-3
Toluene-2,4-diisocyanate	584-84-9
Toluene-2,5-diamine	95-70-5
Toluene-2,6-diisocyanate	91-08-7
Toluidine, o- (Methylaniline, 2-)	95-53-4
Toluidine, p-	106-49-0
TPH Aliphatic (Tier 2):	(High) C19-C32
TPH Aliphatic (Tier 2):	(Low) C5-C8
TPH Aliphatic (Tier 2):	(Medium) C9-C18
TPH Aromatic (Tier 2):	(High) C17-C32
TPH Aromatic (Tier 2):	(Low): C6-C8
TPH Aromatic (Tier 2☺	(Medium): C9-C16
Toxaphene	8001-35-2
Tralomethrin	66841-25-6
Triacetin	102-76-1
Triadimefon	43121-43-3
Triallate	2303-17-5
Trialuminum sodium tetra decahydrogenoctaorthophosphate (dihydrate)	15136-87-5
Triasulfuron	82097-50-5
Tribenuron-methyl	101200-48-0
Tribromobenzene, 1,2,4-	615-54-3
Tributyl Phosphate	126-73-8
Tributyltin Compounds	E1790678
Tributyltin Oxide	56-35-9
Tricalcium phosphate	7758-87-4
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1

Chemical	CAS No.
Trichloroacetic Acid	76-03-9
Trichloroaniline HCl, 2,4,6-	33663-50-2
Trichloroaniline, 2,4,6-	634-93-5
Trichlorobenzene, 1,2,3-	87-61-6
Trichlorobenzene, 1,2,4-	120-82-1
Trichloroethane, 1,1,1-	71-55-6
Trichloroethane, 1,1,2-	79-00-5
Trichloroethylene (TCE)	79-01-6
Trichlorofluoromethane (Freon 11)	75-69-4
Trichlorophenol, 2,4,5-	95-95-4
Trichlorophenol, 2,4,6-	88-06-2
Trichlorophenoxyacetic Acid, 2,4,5-	93-76-5
Trichlorophenoxypropionic acid, -2,4,5	93-72-1
Trichloropropane, 1,1,2-	598-77-6
Trichloropropane, 1,2,3-	96-18-4
Trichloropropene, 1,2,3-	96-19-5
Tricresyl Phosphate (TCP)	1330-78-5
Tridiphane	58138-08-2
Triethylamine	121-44-8
Triethylene Glycol	112-27-6
Trifluoroethane, 1,1,1-	420-46-2
Trifluralin	1582-09-8
Trimagnesium phosphate	7757-87-1
Trimethyl Phosphate	512-56-1
Trimethylbenzene, 1,2,3-	526-73-8
Trimethylbenzene, 1,2,4-	95-63-6
Trimethylbenzene, 1,3,5-	108-67-8
Trimethylpentene, 2,4,4-	25167-70-8
Tri-n-butyltin	688-73-3
Trinitrobenzene, 1,3,5-	99-35-4
Trinitrotoluene, 2,4,6- (TNT)	118-96-7
Triphenylphosphine Oxide	791-28-6
Tripotassium phosphate	7778-53-2
Tris(1,3-Dichloro-2-propyl) Phosphate	13674-87-8
Tris(1-chloro-2-propyl)phosphate	13674-84-5
Tris(2,3-dibromopropyl)phosphate	126-72-7
Tris(2-chloroethyl)phosphate	115-96-8
Tris(2-ethylhexyl)phosphate	78-42-2
Trisodium phosphate	7601-54-9
Tungsten	7440-33-7

Chemical	CAS No.
Uranium	7440-61-1
Urethane	51-79-6
Vanadium and Compounds	7440-62-2
Vanadium Pentoxide	1314-62-1
Vernolate	1929-77-7
Vinclozolin	50471-44-8
Vinyl Acetate	108-05-4
Vinyl Bromide	593-60-2
Vinyl Chloride	75-01-4
TPH – DRO + ORO (Tier 1)	C10 – C40
Xylene, m-	108-38-3
Xylene, o-	95-47-6
Xylene, P-	106-42-3
Xylenes	1330-20-7
Zinc and Compounds	7440-66-6
Zinc Cyanide	557-21-1
Zinc Phosphide	1314-84-7
Zineb	12122-67-7
Zirconium	7440-67-7
TPH – GRO (Tier 2)	C6-C10
TPH – DRO (Tier 2)	C10-C28
TPH – ORO (Tier 2)	C28 – C40
Benzo(g,h,i)perylene	191-24-2
Dichloroethylene, 1,2	540-59-0
Guanidine Nitrate	506-93-4

APPENDIX B
IRBCA Spreadsheet Model Instructions

Table of Contents **Page**

Downloading IRBCA Spreadsheet Model 2
IRBCA Spreadsheet Model Architecture 2
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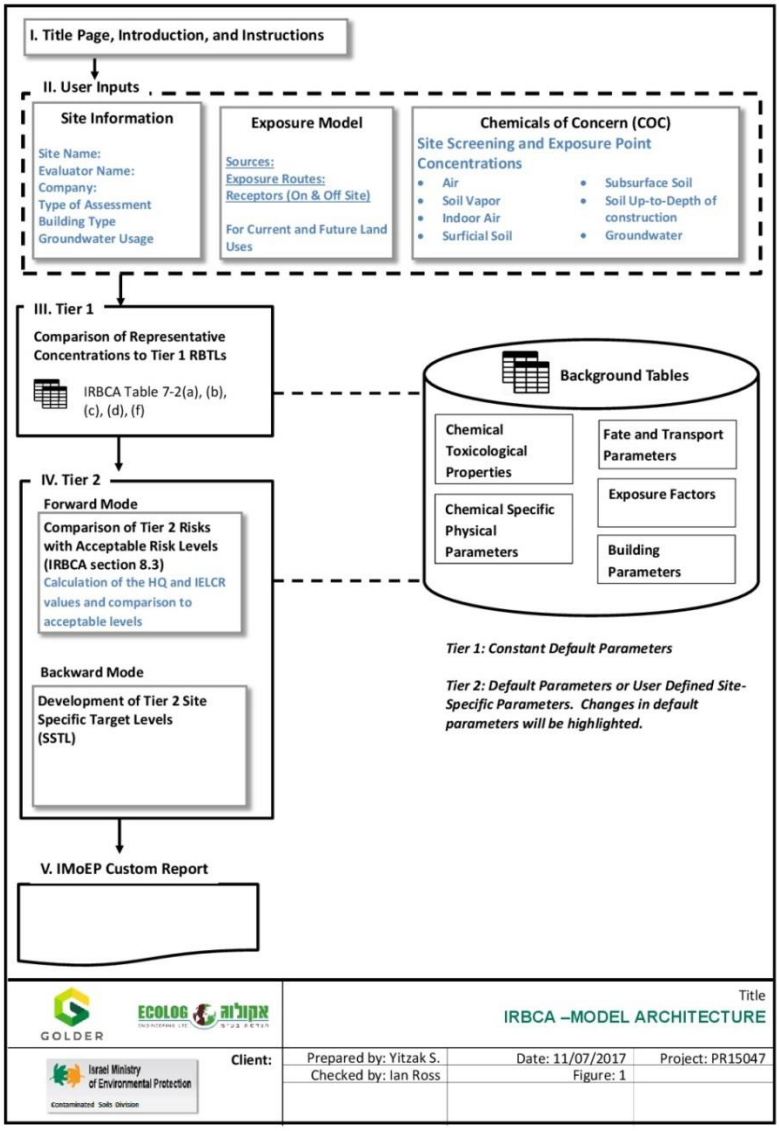
Using the IRBCA Excel ™ Software 4

Downloading IRBCA Spreadsheet Model

The IRBCA Excel™ spreadsheet model can be either be downloaded from the MoEP's website or requested from the Division of Contaminated Soils at the MoEP.

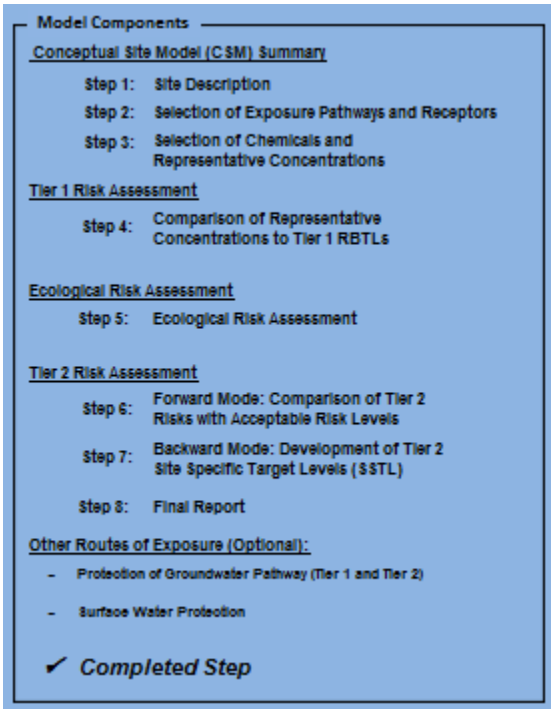
IRBCA Spreadsheet Model Architecture

Figure 1 provides a schematic of the IRBCA model architecture.



IRBCA Model Components

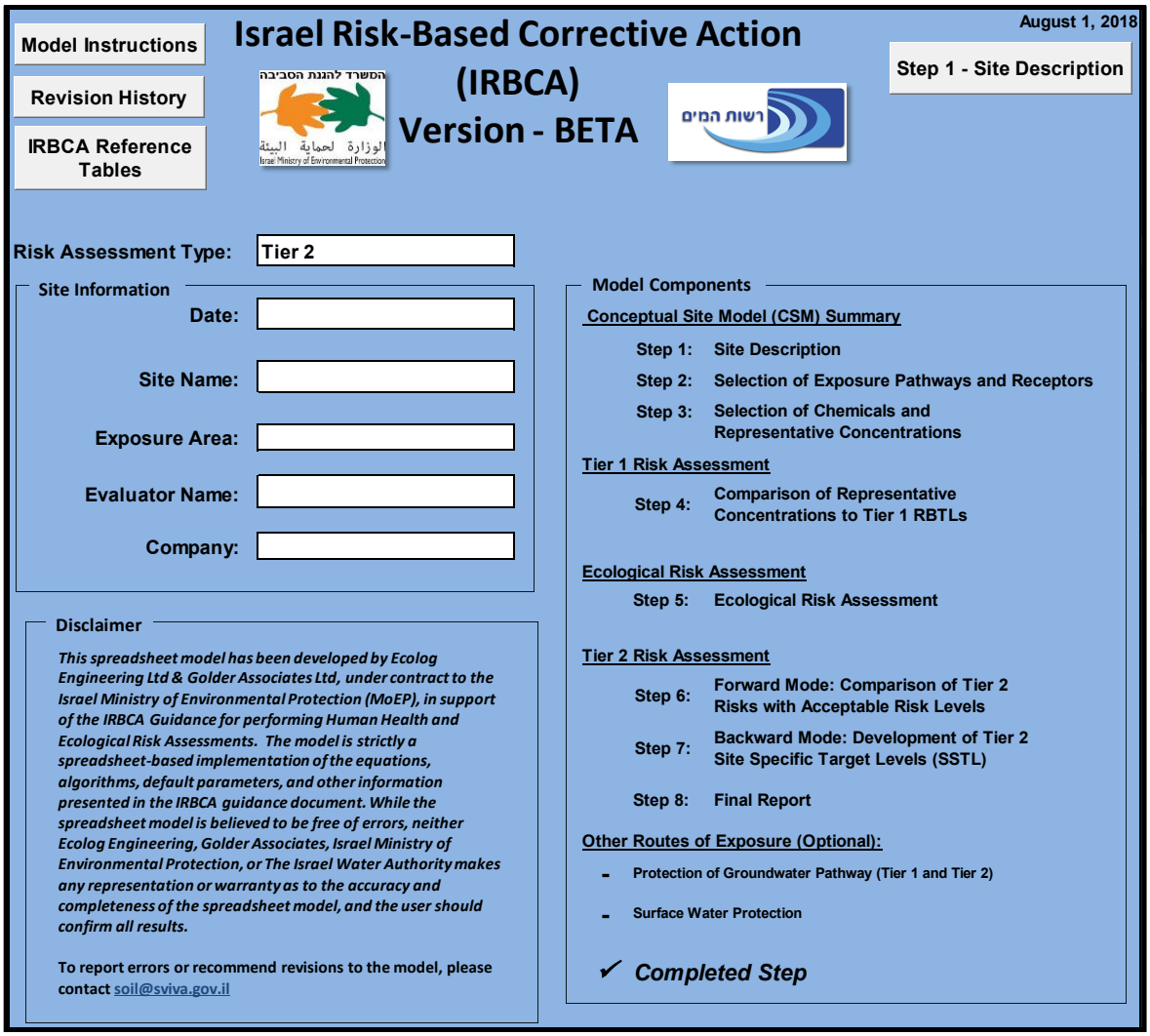
There are 8 primary Steps to the IRBCA spreadsheet model. Users are required to complete each step of the model prior to submitting the risk assessment to the regulator for approval. The user will receive a check ("√") as each step of the model is completed.



Using the IRBCA Excel ™ Software

Creating a Risk Assessment Project

The following **menu** will appear when the IRBCA software is executed.



Menu Buttons

- **Model Instructions** - Link to the IRBCA Excel ™ spreadsheet model instructions
- **Revision History** – Link to a list of model revisions made to the IRBCA spreadsheet model. This table includes a description of the change and date the revision was made.
- **IRBCA Reference Tables** – Link to a list of all the tables referenced in the IRBCA reference document
- **Step 1 – Site Description** – Link to the Step 1 of the model which requires the user to summarize the site details.

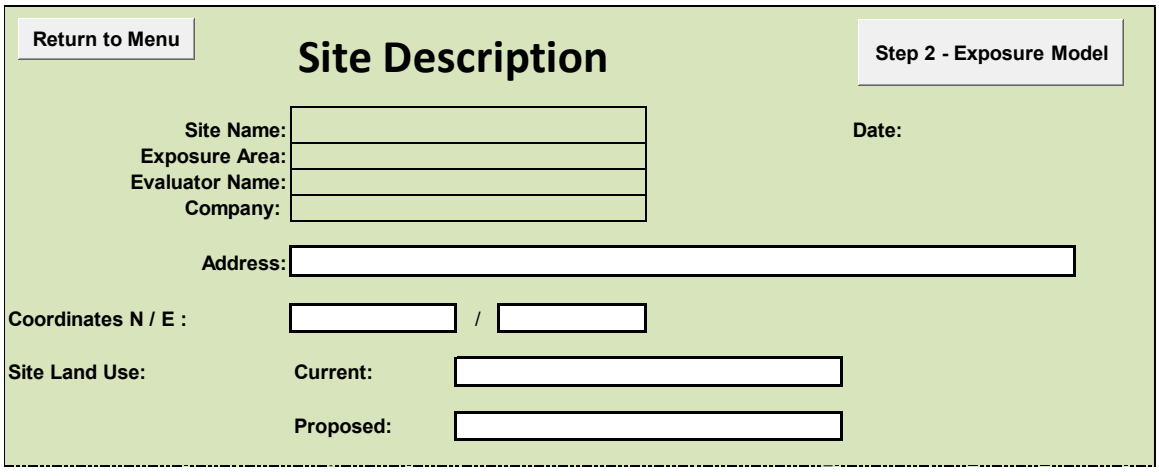
User Inputs Required on the Menu Page

- **Risk Assessment Type:** Select **Tier 1** or **Tier 2**. Users can change this later when results of the Tier 1 risk assessment is performed.
- **Basic Site Information**: Date, Site Name, Exposure Area, Evaluator Name, Company

Step 1 - Site Description

Site Description Buttons

- **Return to Menu:** Return to the main menu of the model.
- **Step 2 – Exposure Model:** Link to the next step in the model



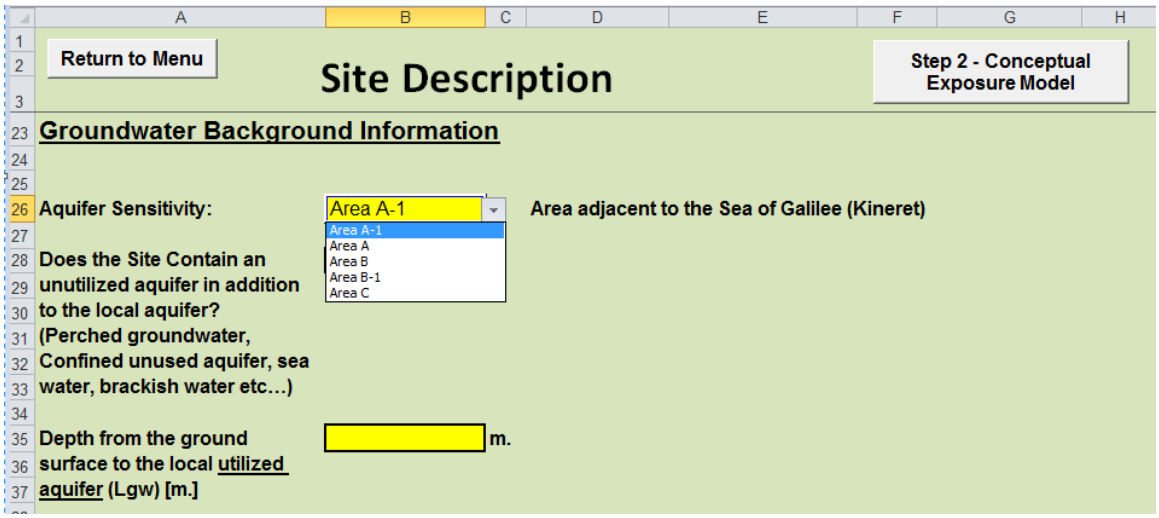
User Inputs Required on the Menu Page

- Site Address
- Coordinates
- Site Land Use (Current and Proposed)
- Groundwater Information

- **Aquifer Sensitivity**

Aquifer Sensitivity	Description
Area A-1	Area adjacent to the Sea of Galilee (Kineret)
Area A	Main aquifer where damage cannot be repaired
Area B	A main aquifer where the damage can be repaired or a secondary aquifer where the damage cannot be repaired
Area B-1	Aquifer of minor importance where the water is small and / or the water is brackish
Area C	Area where there is no danger to water sources

- Note: If the site is located above Areas A, A-1, or B, the soil concentration protective of groundwater pathway will be considered complete.

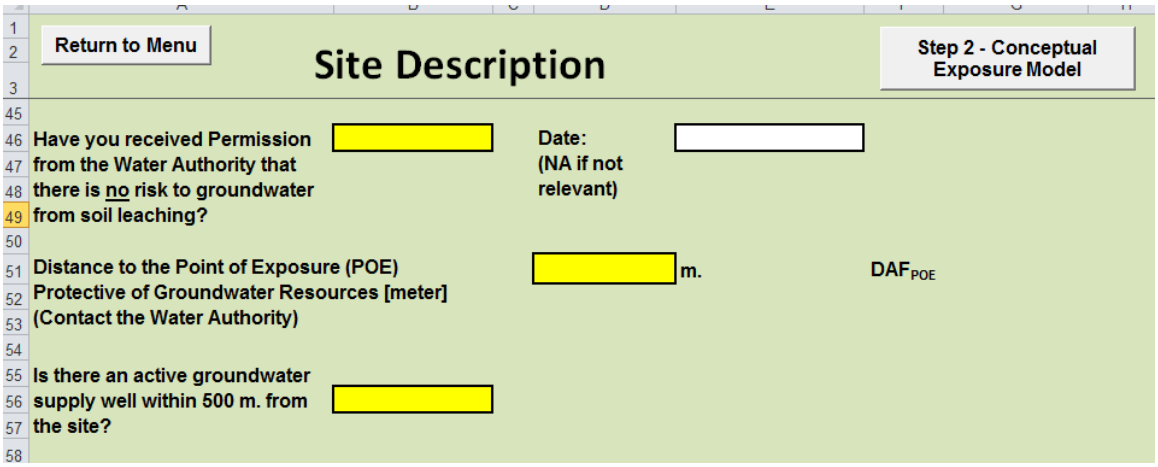


- Does the site contain an unutilized aquifer in addition to the local aquifer (Perched groundwater, confined unused aquifer, sea water, brackish water, etc…)

***Note**: users will be asked to provide a depth to the unutilized shallow aquifer. This value will be used in the calculation of risks and target levels for the vapor intrusion from groundwater pathway.*

- Depth from the ground surface to the local utilized aquifer (L_{gw}) [m.]

***Note:** The depth from the ground surface to the local utilized aquifer will be used in the calculation of target values for the soil leaching pathway.*



- Have you received permission from the water authority that there is no risk to groundwater from soil? **Yes/No**

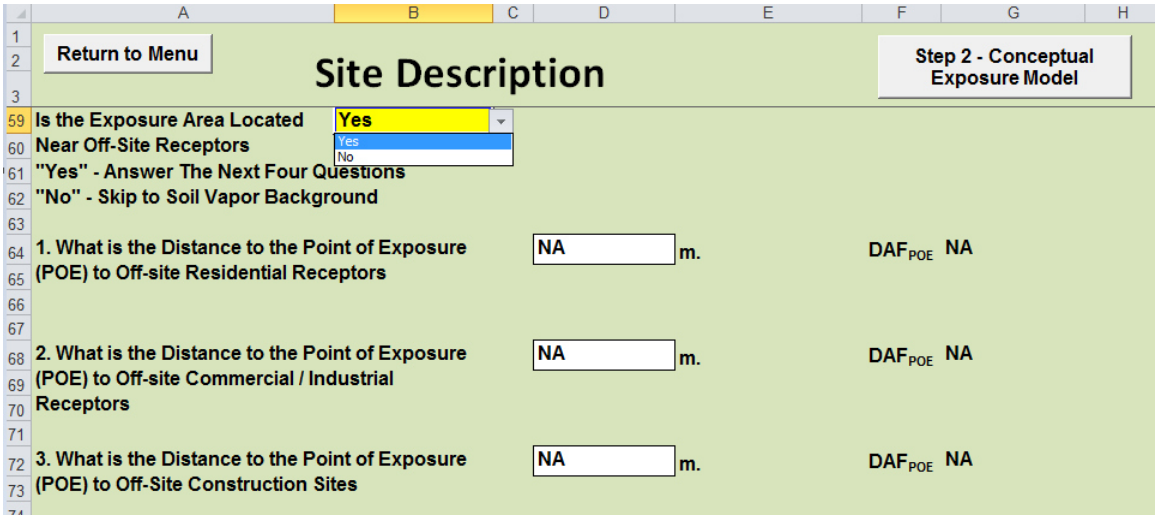
  Note: *In the event the Water Authority provided formal confirmation the model user can select "Yes" and the groundwater leaching pathway will be considered incomplete.*

  - *Distance to the Point of Exposure (POE) protective of groundwater resources [meter]. (Contact the Water Authority for Clarification)*

    Note: *This distance used to calculate the allowable concentrations in groundwater protective of groundwater resources. The Water Authority should be consulted on this issue.*

- Is there an active groundwater supply well 500 m. from the site? **Yes/No**

  Note*: If the answer is "Yes" the Water Authority considers the point of exposure (POE) to be zero (Dilution Attenuation Factor = 1)*



- Is the Exposure Area located near off-site receptors? Yes/**No**

Note: *If the model user selects "Yes", the user will be asked to provide the distance to each off-site receptor (Residential, Commercial/Industrial, Construction Worker, Recreational Site).*

- Soil Vapor Intrusion Information
  - Does the site include a building with an underground parking? **Yes/No**

    Note: *If the answer is "Yes", the MoEP allows the user to use a factor of 4 for the Tier 1 attenuation factor* $\alpha_{sv\text{-}in}$

  - Building Type: **Basement / Slab**
    Basement – A floor of the building is partly or entirely below ground level
    Slab – The foundation of the building foundation is on grade

- Ecological Risk Assessment Required? **Yes/No**
  Note: This will be determined as part of the approved work plan by the regulator. If the answer is "Yes", the user will be required to complete (at a minimum) the Level 1 Ecological Risk Assessment.

- Survey's Performed to Date

  Users are asked to check **Yes/No** for each survey that was performed and provide references, date approved, and the name of the regulator who approved the report.

- Historical Survey (Phase I)
- Soil Vapor Investigation (Phase II)
- Soil Investigation (Phase II)
- Groundwater Investigation (Phase II)
- Surface Water/Sediment Investigation
- Conceptual Site Model (CSM)
- Risk Assessment Work Plan
- Other Relevant Reports (Optional)

Surveys Performed To Date (check if relevant, Provide references Below):

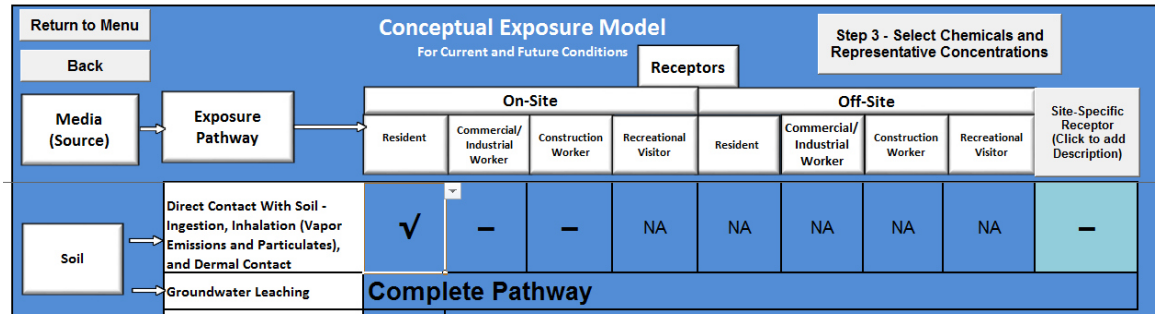
"NA" if not Relevant

Historical Survey (Phase I)	Yes
References: Title, Date, Consultant Name	
Date Approved:	***Approved By:***

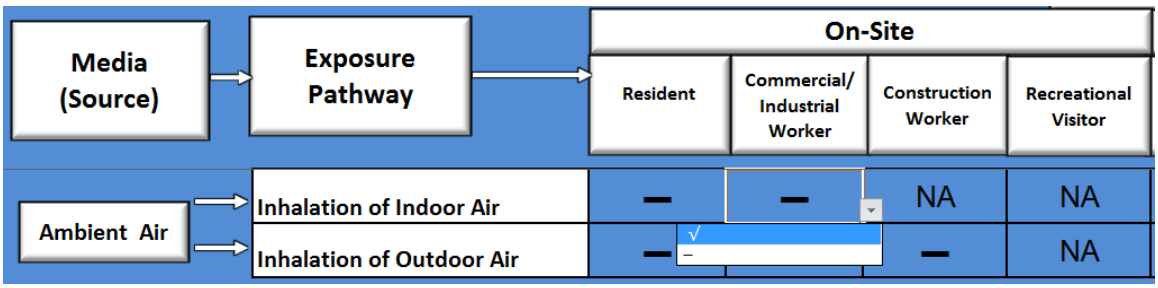
Step 2 - Conceptual Exposure Model

Users are asked to select the relevant pathways that are being evaluated in the risk assessment. The Conceptual Exposure model lists the Media (pollution source), Exposure Pathway, and Receptors. The users can select on-site and off-site receptors (where relevant). A pathway defined as "NA" is not applicable in the current version of the model.

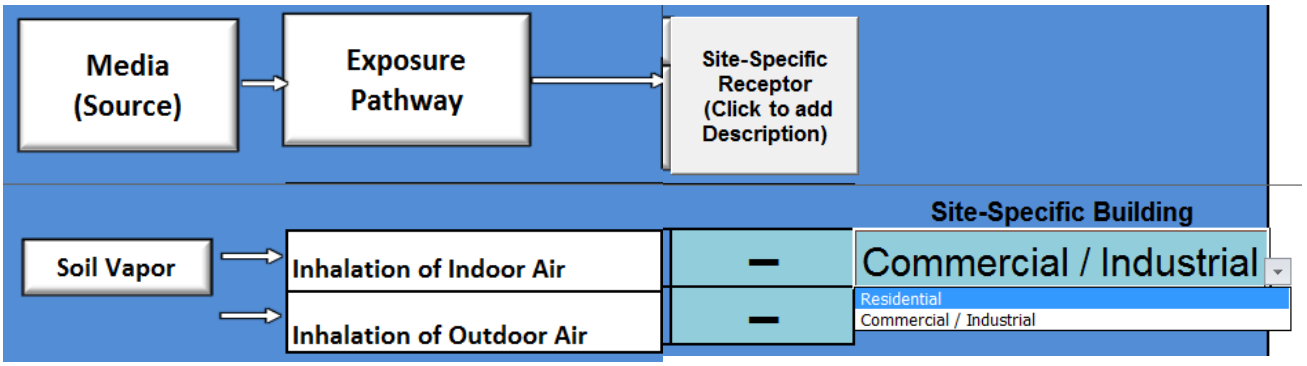
A user can select relevant Media ->Exposure Pathways -> Receptors by selecting the check ("√"). A check pathway is considered complete.



√ - Complete Pathway
– - Incomplete Pathway
NA - Not Applicable



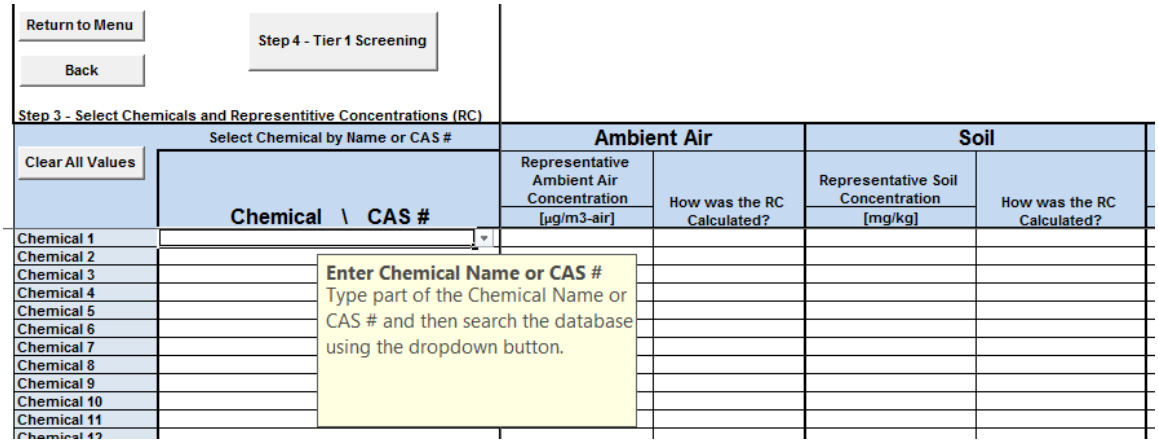
The user has the option of selecting a "Site-Specific Receptor". The user is required to include a description of the receptor which can be performed by selecting the button. If the indoor inhalation of vapors is a complete pathway and must be evaluated for the site-specific receptor, the user is required to select whether the building is residential or commercial.

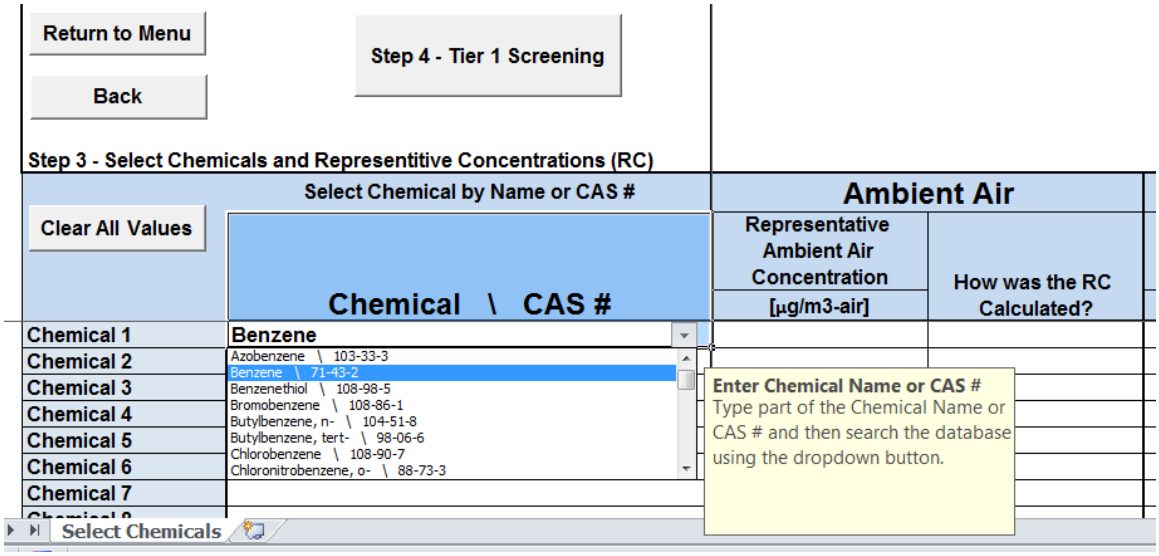


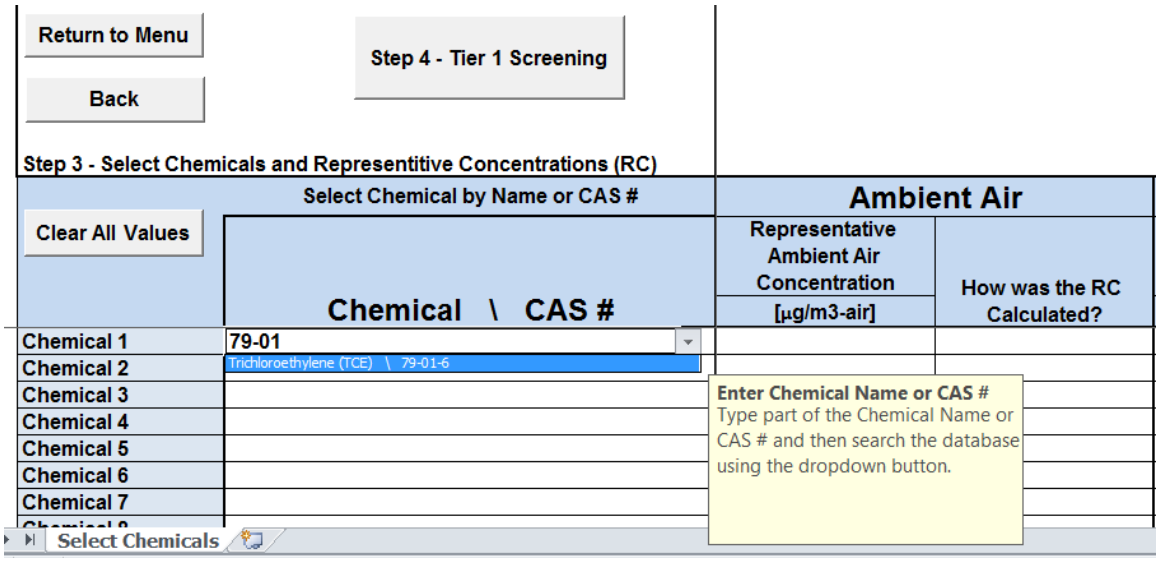
Step 3 - Select Chemicals and Representative Concentrations

The user is required to select the chemicals that are to be evaluated for the risk assessment. The user can select up to 30 chemicals and 10 user defined

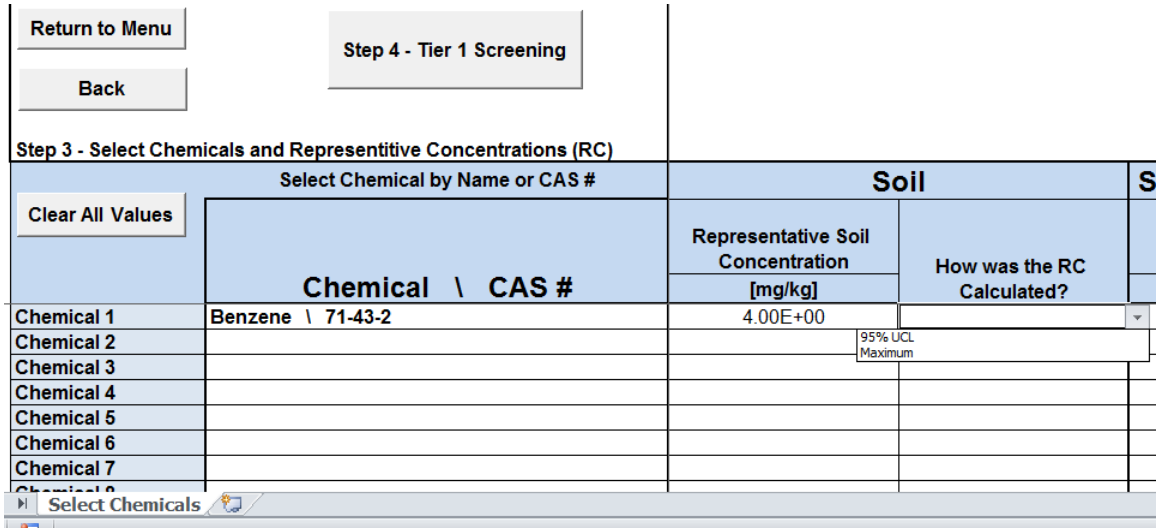
chemicals (see below). Users can search through the data base of over 800 chemicals in the IRBCA spreadsheet by chemical name or CAS Registry number. The user can include all or part of the name or CAS # and search by clicking the dropdown button.



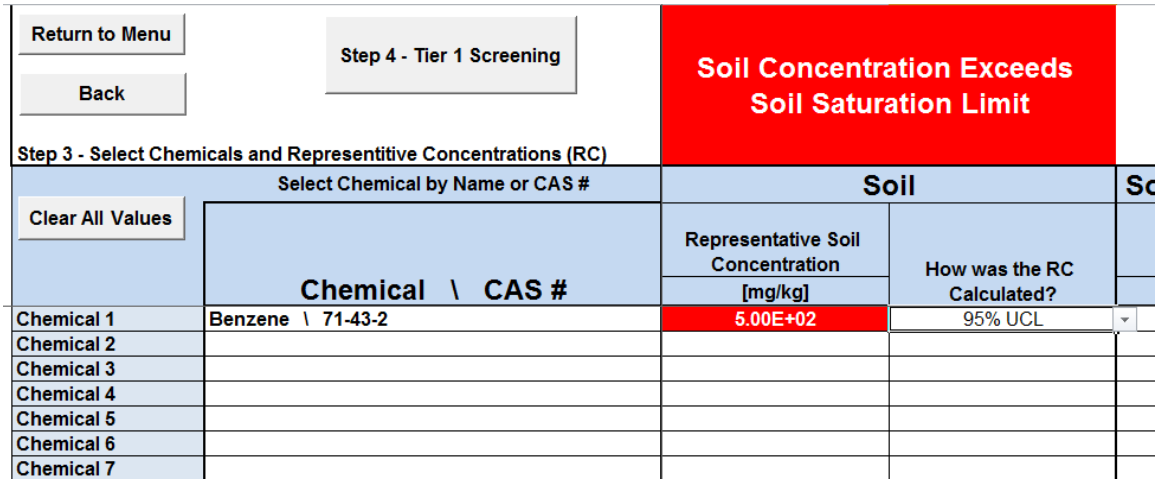




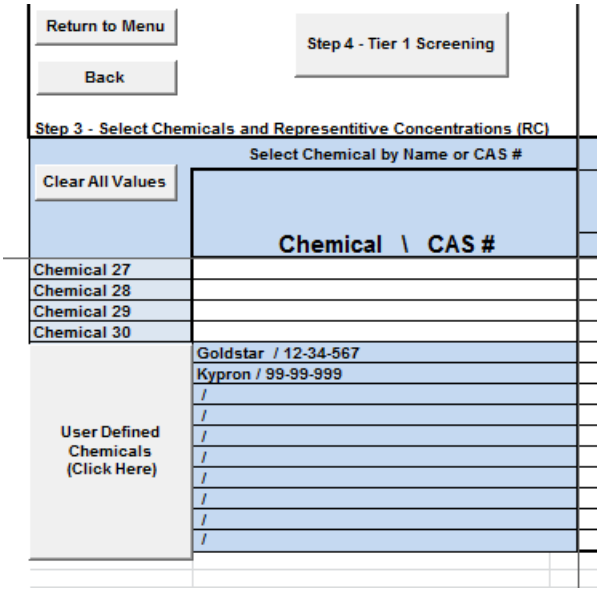
Users are required to enter the representative concentration for each media. Users are asked to define how the representative concentration was calculated **(95% UCL or Maximum Concentration).** See Appendix D of the IRBCA guidance document for instructions calculating representative concentration.



If a soil concentration exceeds the soil saturation limit the user will receive a message in red below. If this occurs there may be concern for free-phase product on-site. The regulator may require removing free-phase product prior to conducting the risk assessment.



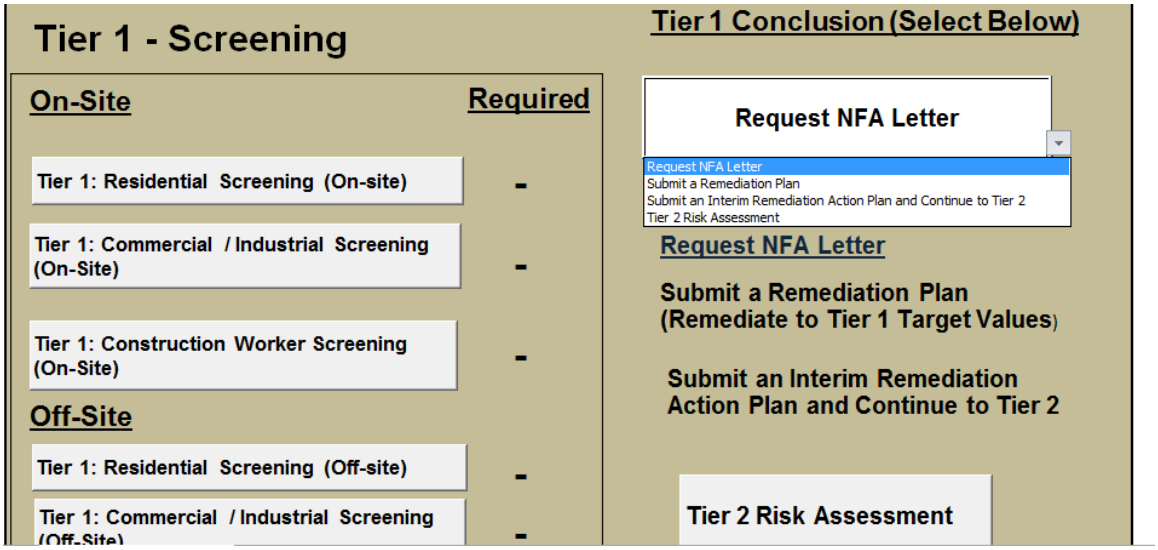
The user has the option of selecting up to 10 user defined chemicals. The user can enter chemical parameters, toxicity parameters, and dermal parameters by clicking the user defined button.



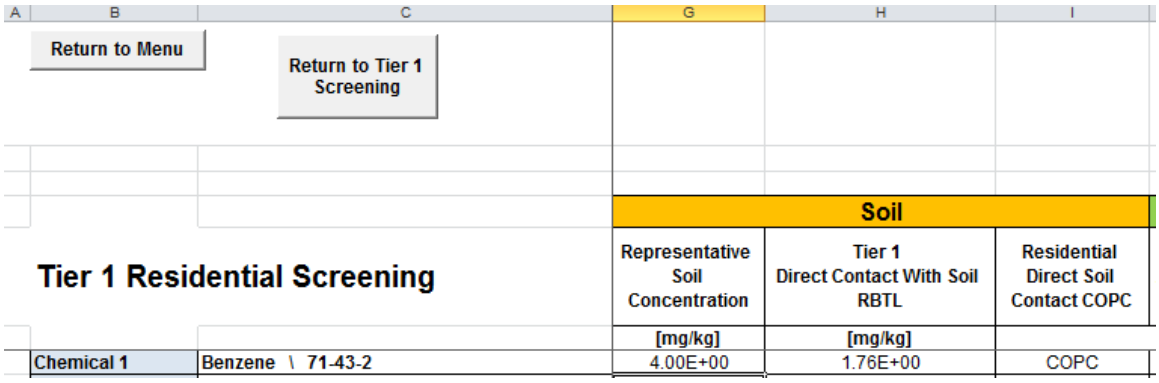
1	User Defined Chemical Parameters and Toxicity Factors													
2	Return to the Chemical Screening Tab					Molecular Weight		Henry's Law Constant			Vapor Pressure			
3						MW		H`	HLC		VP			
4	Chemical		CAS #	Chemical/CAS#	Volatile Substance	Chemical Type (Organic or Inorganic)	g/mole	Ref	(unitless)	(atm-m^3/mole)	Ref	mm Hg	Ref	
5	User Defined 1	Goldstar	12-34-567	Goldstar / 12-34-567										
6	User Defined 2	Kypron	99-99-999	Kypron / 99-99-999										
7	User Defined 3			/										
8	User Defined 4			/										
9	User Defined 5			/										
10	User Defined 6			/										
11	User Defined 7			/										
12	User Defined 8			/										
13	User Defined 9			/										
14	User Defined 10			/										

Step 4 - Tier 1 Screening

The user can view Tier 1 screening results for each receptor (Residential, Commercial/ Industrial, and Construction Worker).



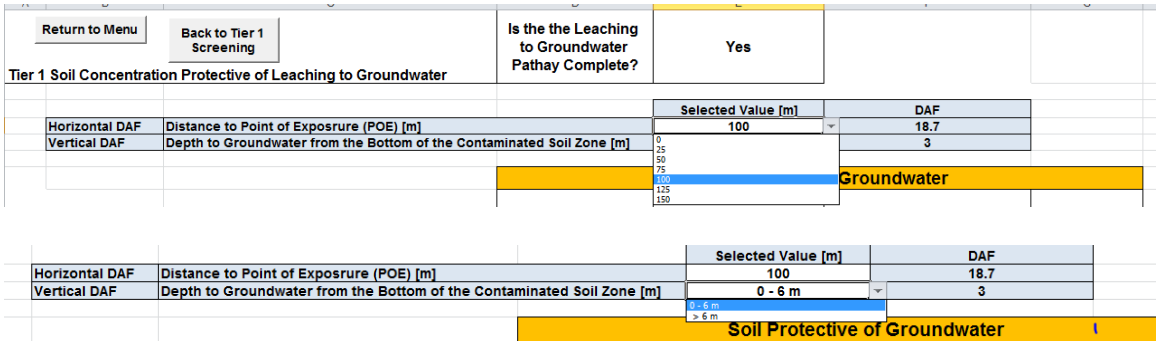
For each Tier 1 screening table, the user will see the representative concentration, Tier 1 risk based target level (RBTL). Chemicals whose representative concentration exceeds the Tier 1 target level is considered a chemical of potential concern (COPC) and must be evaluated further.



Tier 1 Soil Concentration Protective of Leaching to Groundwater
In order to calculate the soil concentration protective of groundwater resources, the user is asked to select two values:

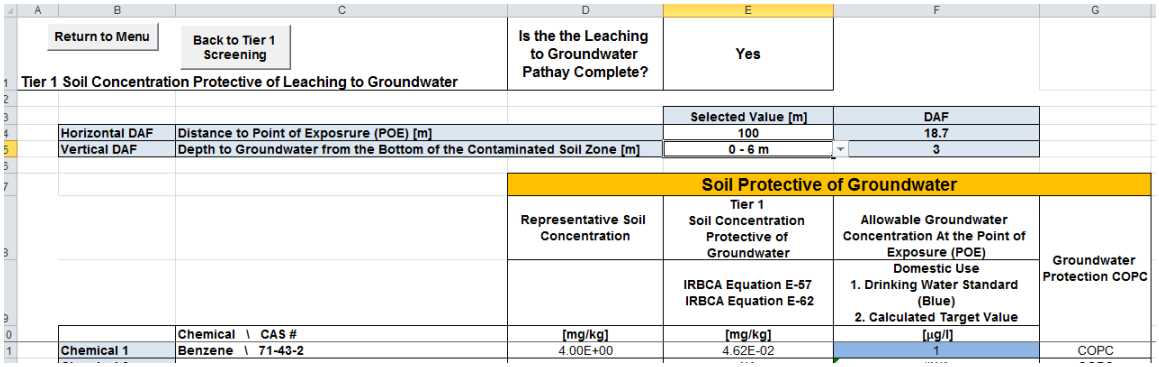
1. The distance to the point of exposure (POE) which will determine the horizontal Dilution Attenuation Factor. Users can select up to a maximum distance of 150 m. for Tier 1. The model will automatically calculate the horizontal DAF based on the selected distance.

2. The user will also select the depth to groundwater from the bottom of the contaminated soil zone which will be used to calculate the vertical DAF. User can selected 0 - 6 m which will result in a vertical DAF of 3 or greater than 6 m (>6m) which results in a DAF of 8.



Users will see the representative soil concentration, calculated Tier 1 soil

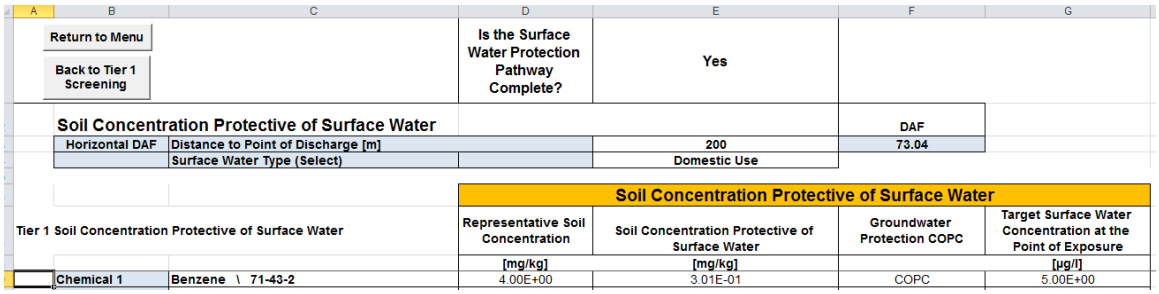
concentration protective of groundwater and the source of the allowable groundwater concentration at the POE (drinking water standard or calculated target value).



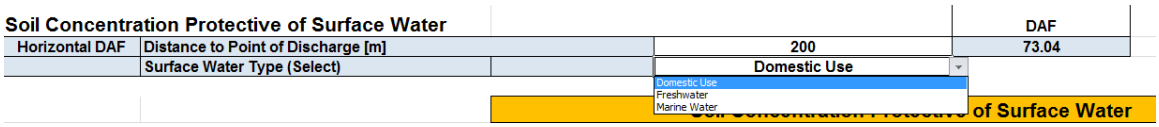
Return to Menu / Back to Tier 1 Screening			Is the the Leaching to Groundwater Pathay Complete?	Yes		
Tier 1 Soil Concentration Protective of Leaching to Groundwater						
				Selected Value [m]	DAF	
	Horizontal DAF	Distance to Point of Exposrure (POE) [m]		100	18.7	
	Vertical DAF	Depth to Groundwater from the Bottom of the Contaminated Soil Zone [m]		0 - 6 m	3	
			Soil Protective of Groundwater			
			Representative Soil Concentration	Tier 1 Soil Concentration Protective of Groundwater	Allowable Groundwater Concentration At the Point of Exposure (POE)	Groundwater Protection COPC
				IRBCA Equation E-57 IRBCA Equation E-62	Domestic Use 1. Drinking Water Standard (Blue) 2. Calculated Target Value	
		Chemical \ CAS #	[mg/kg]	[mg/kg]	[µg/l]	
	Chemical 1	Benzene \ 71-43-2	4.00E+00	4.62E-02	1	COPC

Soil Concentration Protective of Surface Water

If the soil concentration protective of surface water pathway is complete users will be required to evaluate this pathway. Users are required to enter the distance to the point of discharge to the surface waterbody and the surface water body type (domestic use, freshwater or marine water).



Return to Menu / Back to Tier 1 Screening			Is the Surface Water Protection Pathway Complete?	Yes		
	Soil Concentration Protective of Surface Water				DAF	
	Horizontal DAF	Distance to Point of Discharge [m]		200	73.04	
		Surface Water Type (Select)		Domestic Use		
			Soil Concentration Protective of Surface Water			
Tier 1 Soil Concentration Protective of Surface Water			Representative Soil Concentration	Soil Concentration Protective of Surface Water	Groundwater Protection COPC	Target Surface Water Concentration at the Point of Exposure
			[mg/kg]	[mg/kg]		[µg/l]
	Chemical 1	Benzene \ 71-43-2	4.00E+00	3.01E-01	COPC	5.00E+00



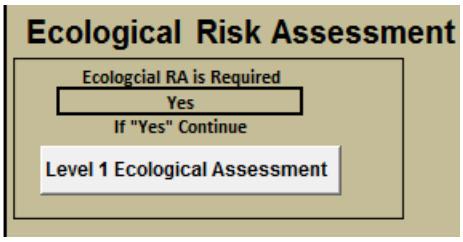
Soil Concentration Protective of Surface Water				DAF
Horizontal DAF	Distance to Point of Discharge [m]		200	73.04
	Surface Water Type (Select)		Domestic Use	

Domestic Use
Freshwater
Marine Water

of Surface Water

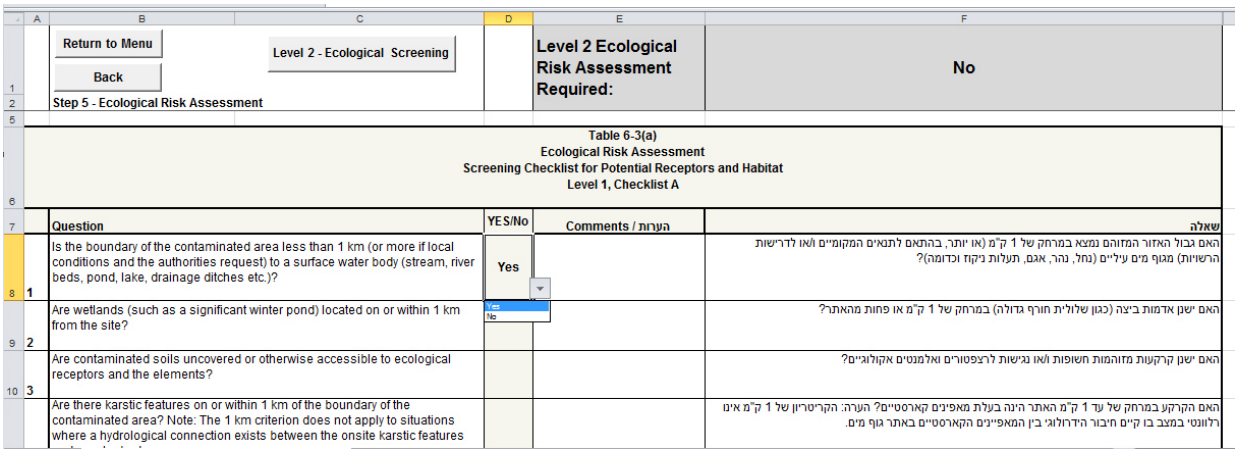
Ecological Risk Assessment

If the user is required to perform the risk assessment, the user will click on the Level 1 Ecological assessment button. This will direct the user to the Level 1 screening checklists as described in the guidance document.



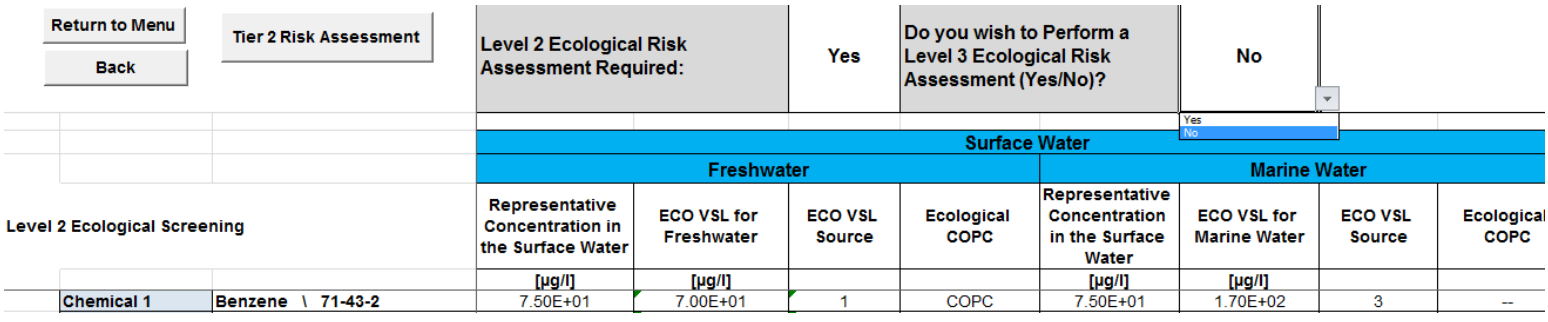
Level 1 Ecological Risk Assessment

Users are required to complete the screening checklist for potential receptors and habitats. The user answers **Yes/No** for each question.



Level 2 Ecological Risk Assessment

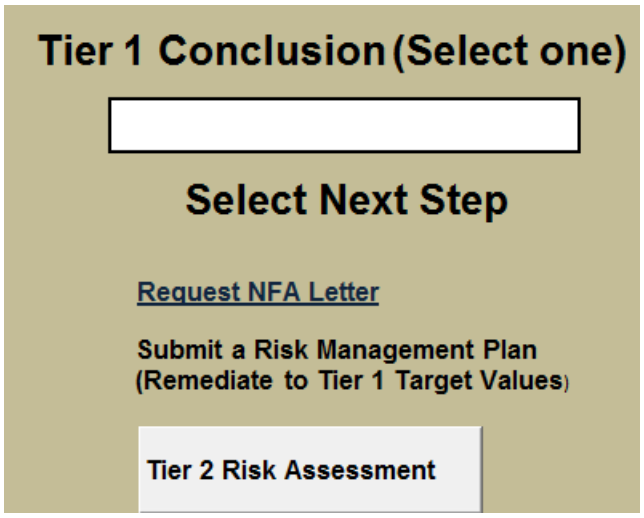
Users that are required to perform a Level 2 risk assessment will be directed to the Level 2 ecological screening where representative concentrations are compared to ECO VSL thresholds. Based on the results the user may decide to perform a level three risk assessment (which is not part of the IRBCA spreadsheet model). The user must submit a work plan to the MoEP prior to performing a Level 3 Ecological Risk Assessment.

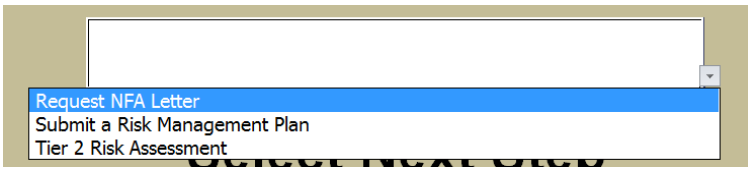


Depending on the results of the Tier 1 Risk Assessment, the user will have three options:

- Request an No Further Action (NFA) letter
- Submit a Risk Management Plan (Remediate to Tier 1 Target levels)
- Proceed to a Tier 2 Risk Assessment

Users will select the option relevant to their assessment.

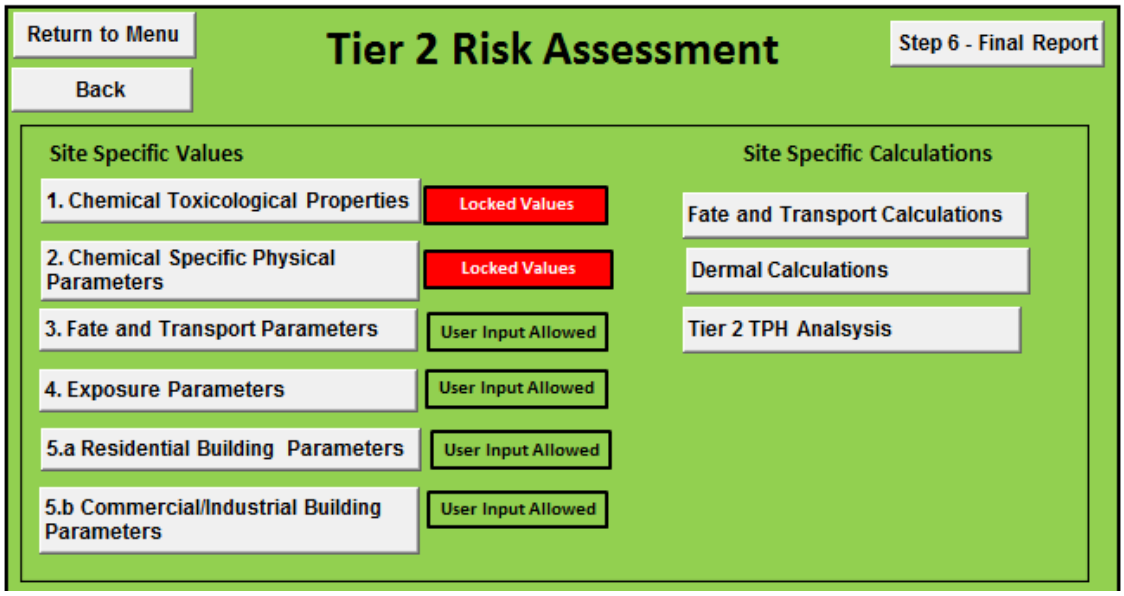




Step 5 – Tier 2 Risk Assessments

If the user has selected to perform a Tier 2 Risk Assessment, the user will have the option to use site specific values. The user will be able to change parameters such as fate and transport parameters, exposure parameters, building parameters. Some parameters the user will not be able to change such as chemical toxicological properties and chemical specific physical parameters.

The user will have the option to view fate and transport calculations, dermal calculations and the Tier 2 TPH analysis.



Chemical Toxicological Properties

Users can view the chemical toxicity factors for each selected COC by clicking the "Chemical Toxicological Properties". Toxicity properties are taking from the USEPA RSL tables. Users are not allowed to change a toxcity property. If the user would like to propose a change, the user can add the chemcial as a "User Defined Chemical" with reference to the toxicity property used.

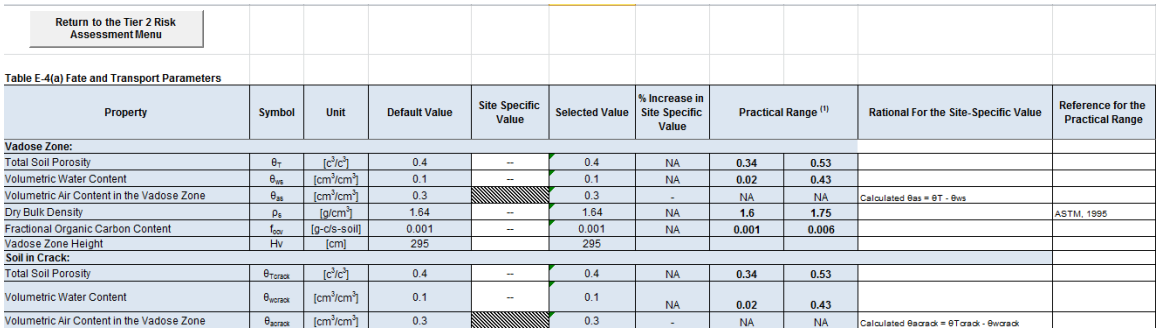
Return to the Tier 2 Risk Assessment Menu

Chemical Toxicity Factors For COCs

	Oral Slope Factor (SF_o)	Inhalation Unit Risk (IUR)	Dermal Slope Factor (SF_d)	Oral Reference Dose (RfD_o)	Reference Concentration (RfC)	Dermal Reference Dose RfD_d	Gastrointestinal Absorption Factor (GIABS)	Dermal Absorption Factor (ABS^d)
	$(mg/kg\text{-}day)^{-1}$	$(\mu g/m^3)^{-1}$	$(mg/kg\text{-}day)^{-1}$	(mg/kg-day)	(mg/m^3)	(mg/kg-day)	unitless	unitless
Benzene \ 71-43-2	5.50E-02	7.80E-06	5.50E-02	4.00E-03	3.00E-02	4.00E-03	1.00E+00	--

Fate and Transport Parameters

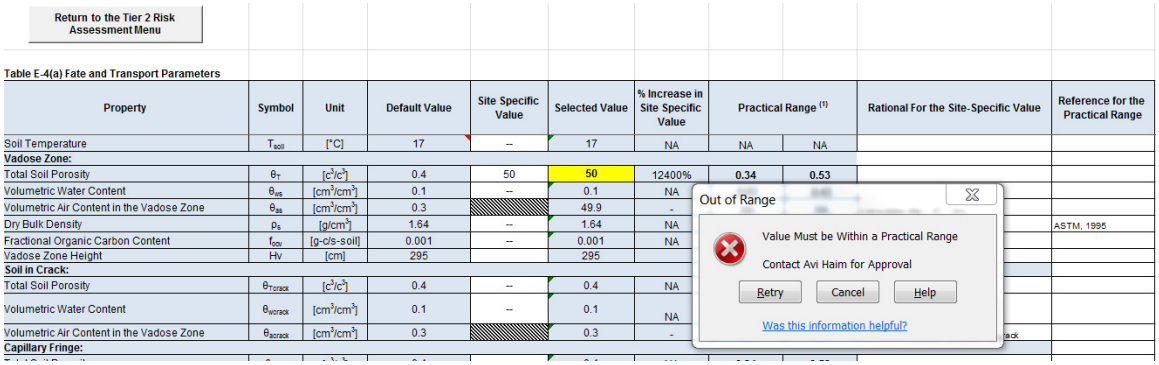
Users can change fate and transport parameters to site specific values at Tier 2. For some parameters, the ministry has set a practical range for the site specific value. Values that fall out of the practical range will receive an error message. Users should provide rational for the site specific value.



Return to the Tier 2 Risk Assessment Menu

Table E-4(a) Fate and Transport Parameters

Property	Symbol	Unit	Default Value	Site Specific Value	Selected Value	% Increase in Site Specific Value	Practical Range [1]		Rational For the Site-Specific Value	Reference for the Practical Range
Vadose Zone:										
Total Soil Porosity	θ_T	[c^3/c^3]	0.4	--	0.4	NA	0.34	0.53		
Volumetric Water Content	θ_{ws}	[cm^3/cm^3]	0.1	--	0.1	NA	0.02	0.43		
Volumetric Air Content in the Vadose Zone	θ_{as}	[cm^3/cm^3]	0.3		0.3	-	NA	NA	Calculated θas = θT - θws	
Dry Bulk Density	ρ_s	[g/cm^3]	1.64	--	1.64	NA	1.6	1.75		ASTM, 1995
Fractional Organic Carbon Content	f_{oc}	[g-c/s-soil]	0.001	--	0.001	NA	0.001	0.006		
Vadose Zone Height	Hv	[cm]	295		295					
Soil in Crack:										
Total Soil Porosity	θ_{Tcrack}	[c^3/c^3]	0.4	--	0.4	NA	0.34	0.53		
Volumetric Water Content	θ_{wcrack}	[cm^3/cm^3]	0.1	--	0.1	NA	0.02	0.43		
Volumetric Air Content in the Vadose Zone	θ_{acrack}	[cm^3/cm^3]	0.3		0.3	-	NA	NA	Calculated θacrack = θTcrack - θwcrack	



Return to the Tier 2 Risk Assessment Menu

Table E-4(a) Fate and Transport Parameters

Property	Symbol	Unit	Default Value	Site Specific Value	Selected Value	% Increase in Site Specific Value	Practical Range [1]		Rational For the Site-Specific Value	Reference for the Practical Range
Soil Temperature	T_{soil}	[°C]	17	--	17	NA	NA	NA		
Vadose Zone:										
Total Soil Porosity	θ_T	[c^3/c^3]	0.4	50	50	12400%	0.34	0.53		
Volumetric Water Content	θ_{ws}	[cm^3/cm^3]	0.1	--	0.1	NA				
Volumetric Air Content in the Vadose Zone	θ_{as}	[cm^3/cm^3]	0.3		49.9	-				
Dry Bulk Density	ρ_s	[g/cm^3]	1.64	--	1.64	NA				ASTM, 1995
Fractional Organic Carbon Content	f_{oc}	[g-c/s-soil]	0.001	--	0.001	NA				
Vadose Zone Height	Hv	[cm]	295		295					
Soil in Crack:										
Total Soil Porosity	θ_{Tcrack}	[c^3/c^3]	0.4	--	0.4	NA				
Volumetric Water Content	θ_{wcrack}	[cm^3/cm^3]	0.1	--	0.1	NA				
Volumetric Air Content in the Vadose Zone	θ_{acrack}	[cm^3/cm^3]	0.3		0.3	-				
Capillary Fringe:										

Out of Range

Value Must be Within a Practical Range

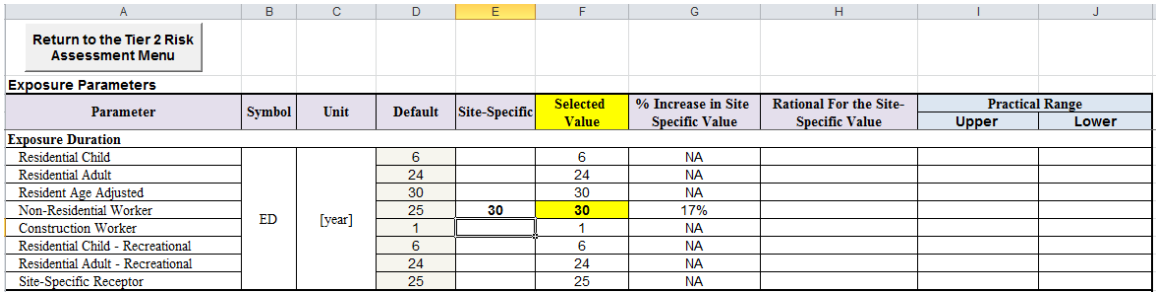
Contact Avi Haim for Approval

Retry | Cancel | Help

Was this information helpful?

Fate and Transport Parameters

During a Tier 2 process, a user may want to view and change exposure parameters. Some parameters cannot be changed such as average time for carcinogens and non-carcinogens, body weight and groundwater ingestion rate. User must provide rational for the site-specific value. Values that are not within a practical range will receive an error message.



Return to the Tier 2 Risk Assessment Menu

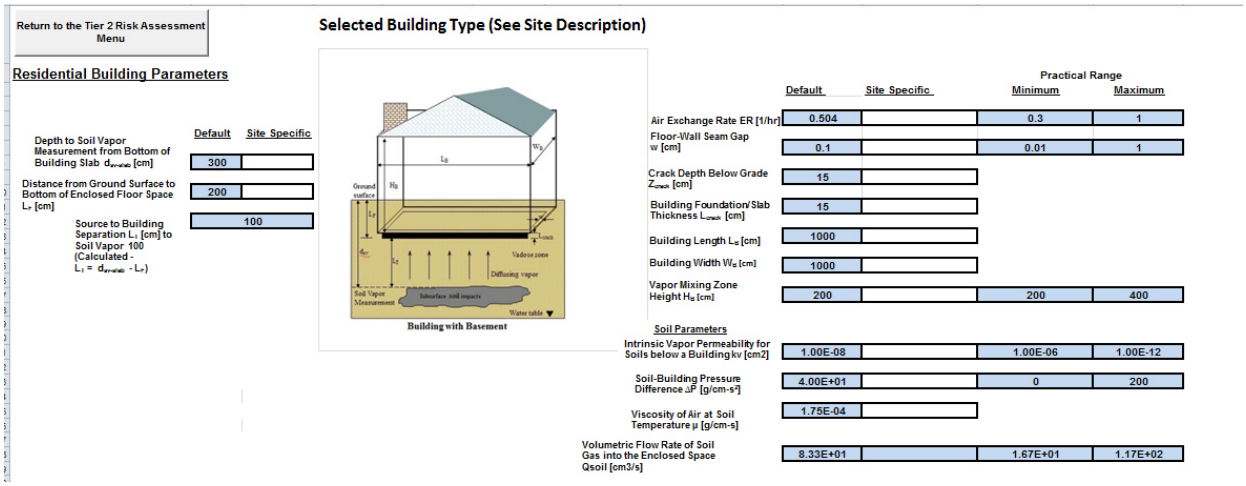
Exposure Parameters

Parameter	Symbol	Unit	Default	Site-Specific	Selected Value	% Increase in Site Specific Value	Rational For the Site-Specific Value	Practical Range	
								Upper	Lower
Exposure Duration									
Residential Child	ED	[year]	6		6	NA			
Residential Adult			24		24	NA			
Resident Age Adjusted			30		30	NA			
Non-Residential Worker			25	30	30	17%			
Construction Worker			1		1	NA			
Residential Child - Recreational			6		6	NA			
Residential Adult - Recreational			24		24	NA			
Site-Specific Receptor			25		25	NA			

Building Parameters

The vapor intrusion model is separated into two sets of equations based on the type of building the user selected (residential and commercial). If the building includes a basement (selected on the "Site Description" page) the default parameters will change. The user will first enter site specific values where

relevant such as the depth to the soil vapor measurement below the building, air exchange rates, building dimensions etc… For some parameters the MoEP has set a practical range of allowable values.



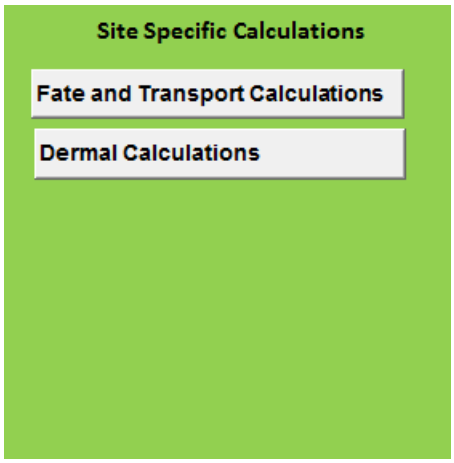
The user can then view the equation results that are used to calculate the attenuation factor (α) for each chemical of concern. The calculated alpha values can be viewed for each chemical on the Fate & Transport Calculation page. Users are asked to describe the rational for the site-specific value.

Parameter	Symbol	Unit	Residential Building				Equation	Rational For the Site-Specific Value
			Residential Default	Residential Site-Specific	Residential Selected	% Increase in Site Specific Value		
Building Height	H_B	[cm]	200		200	NA	-	
Building Width	W_B	[cm]	1000		1000	NA	-	
Building Length	L_B	[cm]	1000		1000	NA	-	
Distance from Ground Surface to Bottom of Enclosed Floor Space	L_F	[cm]	200		200	NA	-	
Depth to Soil Vapor Measurement from the Ground Surface	$d_{sv-slab}$	[cm]	300		300	NA		
Building Foundation/Slab Thickness	L_{crack}	[cm]	15		15	NA	-	
Air Exchange Rate	ER	[1/hr]	0.504		0.504	NA	-	
Floor-Wall Seam Gap	w	[cm]	0.1		0.1	NA	-	
Crack Depth Below Grade	Z_{crack}	[cm]	15		15	NA	-	
Floor-Wall Seam Parameter	X_{crack}	[cm]	Calculated Value:		4000	-	$X_{crack} = 2 \times (L_B + W_B)$	
Area of Total Cracks	A_{crack}	[cm²]	Calculated Value:		400	-	$A_{crack} = 2 \times (L_B \times W_B) \times w$	
Equivalent Crack Radius	r_{crack}	[cm]	Calculated Value:		1.00E-01	-	$r_{crack} = \eta(A_B/X_{crack})$	
Crack to Total Area Ratio	η	[unitless]	Calculated Value:		2.22E-04	-	$\eta = A_{crack}/A_B$	
Source to Building Separation (Soil Vapor)	L_{T-SV}	[cm]	Calculated Value:		100	-	$L_{T-SV} = d_{sv-slab} - L_F$	
Source to Building Seperation (Groundwater)	L_{T-GW}	[cm]	Calculated Value:		100		$L_{T-GW} = L_{gw} - L_F$	
Thickness of the Vadose Zone	H_v	[cm]	Calculated Value:		295	-	$H_v = L_{gw} - L_{cap}$	
Surface Area of Enclosed Space at or Below Grade	A_B	[cm²]	Calculated Value:		1.80E+06	-	W_B)+(2 x L_F x L_B)+(2 X L_F X W_B); if L_F <= L_{crack} then $A_B = L_B \times W_B$	
Building Ventilation Rate	Q_{bldg}	[cm³/s]	Calculated Value:		2.80E+04	-	$Q_{bld} = (L_B * W_B * H_B * ER)/3600$	

Soil Parameters								Rational For the Site-Specific Value
Intrinsic Vapor Permeability for Soils below a Building	k_v	[cm²]	1.00E-08		1.00E-08			
Soil-Building Pressure Difference	ΔP	[g/cm-S²]	4.00E+01		4.00E+01			
Viscosity of Air at Soil Temperature	μ	[g/cm-s]	1.75E-04		1.75E-04			
Volumetric Flow Rate of Soil Gas into the Enclosed Space:	Q_{soil}	[cm³/s]	8.33E+01		8.33E+01			

Site Specific Calculations

The user can view results from fate and transport calculations, dermal calculations and TPH Risk by selecting the button that links to the relevant table.



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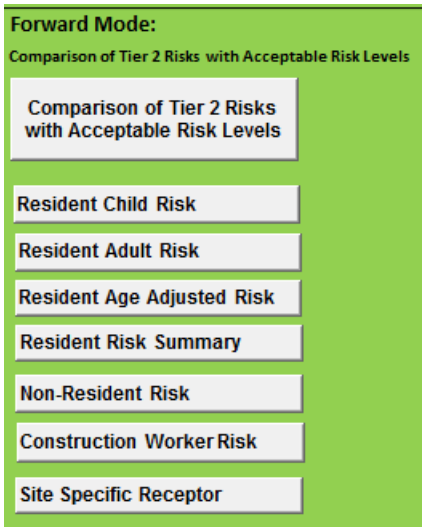
Chemical / CAS #	Effective diffusion coefficient between groundwater and soil surface	Total Overall Effective Diffusion Coefficient (Residential) Groundwater ➔Vadose Zone	Total Overall Effective Diffusion Coefficient (Commercial/Industrial) Groundwater ➔Vadose Zone	Attenuation Factor for Soil Vapor to Indoor Air - Residential Building	Attenuation Factor for Vapor to Indoor Air Commercial/Industri Building
	D_{ws}^{eff}	D_t^{eff}	D_t^{eff}	$\alpha_{sv\text{-}in}$	$\alpha_{sv\text{-}in}$
	[cm^2/s]	[cm^2/s]	[cm^2/s]	unitless	unitless
	IRBCA Equation E-56	J&E Equation 12: $D_T^{eff} = L_T/(\Sigma L_i/D_i eff)$	J&E Equation 12: DTeff = LT/(S Li/Dieff)	IRBCA Equation E-99	IRBCA Equation E-9
Benzene \ 71-43-2	1.2E-03	3.9E-04	3.9E-04	2.04E-03	2.63E-04
	NA	NA	NA	NA	NA
	NA	NA	NA	NA	NA

Tier 2 Forward Mode Risks

Tier 2 Forward mode risks are calculated for all receptors, chemicals of potential concern and for all selected pathways. Calculated risk results can be viewed for each receptor by selecting the appropriate button. Risks are only calculated for selected pathways on the exposure model page.



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Residential Child Risk Summary

Media	Soil											
Pathway	Ingestion			Dermal			Inhalation of Vapors and Particulates			Direct Contact With Soil - Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact		
	COPC Representative Concentration	IELCR	HQ	COPC Representative Concentration	IELCR	HQ	COPC Representative Concentration	IELCR	HQ	COPC Representative Concentration	IELCR	HQ
Chemical / CAS #	[mg/kg]	IRBCA Equation E-75		[mg/kg]	IRBCA Equation E-74		[mg/kg]	IRBCA Equation E-76		[mg/kg]	IRBCA Equation E-77	
Benzene \ 71-43-2	4.00E+00	2.5E-07	1.32E-02	4.00E+00	NA	NA	4.00E+00	NA	NA	4.00E+00	2.48E-07	1.32E-02

A button at the top of the list allows the user to see a page summarize the Tier 2 risk and comparison with acceptable risk levels. On this page the user can see a summary of risks for each chemical of concern and for each exposure pathway.

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Comparison of Tier 2 Risks with Acceptable Risk Levels

Number of Exposure Pathways Being Evaluated:	1
Number of Chemicals	3
Cumulative Site-Wide Risk	

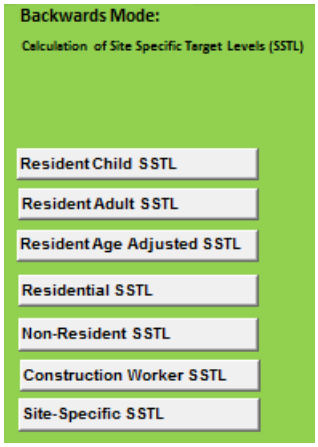
	Resident Child	Resident Adult	Resident Age-Adjusted Individual	Resident	Non-Resident	Construction Worker	Site-Specific
Cumulative IELCR (Sum of all risk for COCs and Complete Exposure Pathways)	4.96E-07	2.13E-07	7.09E-07	7.09E-07	0.00E+00	0.00E+00	0.00E+00
Target Cancer Risk	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05	1.00E-05
Total Site wide IECLR Exceed Target Risk?	No	No	No	No	No	No	No
Cumulative site-wide HI (Sum of all HQ risk for COCs and Complete Exposure Pathways)	2.63E-02	2.82E-03	7.51E-03	2.63E-02	0.00E+00	0.00E+00	0.00E+00
Target Non-Cancer Risk	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total Site wide HI Exceed Target Risk?	No	No	No	No	No	No	No

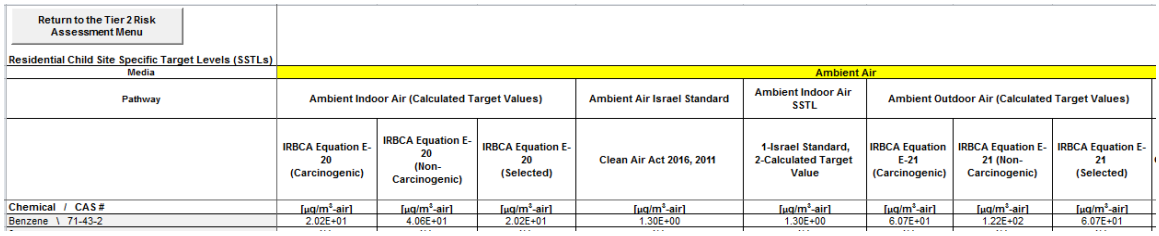
Chemical	Resident Child		Resident Adult		Resident Age-Adjusted Individual		Resident		Non-Resident		Construction Worker		Site-Specific	
	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ
Benzene \ 71-43-2	4.96E-07	2.63E-02	2.13E-07	2.82E-03	7.09E-07	7.51E-03	7.1E-07	2.63E-02	NA	NA	NA	NA	NA	NA

Source	Exposure Pathway	Resident Child		Resident Adult		Resident Age-Adjusted		Resident		Non-Resident		Construction Worker	
		IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ	IECLR	HQ
Ambient Air	Inhalation of Indoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ambient Air	Inhalation of Outdoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Soil	Ingestion	2.48E-07	1.32E-02	1.06E-07	1.41E-03	3.54E-07	3.76E-03	3.54E-07	1.32E-02	7.69E-08	9.78E-04	0.00E+00	0.00E+00
Soil	Dermal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.15E-07	3.44E-02
Soil	Inhalation of Vapors and Particulates	1.65E-06	8.25E-02	6.62E-06	8.25E-02	8.27E-06	6.64E+00	8.27E-06	6.64E+00	4.79E-06	5.73E-02	0.00E+00	0.00E+00
Soil	Direct Contact with Soil	1.90E-06	9.56E-02	6.72E-06	8.39E-02	8.63E-06	6.65E+00	8.63E-06	6.65E+00	4.86E-06	5.83E-02	1.15E-07	3.44E-02
Soil Vapor	Inhalation of Indoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NA	NA
Soil Vapor	Inhalation of Outdoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Groundwater	Dermal Contact	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Groundwater	Domestic Water Use	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NA	NA	NA	NA
Groundwater	Inhalation of Indoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	NA	NA
Groundwater	Inhalation of Outdoor Air	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Backward Mode – Calculation of Site Specific Target Levels

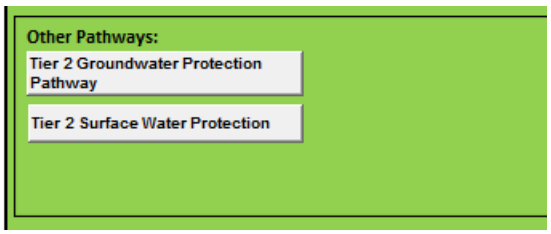
Tier 2 Backward mode site specific target levels (SSTLs) are calculated for all receptors, chemicals of potential concern and for all selected pathways. Calculated SSTLs can be viewed for each receptor by selecting the appropriate button.





Tier 2 Soil Concentration Protective of Leaching to Groundwater

Tier 2 soil concentration protective of leaching to groundwater can be viewed by clicking the button located in the "Other Pathways" section. Horizontal and Vertical DAF calculations take data from the "Fate and Transport" page. The user is change the vertical distance to the drinking water well up to 200 m.



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Is the Leaching to Groundwater Pathway Complete? | Yes

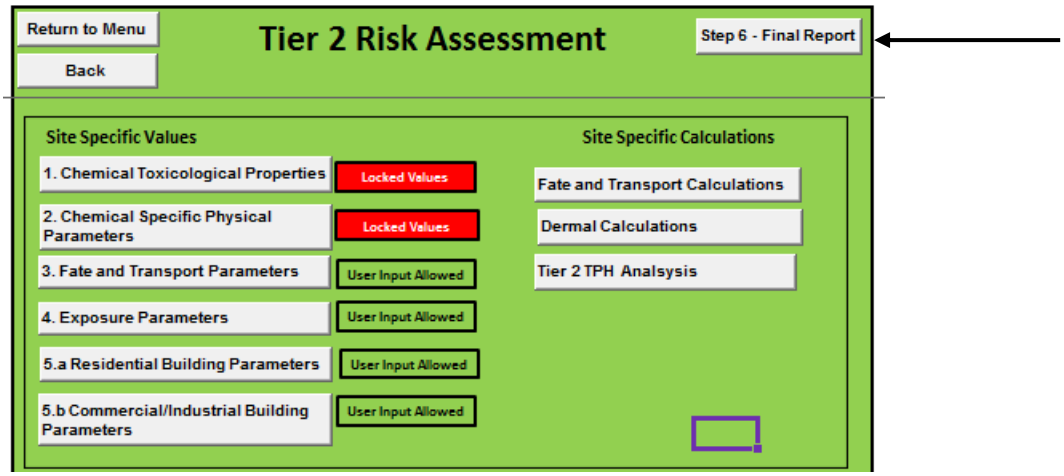
Tier 2 - Soil Concentration Protective of Leaching to Groundwater

			Selected Value [m]	DAF
Horizontal DAF	Distance to Point of Exposure (POE) [m]	See Fate and Transport Parameters (POE)	150	40.8
Vertical DAF	Thickness of the Contaminated Soil (in the Vadose Zone) [cm]	See Fate and Transport Parameters (h_{source})	100	3
	Depth to Groundwater [cm]	See Fate and Transport Parameters (L_{gw})	300	

		Soil Protective of Groundwater		
		Representative Concentration in the Soil	Tier 2 Soil Target Concentration Protective of Groundwater IRBCA Equation E-57 IRBCA Equation E-62	Allowable Concentration At The Point of Exposure (POE) Domestic Use 1. Drinking Water Standard (Blue) 2. Calculated Target Value
	Chemical \ CAS #	[mg/kg]	[mg/kg]	[µg/l]
Chemical 1	Benzene \ 71-43-2	4.00E+00	5.04E-01	5.00E+00

Final Report

User can view the final report summary clicking on the button in the top right corner of the Tier 2 Summary page.



The final report is comprised of a Site Summary and Risk report and individual reports for each exposure pathway. The user can select the relevant pathways to view the summary of SSTLs for each chemical of concern.

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Print All Relevant Reports

Final Report

Site Summary and Risk Report

		Receptors								
		On-Site				Off-Site				
Source	Exposure Route	Resident	Commercial / Industrial	Construction Worker	Recreational Visitor	Resident	Commercial / Industrial	Construction Worker	Recreational Visitor	Site-Specific
Ambient Air	Inhalation of Indoor Air	– SSTL	– SSTL	NA	NA	NA	NA	NA	NA	– SSTL
Ambient Air	Inhalation of Outdoor Air	– SSTL	– SSTL	– SSTL	NA	NA	NA	NA	NA	– SSTL
Soil	Direct Contact With Soil - Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact	√ SSTL	√ SSTL	√ SSTL	NA	NA	NA	NA	NA	– SSTL

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Tier 2 Site Specific Target Level (SSTL)

Receptor: On-Site Resident

Media	Soil			
Pathway	Representative Concentration	Tier 2 SSTL Direct Soil Contact Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact	Minimum Value - Soil Saturation Concentration (1) - Calculated Target Value (2)	Tier 1 RBTL
Chemical / CAS #	[mg/kg]	[mg/kg]		[mg/kg]
Benzene \ 71-43-2	4.00E+00	1.95E+00	2	1.76E+00

APPENDIX C
PARAMETERS THAT CAN BE CHANGED FOR TIER 2 RISK ASSESSMENTS

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C.3 FATE AND TRANSPORT PARAMETERS 3
C.4 BUILDING PARAMETERS 19

APPENDIX C
PARAMETERS TO BE CHANGED FOR TIER 2 RISK ASSESSMENTS

C.1 INTRODUCTION

The IRBCA methodology allows the risk assessor to modify the generic default parameters of the model used in Tier 1 and replace them with site-specific values in Tier 2. These values include exposure factors, fate and transport parameters and building parameters. Wherever possible, The IRBCA spreadsheet model has included a practical range for each parameter that can be changed at Tier 2. The values entered into the spreadsheet must be within this practical range. Users will receive an error message for values that are beyond this range. The user may submit a special request to use values outside this range as part of the work plan submitted to the Ministry prior to performing the risk assessment.

The following sections provide a description of each factor that can be changed at Tier 2 and suggestions when selecting site-specific values.

C.2 EXPOSURE PARAMETERS

When considering site-specific exposure factors, the user is recommend to refer the USEPA Exposure Factors Handbook. The "Handbook" provides a summary of the available statistical data on various factors used in assessing human exposure. These factors include soil adherence factors, soil ingestion, inhalation rates, dermal factors including skin area and soil adherence factors, human activity factors etc…. With the exception of a few parameters, the IRBCA exposure parameters were updated to coincide with the most recent USEPA revisions (USEPA, 2018).

C.3 FATE AND TRANSPORT PARAMETERS

SOIL PARAMETERS

Dimension of Surficial Soil Parallel to Wind (W_a)

This parameter is used to calculate the risk and target levels for outdoor inhalation of vapors and particulates from surficial zone. It represents the longest dimension of the exposure domain for direct contact with the surficial soil pathway parallel to the wind direction. If wind direction is variable or unknown at the site, the longest dimension of the exposure domain must be used. For example, if the exposure domain is rectangular, the diagonal of the rectangle may be used. If it is circular, use the approximate diameter.

Depth to Subsurface Soil Sources (d_{ts})

This parameter is used to calculate the risk and target levels for indoor inhalation from subsurface soil. Tier 2 RAs require the use of the actual measured depth of volatile COCs in soil. The most conservative value of this parameter would be the shallowest depth at which the COC is detected or an average of the shallowest depths at which the COC was detected from multiple borings within the exposure unit(s) for this pathway. Either way, the measurements should reflect the distance from the surface to the top of the first zone of impacted soil.

Thickness of Capillary Fringe (h_c)

The capillary fringe is the zone immediately above the saturated zone where capillary attraction causes upward movement of water molecules from the saturated zone into the soil above. This zone is distinct in that it has characteristics of both the vadose and saturated zones. In a Tier 2 RA, the thickness or height of the capillary fringe can be measured or an appropriately justified value used. Because accurate field measurement of the thickness of the capillary fringe can be difficult, literature values based on the soil type immediately above the water table may be used to assign a site-specific value for the capillary fringe thickness.

The thickness of the capillary fringe affects the calculation of risk and the associated target levels of groundwater protective of indoor inhalation. Because this zone is not usually measured, the MoEP may require that the RP perform a sensitivity analysis. Most models used to perform this calculation assume the capillary fringe to be uncontaminated, which may not be accurate.

This parameter is used to calculate the risk due to indoor inhalation from groundwater. The thickness of the capillary fringe must be representative of the site soils and is primarily dependent on the soil grain size. Typically, the thickness of the capillary fringe is based on literature values because direct measurement is impractical. The sum of the thickness of the capillary fringe and the thickness of the vadose zone should equal the depth to groundwater (i.e., $h_c + h_v = L_{gw}$). Note the groundwater vapor emission model assumes that the capillary fringe is uncontaminated. This may not be an accurate assumption; hence a conservative estimate and a sensitivity analysis for this parameter may be needed.

Thickness of Vadose Zone (h_v)

The thickness of the vadose zone can be determined based on information presented on boring logs and/or from measurements taken from monitoring wells or piezometers. It represents the distance from the ground surface to the depth at which the water table is encountered. For IRBCA process, the capillary fringe thickness is not considered a part of the vadose zone. Thus, the thickness of the vadose zone is determined by subtracting the thickness of the capillary fringe from the depth to groundwater. Depth to groundwater is used for Tier 2 and 3 risk assessment to estimate vapor emissions from groundwater and to determine the vadose zone attenuation factor.

At sites where significant secondary porosity features (e.g. Karst formations) are identified or in fractured media , the calculation of the dilution attenuation factor

(DAF) should not be based on the assumption of granular media. Alternative methods to estimate the DAF and any alternative data needs must be proposed to the MoEP. For sites where DAF cannot be accurately evaluated, the remediating party may propose alternative methods to evaluate the indoor inhalation pathway for MoEP approval.

For sites where the water table fluctuates considerably, the available data must be evaluated to determine whether the fluctuations are seasonal or represent a consistent upward or downward regional trend. For sites with significant seasonal fluctuations, the average depth to groundwater and the average thickness of the vadose zone should be used in the development of the overall CSM and any related modeling efforts. Averages can be determined by periodic groundwater level measurements. These averages should not, however, be used in the development of site-specific potentiometric maps, plans for well installation, or any other activities that require specific knowledge of fluctuations in groundwater flow direction(s). At sites with consistent, long-term (greater than one year) upward or downward water level trends that do not appear to represent seasonal fluctuations, the most recent data should be used to estimate the depth to groundwater and the thickness of the vadose zone.

At sites where the cleanup decision critically depends on the vadose zone thickness and/or depth to groundwater, and the depth to groundwater is known to fluctuate significantly, the authorities may request a sensitivity analysis. The analysis should be performed using different depths to groundwater and vadose zone thicknesses to assess the degree to which these parameters may affect the cleanup decision.

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. This parameter is used to evaluate the indoor inhalation pathway. The thickness of the vadose zone is calculated by subtracting the capillary fringe thickness from the depth to groundwater ($L_{gw} - h_c = h_v$).

Vadose Zone Dry Soil Bulk Density (ρ_s)

Dry bulk density is the dry weight of a soil sample divided by its field volume. An accurate measurement of dry bulk density requires determination of the dry weight and volume of an undisturbed sample of soil. An undisturbed soil core sample may be collected using a Shelby™ tube, a thin-walled sampler, or an equivalent method. The sample must not be disturbed prior to laboratory analysis.

This parameter is used for the calculation of risk or target levels from all indirect exposure pathways that involve equilibrium calculations between various phases. Examples include leaching to groundwater and indoor and outdoor inhalation from soil and groundwater. If multiple measurements from the vadose zone are available or when multiple values are necessary to represent different soil types, the average value may be used.

Dry bulk density is estimated using the ASTM Method D2937.94, *"Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method."* At sites where multiple, widely differing soil types occur in the vadose zone, one sample must be collected from each distinct, predominant soil type. At such sites, the percentage of each soil type relative to the overall volume of the vadose zone should be considered in collecting samples and calculating bulk density. Where soil at a site is homogeneous or nearly so, a single sample for bulk density analysis may suffice.

Fractional Organic Carbon Content in Vadose Zone (f_{ocv})

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. This parameter is used to perform equilibrium conversion calculations, i.e. to estimate the pore water concentration and pore air concentration based on a total soil concentration.

Organic carbon content must be determined using soil samples not impacted by petroleum or other anthropogenic chemicals. Therefore, a soil boring away from the contaminated area but within a soil type that is the same as, or very similar to, that found at the site must be drilled to determine fractional organic carbon content. At a screening level, one method of determining if certain anthropogenic chemicals have impacted the sample is to take a PID reading.

Samples representative of the vadose zone must be collected for fractional organic carbon content analysis. At sites where the vadose zone consists of several different soil types, each predominant soil type must be sampled. Multiple aliquots of soil samples from the same lithological unit may be collected vertically from a boring and horizontally from different borings and composited in the field to create a single sample. While creating a composite sample, care should be taken not to combine samples collected from different lithological units. Surficial soils typically have the highest organic carbon content, and care should be taken not to bias the samples by collecting too much surficial soil.

For sites where subsurface soil types vary significantly, soil samples from the vadose and saturated zones should be collected at two or more boring or probe points that represent the different soil types. As appropriate, the resulting fractional organic carbon content can then be averaged to establish a representative value of fractional organic carbon content for each medium. If the individual values are representative of significantly different volumes of soil, a weighted average is preferable to the arithmetic average.

Fractional organic carbon content may be estimated using the Walkley Black

Method (Page et al., 1982 Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, pp 570-57 1, Second Edition) which 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). However, some laboratories may not be familiar with this method. An alternative and more consistent, method is ASTM Method D2974 (Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils). This method measures the organic matter content of a sample. When using Method D2974, the result must be divided by 1.724 to get fractional organic carbon content. If the laboratory results are reported as a percent, fractional organic carbon content is obtained by dividing the results by 100.

This parameter is used for the calculation of risk or target levels from all indirect exposure pathways that involve equilibrium calculations between various phases. If measurements of fractional organic matter (not the same as fractional organic carbon) are available, the value must be converted to fractional organic carbon as discussed in Section 6.7.4. Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and may be composited into one sample for fractional organic carbon content analysis.

If multiple values are available (as is recommended), and if technically appropriate, the average value should be used. For example, assume that soil is impacted between 3 to 5 m below ground surface (bgs) and the water table is at 15 m bgs. If three soil samples at 1.5, 4, and 7 m bgs have been collected for geotechnical parameters, it would not be appropriate to average the values. For the evaluation of indoor inhalation from soil, the sample collected at 7 m bgs is irrelevant because the sample was taken from below the impacted zone and vapors. The average of the values from the samples at 1.5 and 4 m bgs may be used. Similarly, for soil leaching to the groundwater pathway, the sample

collected at 1.5 m should not be used because this sample is from above the zone through which the leachate would move. This concept would apply to all the soil geotechnical parameters.

If it is not appropriate to use an identical value, for all the pathways, different values may be used for different exposure pathways.

Porosity in the Vadose Zone (θ_T)

Total 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 of soil particles to calculate total porosity using the following:

$$n = 1 - \rho_b/\rho_s$$

Thus, specific gravity and soil dry bulk density are needed to determine total porosity.

This parameter is used to calculate risk and target level from all indirect exposure pathways that involve equilibrium calculations between various phases. It is also used to calculate the chemical specific effective diffusion coefficient in the vadose zone. Both Tier 1 and Tier 2 RAs assume that the porosity of the vadose zone, capillary fringe, and soil that fills the foundation or wall cracks is identical. This assumption is necessary because measuring porosity in the capillary fringe and in foundation and wall cracks is generally not practical. If multiple porosity values are available, an average value should be used. See Section 6.7.2 for a discussion of methods used to estimate porosity. Where total and effective porosity differ or are expected to differ, the effective porosity value must be used.

The *"Standard Test Method for Specific Gravity of Soil Solids by Water Pycnometer,"* ASTM Method D854, may be used to determine specific gravity. If specific gravity or particle density is not available, a value of 2.65 g/cc can be

assumed for most mineral soils. However, the use of this value must be justified.

If a site-specific total porosity value cannot be determined, literature values consistent with the site lithology may be used, provided the source(s) of the value(s) is cited and justified. Effective porosity is the amount of void space available for fluid flow. Various studies have identified that even in very fine clays, such as lacustrine deposits, the effective porosity is practically the same as total porosity (Fetter, 2001). Where the total and effective porosities differ significantly, the authorities may require a sensitivity analysis.

Volumetric Water Content in Vadose Zone (θ_{ws})

Volumetric water content is the ratio of the volume of water to the volume of field or undisturbed soil. The ASTM Method D2216-98, "*Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soils and Rock by Mass*," may be used to calculate this ratio. However, this is a gravimetric method that uses the mass of the sample, not the volume, to determine the ratio of water to soil. Therefore, to obtain the volumetric water content, the following conversion should be used:

$$\theta_{wv} = \theta_{wg} \times \frac{\rho_b}{\rho_l} \qquad (6\text{-}2)$$

Where,

θ_{wv} = volumetric water content (cc water/cc soil),
θ_{wg} = gravimetric water content, typically reported by the laboratory (g of water/g of soil),
ρ_b = dry bulk density (g of dry soil/cc of soil), and
ρ_l = density of water (g/cc).

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 Equation 6-1, it may be overestimated. In other words, if the gravimetric water content is wrong, dry bulk density and porosity will also be wrong.

Multiple samples from across the site at varying depths should be analyzed for water content to estimate representative water content for the vadose zone. Each soil sample analyzed for one or more of the applicable COCs must also be analyzed for water content (at sites where multiple samples from multiple depths are analyzed for COCs on a dry weight basis, additional samples solely for analysis of water content may not be necessary). In addition, water content values representative of each of the lithological units that comprise the vadose zone must be determined. Because all soil COC concentration data must be reported on a dry weight basis, the water content for each soil sample must be compiled, reported and used as needed in calculating target levels.

This parameter is used to calculate the risk and target levels for all indirect exposure pathways that involve equilibrium calculations between various phases and to calculate the effective diffusion coefficient of COCs in the vadose zone. Water content is typically measured on a weight basis (gravimetric: grams of water/grams of dry soil) and must be converted to a volumetric value (cm^3 of water/cm^3 of soil) as discussed in the guidance document. An average value based on multiple representative samples may be used. Care should be exercised to make sure that water content measurements from the capillary fringe are not assumed to be values representative of the vadose zone. Moisture content values may be obtained from soil samples analyzed for COCs. (The RP must direct their laboratories to report soil COCs concentration on a dry weight basis and the moisture content for each sample).

Volumetric Air Content in Vadose Zone (θ_{as})

This parameter is used for the calculation of risk and target levels for all indirect exposure pathways that involve equilibrium calculations between various phases and to calculate the chemical specific effective diffusion coefficient in the vadose zone. Volumetric air content in the vadose zone is rarely measured but can be calculated as the difference between the total soil porosity and the volumetric

water content in the vadose zone (i.e., $\theta_T - \theta_{WS} = \theta_{as}$).

Volumetric Water Content in Capillary Fringe (θ_{wcap})

This parameter is used to estimate the chemical specific effective diffusion coefficient in the capillary fringe. Volumetric water content in the capillary fringe is typically estimated as 90 per cent of the total vadose zone soil porosity (i.e., $0.9\theta_T$). Total soil porosity in the capillary fringe is typically assumed to be equal to the total vadose zone porosity.

Volumetric Air Content in Capillary Fringe (θ_{acap})

This parameter is used for the calculation of the chemical specific effective diffusion coefficient in the capillary fringe. Volumetric air content in the capillary fringe is rarely measured but can be calculated as the difference between the total soil porosity in the capillary fringe and the volumetric water content in the capillary fringe ($\theta_{Tcap} - \theta_{wcap} = \theta_{acap}$).

Volumetric Water Content in Foundation or Wall Cracks (θ_{wcrack})

This parameter is used to calculate the effective diffusion coefficient of COCs in the foundation or wall cracks. The volumetric water content in soil that fills foundation or wall cracks is assumed to be the same as the volumetric water content of the soil in the vadose zone ($\theta_{wcrack} = \theta_{ws}$).

Volumetric Air Content in Foundation or Wall Cracks (θ_{acrack})

This parameter is used to calculate the effective diffusion coefficient of COCs in the foundation or wall cracks. The volumetric air content in foundation or wall cracks is assumed to be the same as the volumetric air content of the soil in the vadose zone. The latter is determined as described above.

GROUNDWATER PARAMETERS

Hydraulic Conductivity (K)

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 can be obtained by field tests such as pump tests or slug tests. 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.

In the justified absence of these tests and only after approval by the authorities, literature values corresponding to the type of soil in the saturated zone may be used. When a literature value is used, adequate reference and justification for the value based on consideration of all predominant soil types comprising the saturated zone must be provided. Hydraulic conductivity may also be estimated based on the grain size distribution of the porous formation.

The hydraulic conductivity can vary significantly in the horizontal and vertical directions. When referring to hydraulic conductivity, always indicate whether reference is to horizontal or vertical direction. Horizontal hydraulic conductivity and horizontal gradient should be used to calculate the horizontal velocity of water and vertical hydraulic conductivity and vertical gradient should be used to estimate the vertical velocity of water.

Horizontal and Vertical Hydraulic Gradients

The magnitude and direction of the hydraulic gradient is estimated by comparing water levels measured in monitoring wells across a site. Water level contour maps must be prepared based on the measured data using a computer program or professional interpretation. All data must refer to a common datum e.g. mean sea level. The contour maps can be used to estimate both the direction and magnitude of the horizontal hydraulic gradient. When drawing the contour maps, care should be taken to ensure that measurements from monitoring wells

screened in the same interval or hydrologic unit are used. For sites where wells are screened in multiple zones, a contour map for each zone must be developed (data from wells screened in different zones should not be combined to draw one contour map). For sites that have seasonal variation in hydraulic gradient or predominant flow direction, estimates of the average hydraulic gradient for each season and each flow direction can be used in modeling efforts.

However, these estimates should be used with caution in the preparation of potentiometric maps or other activities where specific knowledge of the range of fluctuation in the groundwater flow direction is necessary (for example, locating and installing down gradient monitoring wells). 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.

At sites with multiple groundwater zones, vertical gradients must also be determined via a comparison of water levels in wells screened at different depths. The authorities may consider exceptions to this requirement on a site-specific basis.

Depth to Groundwater (L_{gw})

This parameter is used to estimate the risk due to indoor inhalation from groundwater and the dilution attenuation factor in the vadose zone.

When the depth to groundwater is significantly less than 10 feet, then a Tier 2 RA should be conducted that utilizes the site-specific depth to groundwater. At sites where the depth to groundwater fluctuates due to seasonal variations, the average depth to groundwater should be based on multiple years of site-specific data. Thus, calculating an average depth to groundwater using data collected from several monitoring events over an extended period of time is preferable. If

such data are available for multiple wells in an exposure domain, first, the average depth should be calculated for each well. Second, (for modeling purposes) the average of the average depth of each well should be calculated and considered the average depth to groundwater. In areas where there is a systematic long-term water level change, only recent data should be used.

For consistency, static water levels should be used unless justification can be provided for the use of the depth to the "first water encountered while drilling." Where significant differences in static water levels occur across the site, conservatively the shallowest average depth to groundwater should be used.

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

This parameter is used by Domenico's model to simulate migration in the saturated zone and estimate the saturated zone DAF. This parameter is necessary only in cases where horizontal migration of COCs in the groundwater is quantitatively evaluated. A common assumption is that COCs migrate vertically downward from the area of release to groundwater. By projecting the area of release to the water table, this dimension (Y) can be estimated. Figure C-1 shows a schematic of the groundwater source for Domenico's groundwater model.

Length of Groundwater Source Area Parallel to Groundwater Flow Direction (W_{ga})

This parameter is necessary when the horizontal migration of COCs in groundwater is quantitatively evaluated. As mentioned above, a Tier 2 RA assumes that COCs migrate vertically downward from the area of release to groundwater. By projecting the area of release to the water table this parameter can be estimated.

Figure C-1 illustrates the Domenico's model that uses the above three groundwater parameters.

Porosity in Saturated Zone (θ_{TS})

Porosity in the saturated zone is necessary only when biodecay is considered in the horizontal migration of COCs. Refer to Section 6.7.2 for methods used to estimate site-specific values of porosity. If the unsaturated and saturated zone stratigraphies are similar, the saturated zone porosity may be set equal to the vadose zone porosity. If multiple values are available, an average should be used. If the vadose and saturated zone soil stratigraphies are significantly dissimilar, the porosity of the saturated zone must be measured in the field. If a literature value is used, it must be justified based on the site-specific conditions. Where total and effective porosity differ or are expected to differ, the effective porosity value must be used.

Saturated Zone Dry Soil Bulk Density (ρ_{ss})

Estimate of the dry soil bulk density in the saturated zone is essential only when biodecay is considered in the horizontal migration of COCs. Refer to Section 6.7.1 for methods used to estimate site-specific values of dry soil bulk density. If the unsaturated and saturated zone stratigraphies are similar, the saturated zone dry soil bulk density may be set equal to the vadose zone dry soil bulk density. If multiple values are available, an average should be used. If the vadose and saturated zone stratigraphies are significantly dissimilar, the dry soil bulk density of the saturated zone must be measured in the field or an appropriate literature value used.

Fractional Organic Carbon Content in Saturated Zone (f_{ocs})

Estimate of the fractional organic carbon content in the saturated zone is essential only when biodecay is considered in the horizontal migration of COCs. If a site-specific value is to be used in Tier 2 RA, the value must be determined based on field samples collected below the water table or by choosing a justifiable literature value.

Groundwater Mixing Zone Thickness (δ_{gw})

Mixing zone thickness is used by Summers and Domenico's model to estimate the dilution attenuation factors in the saturated zone. The groundwater mixing zone thickness is a measure of the thickness over which COCs mix within the saturated zone, primarily due to water table fluctuations. While difficult to estimate accurately, the mixing zone thickness may be approximated based either on PID readings, soil concentrations measured in borings extending below the water table or by measuring groundwater concentrations at various depths. The 200 cm Tier 1 default value should be considered a minimum. The following model from USEPA's *Soil Screening Guidance: Technical Background Document* (1996b, page 45, equation 45) may be used in higher tier evaluations:

$$d = (0.0112\ L2)^{0.5} + da\ \{1 - \exp[(-LI)/(Kida)]\}$$

d = mixing zone depth (m)
L = source length parallel to ground water flow (m)
I = infiltration rate (m/yr)
K = aquifer hydraulic conductivity (m/yr)
I = hydraulic gradient (m/m)
Da = aquifer thickness (m)

The mixing zone thickness should not exceed the thickness of the aquifer.

Groundwater Darcy Velocity (U_{gw})

This parameter may be used by models that calculate soil and groundwater target concentrations protective of the domestic use of water, such as the Summers and Domenico's models.. For Tier 2 RA, the groundwater Darcy velocity must be a site-specific value calculated by mutiplying the saturated zone hydraulic conductivity and the hydraulic gradient.

Site-specific hydraulic conductivity must be estimated based on the results of site-specific pump tests, and only if the authorities are convinced that site conditions do not allow the conduct of specific pump tests or that such tests are

not required. In such situations, literature values based on site-specific lithology that were pre-approved by the authorities can be used instead of default values. The hydraulic gradient should be estimated (as the average gradient) using representative groundwater elevation data preferably not more than two years old. At sites where the groundwater flow direction shows marked variations, the hydraulic gradient and, hence, the Darcy velocity may have to be estimated for more than one direction and/or a range of velocities..

Infiltration Rate (I)

The Summers model uses the infiltration rate (I) to estimate the DAF in the groundwater mixing zone. Unless site-specific information is available, the infiltration rate may be estimated as 10 per cent of the average annual rainfall at the site. Average annual rainfall values may be obtained from literature.

C.4 BUILDING PARAMETERS

The building parameters presented in Table E-4(b) are required to evaluate the indoor inhalation pathway from subsurface soil, soil vapor, and/or groundwater. In a Tier 2 RA, site-specific building parameters should be used for the following:

Building Height (H_B)

During field activities the height of building must be measured. For multi-story buildings, the height should include all the floors where any vapors that may enter the building will mix due to the internal ventilation/air conditioning system. The risk assessment must consider the "worst case scenario" and therefore to evaluate the risk for the floor (usually the bottom floor) in which maximal exposure can occur. The risk assessor should not use the entire building i.e. multiple floors for the RA. As appropriate, the risk assessor may conduct a separate risk assessment for each potentially impacted floor in which case the lowest (most conservative) SSTLs must be selected. For future building, reasonable effort should be made to estimate the future building height.

Building Width (W_B)

During field activities the width of building must be measured. For future building, reasonable effort should be made to estimate the building width. The risk assessor should not use a single width if the building consists of separate enclosed structures. Instead risk must be evaluated separately for each enclosed structure. **The Tier 2 vapor intrusion model should be performed using the dimensions of the smallest room within each enclosed structure.**

Building Length (L_B)

During field activities the length of building must be measured. For future building, reasonable effort should be made to estimate the building length. The risk assessor cannot use one single length if the building is divided into separate

enclosed structures and the risk must be evaluated separately for each enclosed structure.

Depth below Grade to Bottom of Enclosed Space Floor (L_F)

This parameter is the distance from ground surface to the bottom of building foundation. During field activities the depth below grade to bottom of enclosed space floor must be obtained by visual examination or from building construction diagrams. For future building, reasonable effort should be made to estimate the depth below grade to bottom of enclosed space floor. Refer to Figure E.4 for a definition of the parameters.

Air Exchange Rate (AER)

For proposed buildings, discussions with the architect may help determine the ventilation rate. For existing building, reasonably conservative literature values must be used. The AER represents the amount of air exchanged with outdoor air and not the amount of air passed through a heating/air conditioning unit. AER should not be confused with internal recirculation of air, which is often what mechanical systems are designed for. It is the amount of air from outside the building that enters the building. The actual AER may be determined using a method such as described in ASTM E741 or equivalent.

APPENDIX D
CALCULATION OF REPRESENTATIVE CONCENTRATIONS

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D.1 BACKGROUND AND DEFINITIONS

The IRBCA process requires the calculation of representative concentrations to perform the Tier 1 screening and estimate forward mode risk (incremental excess lifetime cancer risk (IELCR) for carcinogenic effects and the hazard quotient (HQ) for non-carcinogenic adverse health effects).

The estimation of representative concentrations requires considerable professional judgement. The selection of representative concentrations to be utilized in a risk evaluation requires proper identification of complete pathways, defining appropriate exposure areas and proper delineation of concentrations of chemicals of potential concern at the site.

The IMoEP requires either the maximum concentration or the 95th Upper Confidence Limit (UCL) of the mean to be used in IRBCA evaluations. 95% UCL of the mean should be computed with USEPA ProUCL version 5.1 software (or a subsequent version) or equivalent.

Definitions

Exposure Areas: Geographical areas located within a larger site that have similar exposure characteristics. Typically, within an exposure area, a receptor would be exposed to COCs by multiple exposure pathways.

Representative Concentration: A site constituent concentration for a specific chemical of potential concern (i.e., lead, benzene, toluene) for a particular media (soil, soil vapor, groundwater) that represents the concentration measured in an Exposure Area. The calculation of representative concentration is complicated by many factors including spatial and temporal variability in the concentrations.

D.2 STEPS TO CALCULATE REPRESENTATIVE CONCENTRATION

Primary steps used to calculate a representative concentration include:

1. Identification of the boundaries of the exposure areas (including consideration to future site uses). This includes identifying the size and location of the area over which the representative concentration will be calculated. The Exposure Area is an area over which the receptor may be exposed to the contaminated medium (soil, groundwater, soil vapor). The exposure area must be delineated for onsite and off-site scenarios that may exist. In addition, different exposure areas may exist for current versus future land use scenarios.

2. Identification of all the complete exposure pathways under current and future conditions for the exposure area.

3. Identification of the media of concern for each complete exposure pathway. Typically these include soil vapor, soil up to the depth of construction, and groundwater. However, media of concern may also include: air (indoor, outdoor), soil gas, surface waters, sea water, and sediments.

4. Identification of the COC concentration data for each medium available within each exposure area.

5. Documentation of the Selection of the Representative Concentrations.

   The guidance requires detailed documentation of the calculation of the representative concentrations used in the IRBCA report. Information should include:

- Maps indicating the exposure areas selected for the various media,

- Conceptual models for operable exposure pathways both on on-site and off-site scenarios as well as current and future land use must be considered. Separate conceptual models may be needed for on- and off-site scenarios as well as current and future land use

- Tables must be submitted as part of the IRBCA documentation in Microsoft Excel™ format listing the soil borehole and monitoring well data used to determine the representative concentrations for each boring well and/or groundwater monitoring location. The tables must include at a minimum

    - Groundwater well screen depth and core sample depths;
    - Soil and water concentration data;
    - Laboratory methods used in the analysis;
    - Analytical detection limits;
    - Date Sampled;
    - Geographical Coordinates

- A risk assessor is required to submit to the IMoEP the raw data (measured concentrations) used to calculate the RC in an Excel table and the corresponding ProUCL output.

D.3 GENERAL CONSIDERATIONS

Prior to performing the computations, the following should be considered:

- A representative concentration must be calculated for each COC within each Exposure Area for each media.

- Data beyond the exposure area should not be used to calculate the representative concentration. Note such data may be required for delineation or other purposes.

- Evaluate whether the spatial resolution of the data is sufficient and whether delineation of contamination was properly attained. While an exact number of samples cannot be specified herein due to variability in site-specific conditions, delineation of COC in every relevant medium is mandatory.

- If the data are old (greater than three years old) and the COC concentrations exceed Tier 1 RBTLs, new data may be collected in every medium. If a new release has been documented, new data must be collected to characterize accurately the nature and extent of the current impact.

- If the maximum concentration of any COC (for any exposure pathway for any medium) within the exposure area exceeds ten times the representative concentration, further evaluation of the data may be necessary to explain the exceedance. Possible reasons for an exceedance could be:

    - The maximum concentration is an outlier;
    - The exposure area has not been adequately characterized; or

- A hot spot may exist within the exposure area.

- Suspected 'outlier' results cannot be excluded merely because they are very large relative to the rest of the data set. Extreme values in the data set may represent true spatial variation in concentrations, could represent a different contamination source, or a specific 'hot spot'. Additional sampling may be necessary to confirm the “outlier” concentration.

- For the groundwater-to-indoor-inhalation pathway, groundwater data from the first encountered saturated zone must be used.

95% UCL of the mean can be calculated using parametric type distributions such as: normal, gamma, lognormal or non-parametric distributions, depending on sample size and degree of skewness. It is recommended to follow the ProUCL software guide when selecting the appropriate distribution to use.

For more information refer to the *Calculating Upper Confidence Limits for Exposure Point Concentrations as Hazardous Waste Sites* (USEPA, 2002d). 95% UCL of the mean should be computed with USEPA ProUCL version 5.1 software (or a subsequent version) or equivalent.

It should be noted that as the sample size increases, a UCL approaches the sample mean. For more details refer to:

- ProUCL Version 5.1 (or most updated version) User guide
- Calculating Upper Confidence Limits for Exposure Point Concentrations as Hazardous Waste Sites (USEPA, 2002d); and
- ASTM E-2081-00 Standard Guide for Risk-Based Corrective Action.

D.3 CONSIDERATIONS FOR EACH MEDIA

D.3.1 Soil

This section provides general considerations for Calculating Representative Concentrations for Surficial Soil (0 – 1 m below ground surface) and sub-surficial soil (greater than 1m below ground surface).

The IRBCA process requires the evaluation of the following exposure pathways associated with soil:

1. Ingestion of COCs in groundwater due to leaching of residual COCs and degradation products;
   Direct Contact with Soil (Incidental Ingestion), Dermal Contact and Outdoor inhalation of vapors and particulates from surficial soil emissions;
2. Impact on surface water
3. Impact on ecological receptors

The following should be considered when calculating representative concentration for soil media.

- If 10 discrete sampling points or more are taken per exposure area, the representative concentration will be the upper limit of the two sided 95% UCL of the mean. If less than 10 discrete sampling points are available the maximum concentration should be considered the representative concentration.

- In calculating the 95% UCL, concentrations reported below the reporting limit, i.e., non-detect samples can be included in the calculations only if no more than approximately 15% of the total number of samples are non-detect;

- In in the event an exposure area includes more than 15% non-detects and the location or the quality of data is suspect, the risk assessor may consider re-sampling;

- If more than 15% of the concentrations are reported below the reporting limit, then the maximum value should be used as an alternative to the 95% UCL

- For soil boring wells with multiple samples (i.e. samples taken from multiple depths), the maximum concentration from all samples from a single boring well should be used to calculate the representative calculation.

D.3.2 Soil Vapor

The risk assessor should refer to the following instructions and MoEP guidance documents[1] when calculating representative concentrations for vapor intrusion pathways (Indoor and Outdoor Inhalation of Soil Vapors).

The representative concentration for soil vapor will be the maximum concentration of three (3) active soil vapor samples taken over a period of six (6) months.

Site-specific data needed to evaluate vapor intrusion pathways will only include measurement of volatile COCs from soil gas within the fill or native soil below existing buildings and/or within the pore space of the vadose zone soil;

Site specific data may also be collected from:

1. Ambient VOCs in (i.e., unrelated to the release) that may contribute to

[1] Israel Guidance for Performing Active Soil Vapor Sampling (TO-15) March, 2013

VOCs measured at the facility;

2. Indoor (in existing buildings) or outdoor air within the exposure area; and
3. Preferential migration pathways such as subsurface utility corridors.

To evaluate the potential future indoor inhalation pathway - vapor intrusion, (i.e., an enclosed structure is constructed over contaminated soil), the size (footprint) and location of the planned structure must be estimated. In the absence of site-specific information regarding planned structures, the future location and size of the structure must be approximated based on the evaluator's professional judgment. A conservative option is to locate the hypothetical structure over the area of impact (that is, the area of maximum COC concentrations). However, this is only one conservative option and its applicability will vary from site to site. For sites where the footprint of a current on -site structure is or might be different from that of a structure erected in the future, a representative subsurface soil concentration must be calculated for both the current and potential future structure.

Due to the lateral diffusion and advection of vapors in the subsurface, the vapor plume may extend beyond soil and groundwater plume boundaries. While many factors may affect the extent of lateral vapor migration, the vapor intrusion pathway should initially be considered a potential threat for all current or potential future buildings located within about 30 m of soil or groundwater plume which is defined here as soil or groundwater volatile COC concentrations exceeding VSL or RBTLs. For sites with deeper, larger sources or where sources are intersected by utilities or other preferential transport pathways, the distance may need to be increased. As the investigation progresses, the results of soil gas sampling will be used to establish site-specific boundaries for areas with vapor intrusion concerns.

Sub-slab vapor data should be collected as they have the strongest correlation to, and are the best predictor of, vapor intrusion into existing buildings. Soil gas

sampling is appropriate for areas where new construction is reasonably likely and for areas adjacent to existing buildings where sub-slab sampling is not feasible. Soil gas samples differ from sub-slab samples based on depth; they are typically collected approximately 1.5 m below slabs, foundations or the soil surface. In contrast, sub-slab samples are collected in soil or sub-grade drainage layers immediately beneath (< 15 centimeters) the slab foundation. Crawlspace samples may also be collected, if appropriate. If sub-slab or soil gas VOC concentrations clearly do not exceed VSL or RBTLs, additional investigation is not warranted.

To control uncertainty and reduce the chance of decision error in a site investigation, dense sampling within an exposure area is recommended. In general, the greater the heterogeneity in a particular exposure area, the more samples are required for accurate characterization.

For more representative samples, vapor samples should be collected directly beneath buildings than in surrounding areas, and at least 3 feet inside the foundation edges. Additional samples should be collected near utility trenches (i.e., vapor transport) that intersect VOC plumes.

To avoid the effect of barometric pumping (the movement of gases into and out of the vadose zone in response to changes in atmospheric pressure) and atmospheric mixing, soil gas samples collected in should be collected from at least 1.5 m or more below the ground surface.

For more information refer to the *Vapor Intrusion Pathway: A Practical Guidance* (Interstate Technology & Regulatory Council (ITRC), 2007). For soil gas, sub-slab soil gas and indoor air sampling with regard to evaluation of vapor intrusion/soil-to-indoor air inhalation, please refer to MoEP guidance for TO-15 active soil gas sampling guidelines (2013).

Soil vapor should be collected in the vadose zone above the capillary fringe and areas of water saturation should be avoided. At sites with areas with shallow bedrock, shallow groundwater or homes with "wet basement" an investigation may bypass soil gas sampling and move directly to indoor air sampling (for existing buildings) and use soil gas samples taken from shallower than 1.5 m depth and/or use a larger footprint according to MoEP site-specific instructions.

To estimate the representative concentration, the evaluator must:

1. Identify the footprint of the structure within which the receptor is located,
2. Identify the foot print of the potential future enclosed structure,
3. Identify the soil gas concentration data available within each of these two footprints, and
4. Calculate the maximum or 95% UCL of the average.

If several samples within and adjacent to the building footprint are available, more weight should be given to the samples collected within the footprint. Two scenarios are possible: (i) the building footprint is located entirely within the contaminated area, and (ii) the building footprint is partially located within the contaminated area. For both scenarios, the representative soil gas concentration would typically be based on data collected within and directly adjacent to the footprint of the building.

D.3.3 Ambient Air

Ambient air concentrations will be collected following the MoEP guidance documents for sampling indoor and outdoor air for examining infiltration of soil vapor into building[2].

[2] Israel Guidance for Sampling Indoor Air for Assessing Vapor Intrusion into Buildings (IMoEP, August 2017)

D.3.5 Groundwater

The IRBCA process requires the evaluation of the following pathways associated with groundwater:

1. Domestic use of groundwater,
2. Dermal contact with groundwater, and
3. Indoor inhalation of vapor emissions from groundwater.
4. Outdoor inhalation of vapor emissions from groundwater.
5. Groundwater protective of surface water bodies
6. Protection of Groundwater Resources

The representative concentration within each exposure area should be calculated based on measured COC concentrations. The following steps are necessary to determine the representative concentration of groundwater:

To account for temporal variation in groundwater concentrations, the RC in a single well may be estimated.

1 Five or more measurements - Mann-Kendall Test is required to determine the stability of the plume.

- Trend is Increasing or Unknown – Maximum Concentration is used for the RC for the well.
- Trend is Stable or Decreasing – Average Concentration for the last three measurements are used to calculate the RC for the well

2. Upon approval with the regulator, if less than five measurements were taken for the well, the maximum concentration is used for the RC for the well.

The RC for an exposure area will be the maximum value from the RCs from the wells within the exposure area.

- Where multiple aquifers are present, representative concentrations must

be calculated for each aquifer.

For wells that contain or have contained LNAPL within the most recent five years, the representative concentration of the well should be the effective solubility

- The model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe and the vadose zone and into the enclosed space. Thus, RCs for this pathway should be based on groundwater concentrations measured within the footprint of the building or up to 3 m away from the building. As mentioned above for soil, data beyond 3 m may be considered/ necessary based on the presence of features in vadose zone soils (e.g., macropores, fractures, utility conduits, etc.) that could influence vapor migration. Refer to section below for a discussion of the evaluation of future structures and their relationship to the area of impact.

- Where multiple aquifers are present, the shallowest aquifer would be considered for the volatilization pathway.

- For exposure areas where the groundwater to indoor air pathway is a concern, RCs should be calculated based on the following:

  - Multiple exposure areas might be needed if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings, one on-site and one off-site, a RC would have to be calculated for each building.

  - After identifying the location of the building footprints (whether real or hypothetical) and the available groundwater monitoring data within or adjacent (within 3 m) to each footprint, the representative concentration within each footprint must be estimated.

– When groundwater data are not available for each exposure area, following options are available:

  - Installation of additional monitoring wells within or adjacent to the footprint lacking data;
  - Interpolation or extrapolation of existing data (in the case where the plume originates under a building, extrapolated data gathered from areas adjacent to the footprint may not be adequate); or
  - As a conservative approach, use of data from wells located up gradient of the building that is, between the building and the source of contamination.

APPENDIX E1
DEVELOPMENT OF TIER 1 RISK-BASED TARGET LEVELS

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APPENDIX E1
DEVELOPMENT OF TIER 1 RISK-BASED TARGET LEVELS

E.1 INTRODUCTION

This appendix provides the inputs required to calculate Tier 1 RBTLs, several of which may also be used in Tier 2 RA (refer Section 8.0 and Appendix C). The tiered RA requires the following:

- Acceptable risk level,
- Chemical-specific toxicological factors,
- Physical and chemical properties of the COCs,
- Receptor-specific exposure factors,
- Fate and transport parameters, and
- Mathematical models.

Each of these factors is discussed below. In addition, this appendix discusses the target levels for lead (Section E.10) and the estimation of risk and target levels when LNAPL is present (Section E.9).

For Tier 1 RA, RBTLs have been calculated using conservative assumptions applicable to most Israeli sites for various human receptors (child, adult resident, age-adjusted resident, non-residential worker, and construction worker), and various media (soil, soil vapor, groundwater etc.).

For a residential scenario, Tier 1 RBTLs are calculated for a child, age-adjusted receptor, and an adult for both carcinogenic and non-carcinogenic effects (for chemicals that are regulated as carcinogens and non-carcinogens) and the minimum of all these RBTLs is considered the final RBTL. These RBTLs are referred to as the residential RBTLs. Similarly, for Tier 2 and Tier 3 evaluation, risk has to be calculated for these cases and the highest risk is considered the Tier 2 residential risk. For non-residential scenario, Tier 1 RBTLs are calculated

for an adult and for both carcinogenic and non-carcinogenic effects (for chemicals that are regulated as carcinogens and non-carcinogens) and the minimum of all these RBTLs is considered the final RBTL. These RBTLs are referred to as the non-residential RBTLs. Similarly, for Tier 2 and Tier 3 evaluation, risk has to be calculated for these cases and the highest risk is considered the Tier 2 non- residential risk.

Pathways for Soils

- Leaching to groundwater and potential use of groundwater;
- Leaching to groundwater and subsequent migration to a surface water body;
- Ingestion of soil;
- Dermal contact with soil; and
- Outdoor inhalation of vapors and particulates emitted by surficial soils.

At sites where contaminated soil may migrate to adjacent properties by surface runoff, atmospheric deposition, or any other mechanism, the Tier 1 RBTLs for surface soil will apply to the adjacent property. For existing buildings where soil immediately below the building is impacted or future buildings where surficial soil is impacted but is not planned to be excavated and removed or otherwise remediated, subsurface soil and soil gas RBTLs protective of indoor inhalation are applicable.

For Tier 1 evaluation of areas that are currently vacant but a building may be constructed in in the future, the Tier 1 RBTLs for subsurface soil apply for surficial soil also.

If the soil to groundwater or soil to surface water pathway is complete, the soil concentrations presented in the IRBCA spreadsheet model (Tables 10 and 11) will be used for subsurface soil concentrations.

Pathways for Groundwater include:

- Volatilization and upward migration of vapors from groundwater and potential indoor inhalation of these vapor emissions;
- Volatilization and upward migration of vapors from groundwater and potential outdoor inhalation of these vapor emissions;
- Ingestion, inhalation and dermal contact with water if the domestic use of groundwater pathway is complete (on-site and/or off-site);
- Dermal contact with groundwater; and
- Migration to a surface water body and potential impacts to surface waters.

The following pathways for surface water and sediments are not included in Tier 1 calculations:

- Ingestion of surface water, unless the domestic use of surface water pathway is complete (on-site and/or off-site), and if so, ingestion, inhalation and dermal contact of surface water will be considered in Tier 1 RA and the IDWS for the chemical is not available;
- Contact with surface water during recreational activities (ingestion, inhalation of vapors, and dermal contact);
- Ingestion of fish; and
- Contact with (accidental ingestion and dermal contact) sediments.

Other Pathways

At sites where other pathways are complete, they must be evaluated under Tier 2 or 3 RA.

In a Tier 2 RA, at some sites, leaching to groundwater, horizontal migration of the plume under a building, and volatilization from the plume into the building are

pathways that may be complete.

In a Tier 3 RA, the following additional exposure pathways must be considered if complete:

- Ingestion of produce grown in impacted soils;
- Exposures associated with use of groundwater for irrigation purposes;
- Use of groundwater for industrial purposes;
- Ingestion of fish or other aquatic organisms that have bio-accumulated COCs through the food chain as a result of surface water or sediment contamination; or
- In Tier 2 or Tier 3 at large sites (several hundreds of square meters in area) that are unpaved, runoff may come in direct contact with impacted soils and/or discharge into surface waters and/or seawater. At such sites, runoff may have to be considered as a media of concern that may impact surface water, sea water and sediments. The potential impact of contaminated surface runoff on adjacent properties and water ways may have to be evaluated.

For Tier 2 RA, the RP must calculate the SSTLs using technically justifiable, measured site-specific data. The default fate and transport models, toxicity values, exposure factors, and chemical specific properties must be used to develop the Tier 2 SSTLs. For Tier 3 RA, SSTLs would be calculated using site-specific data and possibly alternative fate and transport models, if approved by the authorities.

At sites where there are no complete human exposure pathways target levels protective of groundwater will apply. Further, in such areas the soil target levels protective of ecological receptors presented in Table 4 in the IRBCA spreadsheet model will be applicable. If there is a spill that may directly impact a surface water body, the ecological target levels for soils and sediments apply.

E.2 ACCEPTABLE RISK LEVELS

Risk-based decision making process requires acceptable risk levels for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, risk is quantified using IELCR and for non-carcinogenic effects, the risk is quantified using a HQ or a HI, which is the sum of HQs for multiple chemicals and/or multiple exposure pathways.

For domestic use of water, the IDWS are used as the target concentrations at the POE. For COCs that do not have IDWS, the target concentration at the POE is calculated assuming ingestion of groundwater, dermal contact, and indoor inhalation of vapors due to water use for residential conditions. For commercial sites the same target level may be used at the POE, though the location of the POE will be determined based on site-specific considerations. In no case will the POE be more than 100m from the source.

The acceptable risk levels are as follows:

The Tier 1 RBTLs are based on acceptable carcinogenic risk level of 1×10^{-6} for each COC and each pathway and a HQ of 1.0 for each pathway and for each COC.

The Tier 2 and Tier 3 risks will be compared with the following acceptable risk criteria for each individual receptor:

<u>Carcinogenic Risk</u>

- The sum of IELCRs for each COC across all exposure pathways must be equal to or less than 1×10^{-5}.

- The sum of IELCRs for all the COCs evaluated across each exposure

pathway must be equal to or less than 1×10^{-5}.

- The cumulative IELCR, i.e., sum of risk for all COCs and all exposure pathways must not exceed 1×10^{-5}.

Non-carcinogenic Risk

- The hazard index (HI) for each chemical, which is the sum of hazard quotient (HQs) for all exposure pathways for each chemical (the total risk), must not exceed 1.0.

- The hazard index (HI) for each exposure pathway, which is the sum of HQs for all COCs for each exposure pathway (the total risk), must not exceed 1.0.

- The cumulative HI (the sum of the hazard quotients for all chemicals for all exposure pathways) must be equal or less than 1.0.

E.3 QUANTITATIVE TOXICITY FACTORS

The IRBCA Spreadsheet Model contains the toxicity values used in Tier 1 and Tier 2 RAs for the chemicals considered in the IRBCA process. The source of the values is the November 2012 version of the USEPA .*Regional Screening Level (RSL) Summary Table November 2012* Typically, these toxicity values will be used for Tier 2 and Tier 3 RA, although alternate values with adequate justification and the approval of the authorities may be used.

The hierarchy of sources for toxicity information, per the *Human Health Toxicity Values in Superfund Risk Assessments," OSWER directive 9285.7-53 December 5, 2003* is as follows:

1. Integrated Risk Information System (IRIS),

2. USEPA Regional Screening Level (RSL) most updated Summary Table
3. National Center for Environmental Assessment (NCEA),
4. Health Effects Assessment Summary Tables (HEAST), and
5. California Human Health Screening Levels (CHHSL) CalEPA.

The RSL guidance generally follows the above hierarchy. For toxicity of TPH carbon fractions refer to Section 6.4.4.

For chemicals that do not have toxicity values but are COCs at a site, the risk assessor is required to develop the necessary toxicity values based on the above hierarchy or of necessary, literature review, available guidance from USEPA, WHO, California EPA. Prior to the use of such values, they have to be approved by the MoEP and the Ministry of the Health. In the past, USEPA used route to route extrapolation and this approach may also be considered.

E.3.1 Dermal Toxicity

Dermal toxicity values are not available in the above sources; therefore the dermal toxicity values were calculated using the assumption that the dermal toxicity of the chemical is the same as the oral toxicity values, except that a semi-permeable barrier (the skin) affects absorption. Using oral toxicity values to calculate dermal toxicity values is based on sound toxicological principles, and in the absence of direct measurement of dermal toxicity, considered an acceptable alternative by the USEPA. However, the calculation is complicated due to the fact that different chemicals pass through the skin with different efficiencies. These differing efficiencies are factored into the formulae for dermal toxicity as the term oral absorption factors *(RAF_d)*.

Dermal slope factor (SF_d) and dermal reference dose (RfD_d) are calculated as:

$$SF_d = \frac{SF_o}{GIABS} \quad \text{(E-1)}$$

$$RfD_d = RfD_o \times GIABS \quad \text{(E-2)}$$

where,

SF_o = Slope factor for oral exposure $(mg/kg\text{-}day)^{-1}$,
RfD_o = Reference dose for oral exposure $(mg/kg\text{-}day)^{-1}$, and
GIABS = Gastrointestinal absorption factor (dimensionless).

The GIABS were obtained from Regional Screening Level Tables USEPA (2012)The parameters used for dermal contact with groundwater pathway are shown in the IRBCA spreadsheet model and are discussed below:

Permeability Coefficient: For organic chemicals, the chemical-specific permeability coefficients in water were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the permeability constant, K_p (cm/hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW \qquad \text{(E-3)}$$

where,

K_{ow} = Octanol-water partition coefficient (dimensionless), and
MW = Molecular weight (g/mole).

Note the *MW* and K_{ow} are presented in the IRBCA spreadsheet model

For metals and inorganics, the permeability coefficients were obtained from Exhibit B-4 of the *RAGS Volume I, Part E* (USEPA, 2004). If no value is available, the permeability coefficient of 1×10^{-3} cm/hr is recommended as default value (USEPA, 2004).

Relative Contribution of Permeability Coefficient: The relative contribution of permeability coefficients for the chemicals was obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the relative contribution of permeability coefficient, *B* (unitless), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$B = K_p \frac{\sqrt{MW}}{2.6} \qquad \text{(E-4)}$$

Lag Time: The lag times for the chemicals, τ_{event} (hr/event), were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004).

As per the *RAGS Volume I, Part E* (USEPA, 2004), the equation to estimate τ_{event} is derived as below:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80-0.0056MW)} \quad \text{(E-5)}$$

$$\tau_{event} = \frac{l_{sc}^2}{6 \times D_{sc}} \quad \text{(E-6)}$$

where,

D_{sc} = Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr), and

l_{sc} = Apparent thickness of stratum corneum (cm).

The lag time is dependent on the effective diffusion coefficient for chemical transfer through the stratum corneum and the apparent thickness of stratum corneum. Assuming l_{sc} = 10^{-3} cm as a default value for the thickness of the stratum corneum, τ_{event} becomes:

$$\tau_{event} = 0.105 \times 10^{(0.0056MW)} \quad \text{(E-7)}$$

For chemicals not listed in Exhibit B-3, τ_{event} was estimated using Equation E-7.

Equation E-7 is based on the assumption that all chemicals absorbed into the skin during the exposure event would eventually be absorbed into the systemic circulation, with the stratum corneum being the main barrier for most chemicals. For highly lipophilic chemicals, the viable epidermis can be a significant barrier for chemical transfer from the stratum corneum to the systemic circulation. When this occurs, the relative rate of desquamation of the stratum corneum and cell proliferation rate at the base of the viable epidermis contribute to a net decrease in the total amount of absorbed chemical. For similar reasons, stratum corneum desquamation can reduce the amount of absorption for chemicals that are not

highly lipophilic but large enough that penetration through the stratum corneum is slow.

Time to Reach Steady-State: The time to reach steady-state for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the time to reach steady-state, t^* (hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

If B < 0.6 or B = 0.6,

$$t^* = 2.4\tau_{event} \quad \text{(E-8)}$$

If B > 0.6,

$$t^* = 6\tau_{event} \times \left(b - \sqrt{b^2 - c^2}\right) \quad \text{(E-9)}$$

where *b* and *c* are correlation coefficient which have been fitted to the data from Flynn, G.L. (1990) and are expressed as below:

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)} \text{ and } b = 2 \times \frac{(1 + B)^2}{\pi} - c. \quad \text{(E-10)}$$

Fraction Absorbed Water: The fraction absorbed water for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the fraction absorbed water, *FA* (unitless), was estimated from Exhibit A-5 of the *RAGS Volume I, Part E* (USEPA, 2004).

E.4 PHYSICAL AND CHEMICAL PROPERTIES

Physical and chemical properties of the COCs are listed in the IRBCA spreadsheet model. These values must be used for all tiers unless there are justifiable reasons to modify these values and the authorities approve the alternative values. The use of different values would be allowed only under a

Tier 3 RA with proper justification..

The following hierarchy was used to obtain the physical and chemical properties:

1. RSL Chemical-specific Parameters Supporting Table June 2011 (USEPA, 2011b), and
2. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (USEPA, 2002c).

E.5 EXPOSURE FACTORS

The exposure factors and the default values used to develop generic Tier 1 RBTLs are presented in the IRBCA spreadsheet model. These values were evaluated and approved by the IRBCA Task Force. The exposure factors are typically estimated based on literature rather than site-specific measurements. For a Tier 3 RA, site-specific exposure factors may be used with clear justification and the approval of the authorities.

A source of exposure factor information is the *Exposure Factors Handbook Volume 1 – General Factors* (USEPA, 1997c, 2011). Other sources of exposure factor data may be used for Tier 3 risk assessment with approval of the authorities**.**

E.6 FATE AND TRANSPORT PARAMETERS AND BUILDING PARAMETERS

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, area of site, soil porosity, and infiltration rate at a site. For a Tier 1 RA, soil representative of the coastal aquifer soil was selected. The IRBCA spreadsheet model presents the default fate and transport parameter values and building parameters to calculate Tier 1 RBTLs.

These values were selected by the IRBCA Task Force. The term Volumetric Flow Rate of Soil Gas into the enclosed space (Qsoil) represents the volume of soil gas that flows into to the building from the subsurface. Such flow occurs due to the difference in pressure between the subsurface and the interior of the building.

For a Tier 2 RA, a combination of site-specific and default fate and transport values are used as discussed in Appendix C. The value of each parameter used, whether site-specific or default must be justified based on site-specific conditions. Where site-specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used.

For a Tier 3 RA, the specific fate and transport parameters required to calculate the SSTLs would depend on the model used.

E.7 PROTECTION OF GROUNDWATER PATHWAY

If the groundwater use pathway is deemed to be complete under current or future conditions, it must be quantitatively evaluated as follows:

Step 1: Identify the critical POE. The POE is defined in Section E.7.3. The POE is not necessarily an actual well but could be a hypothetical well. Further, the POE may be screened in a deeper uncontaminated zone, and not necessarily a shallow contaminated water bearing zone.

Step 2: Determine target levels at the POE. For COCs that have proposed IDWS, the target level at the POE will be the IDWS. For COCs that do not have IDWS, the target levels will be the risk-based calculated value that assumes groundwater ingestion, dermal contact and indoor inhalation of vapors emitted due to water use. Note that the indoor inhalation of vapors based on water use pathway will be considered only for volatile COCs (refer to Figure E-1)

Step 3: Identification of POD wells and calculation of target levels at the POD. POD wells are located between the source and the POE to monitor the COC concentrations in groundwater as a means of protecting against exceedances at the POE. Risk-based target concentrations will be developed for the POD using appropriate fate and transport models and site-specific parameters as explained in Section E.12.

Step 4: Calculation of representative soil COC concentrations in the area of release. Risk-based target levels for soil should also be calculated for the area of release using the equations and models presented in this appendix.

The protection of groundwater pathway requires the following information:

1. Dimensions of the soil source,
2. Dimensions of the groundwater source,
3. The location of the POE,
4. The location of the PODs, and
5. The standards to be met at the POE.
6. The depth to the groundwater from the bottom of the contaminated soil zone.

Figure E-1 presents a schematic of this pathway. Based on the above inputs, the Summers and Domenico's model can be used to calculate the following:

1. Allowable concentration at the POD(s), and
2. Allowable concentration at the soil source.

The allowable concentrations at the POE and the POD are compared with the representative concentrations measured at these two locations (POD and the soil source) to determine whether the pathway is protected or not.

The selection of the five inputs presented above is discussed below:

E.7.1 Dimension of Soil Source

The dimensions of the soil source are estimated based on site investigation and the historic knowledge of the site activities. The source is considered approximately a rectangle with dimensions 'L' and 'W_{ga}' as shown in Figure 2. Note the definition of the source dimensions are relative to the flow direction as shown in Figure 2.

E.7.2 Dimensions of Groundwater Source

Conservatively, it is assumed that the COCs in the unsaturated zone migrate vertically downwards. Hence, the footprint of the groundwater source is identical to the footprint of the soil source. Additionally, a depth dimension 'δ_{gw}' has to be associated with the groundwater source (Refer Figure E-1) and is estimated as the larger of the:

1. The range of water table fluctuation;
2. The depth below average depth to water table to which COCs have migrated;
3. The well screen thickness; and
4. Or a calculated value.

In no case can this thickness exceed the thickness of the aquifer.

E.7.3 Location of Point of Exposure

In Tier 1 RA, the POE will be located at a distance from the down gradient edge of the source to the minimum of:

1. The location of existing well;
2. The property boundary in the down gradient direction; or

3. For large sites, the POE is located 100 meters from the center of the 'hot spots' or the property boundary whichever is lower.

For domestic use only, the POE will be located at a distance set by the IWA.

In the example scenario shown in Figure E-2(a), minimum of the three points described above is 100 m from the down gradient edge of the source. Hence, POE is at Point 3. Similarly, in Figure E-2(b) Point 1 is the POE since existing well is the closest point from the source. As indicated above, the POE may be a hypothetical point, i.e., a well may or may not exist at the POE.

E.7.4 Location of Point of Demonstration

The POD is a monitoring well located between the source and the POE. COC concentrations will be measured at the POD and compared with the allowable concentration at the POD, calculated as discussed below. This comparison is used to determine whether the groundwater pathway is protective at the site.

E.7.5 Standards at Point of Exposure

The IDWS or a calculated value have to be met at the POE. For all other chemicals without current IDWS, the equivalent domestic water standards have been calculated based on ingestion of water, dermal contact with water, and inhalation of vapors during domestic use. Refer to equations in Appendix E.

E.7.6 Calculation of Allowable Concentration at Point of Demonstration

To estimate the Tier 1 soil concentrations protective of groundwater for different distances to the POE, the soil source and groundwater source concentrations in Table 9 are to be multiplied with dilution attenuation factor in the unsaturated zone values in Table 10. For example, with the POE at a distance of 0 m from the source the soil source and groundwater concentrations of benzene from Table 9 are 0.00411 mg/kg and 5 µg/L, respectively. The DAF value in Table 10 for a distance of 150 m is 40.8. Multiplying these values, the soil source and

groundwater source concentrations are 0.17 mg/kg and 204 µg/L, respectively**.**

$$C_{POD} = C_{TGW} \times \frac{DAF_{POE}}{DAF_{POD}} \quad \text{(E-11)}$$

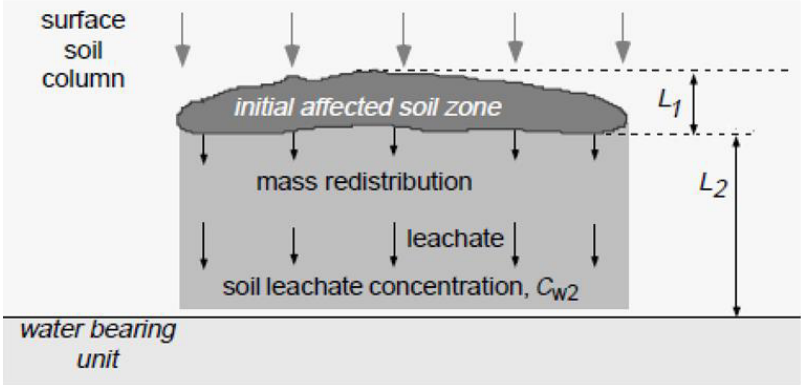
where,

C_{POD}	=	Allowable groundwater concentration at the POD (mg/L),
C_{TGW}	=	Target groundwater concentration below on-site/off-site building (mg/L),
DAF_{POE}	=	Dilution attenuation factor between the on-site/off-site building and source estimated using Domenico's equation, and
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation.

In the above equation, DAF values can be obtained from the IRBCA model (Table 10). If the exact distance is not available, linear interpolations is reasonable.

E.7.7 Calculation of Allowable Concentration at Soil Source

For Tier 1 and Tier 2 RA, the depth dependent unsaturated zone DAF value is calculated based on the distance to the groundwater level from the bottom of the contaminated soil zone. The calculation is based on the soil attenuation model for deriving risk-based soil remediation standards (Conner, J.A. et al). The soil attenuation model (SAM) uses a sorptive redistribution factor which is calculated based on the ratio of the vertical thickness of the affected soil (d1) and the depth to groundwater from the bottom of the contaminated soil zone(d2).



$$\boldsymbol{DAF_{vertical} = \frac{L_1 + L_2}{L_1}}$$

(Conner, J.A. et al)

Tier 1

Depth to Groundwater Level from the Bottom of the Soil Contamination Zone. (L2) [m]	$DAF_{vertical}$
0 – 6 m	3
>6 m	8

Tier 2

The $DAF_{vertical}$ will be calculated using the equation:

$$\boldsymbol{DAF_{vertical} = \frac{L_1 + L_2}{L_1}}$$

However, the maximum allowable Tier 2 $DAF_{vertical}$ is set to 16

The allowable concentration at the soil source can be calculated using the following equation:

$$C_{ss} = C_{TGW} \times \frac{DAF_{horizontal}}{LF_{sw}} \times DAF_{vertical} \qquad \text{(E-12)}$$

where,

C_{SS} = Allowable soil concentration at the source (mg/kg),
C_{TGW} = Target groundwater concentration below on-site/off-site building (mg/L),

$DAF_{horizontal}$ = Dilution attenuation factor between the on/off-site receptor and source estimated using Domenico's equation,
LF_{SW} = Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)], and
$DAF_{vertical}$ = Dilution attenuation factor in the unsaturated zone.

E.8 TARGET LEVELS FOR PROTECTION OF SURFACE WATER BODIES

Potential impacts to all surface water bodies including streams, marine waters, lakes and sea must be evaluated and surface water quality protected. Sampling for COCs in surface water bodies may be necessary when COC migration is known or suspected to adversely affect a surface water body. Cleanup target levels based on nuisance considerations are calculated based on factors that do not affect risk to health and the environment, but nonetheless affect the usability of the water.

Protection of streams requires the (i) estimation of allowable COC concentrations at the point of discharge to the stream, and (iii) calculation of allowable COC concentrations at various locations within the groundwater plume. Note that no mixing zone in the water body is allowed in any of the tiers. Thus, the allowable in-stream COC concentration is equal to the groundwater COC concentration at the point of discharge of the groundwater to the surface water body. Attenuation within the stream due to mixing, dilution, degradation, volatilization, partitioning into sediments is neglected.

Groundwater COC concentrations at PODs at different distances between the source and the soil source concentrations are estimated using the procedure described below. Also refer to Figure E-3.

Step 1: Determine the allowable concentration at the point of discharge to the stream: The allowable concentration at the point of discharge is selected from the concentrations listed in Table 3. This concentration depends on the receiving water body characteristics such as freshwater, estuarine water, and marine water. If the stream is used for drinking water purposes, domestic use

concentrations in Table 6 are to be used. If the stream is to be used for other non-drinking water purposes e.g. irrigation, life stock, wildlife watering, industrial supply, or recreational, it may be necessary to calculate the corresponding target levels. If the stream has multiple uses, the lowest concentration must be used.

Step 2: Estimate groundwater and soil concentrations: Applicable COC concentrations for soil and groundwater can be back-calculated at the point of demonstration wells and groundwater source wells using the concept of DAFs. The specific equations, a combination of the Summer and Domenico's models, are presented in Appendix E. The procedure is similar to calculating the concentrations protective of a POD well in that it is necessary to establish one or more POD wells and calculate the corresponding attenuation factors. Note in this case the POE is the location where the groundwater discharges into the stream.

The soil and groundwater COC concentrations discussed above apply to the protection of surface water. Other routes of exposure from groundwater, such as inhalation of volatiles and ingestion of groundwater, must also be evaluated as part of the process. Therefore, cleanup criteria based on these routes of exposure may result in allowable COC concentrations that are lower than those protective of a surface water body.

E.9 MATHEMATICAL MODELS

The input parameters mentioned above are used in two types of models, or equations, to calculate the risk-based target levels. These are the (i) uptake equations, and (ii) fate and transport models. For Tier 1 and Tier 2 RAs, the authorities have selected the models and equations presented at the end of this Appendix.. Specifically, these models include:

- Indoor inhalation of vapors from subsurface soil and groundwater – Johnson and Ettinger (J&E) model (USEPA, 2004b), Refer to Figure E-4;

- Outdoor inhalation of vapors from soil – Volatilization factor presented in the *Soil Screening Guidance: User's Guide* (USEPA, 1996b) for both finite and infinite source. Of these, infinite source is used for the calculation of Tier 1 RBTLs;

- Outdoor inhalation of particulates from soil – Particulate emission factor presented in the *Soil Screening Guidance: User's Guide* (USEPA, 1996); and

- Groundwater protection pathway – Summer model (ASTM, 1995a) and Domenico model (Domenico and Swartz, 1990).

Note the equations and models can be used in the backward mode to estimate target levels or in the forward mode to estimate risk. Both the forward mode and backward mode equations are presented in this appendix. With the prior approval of the authorities through the submittal of a Tier 3 work plan, alternative models may be used for Tier 3 RA.

E.10 TARGET LEVELS FOR LEAD

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable. Certain behaviors, such as crawling and playing on the floor or ground, result in increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overtly toxic can result in impaired mental development, learning disabilities and behavioral problems.

Because of the greater vulnerability of children to exposure and toxicity, the

primary concern in a residential setting is risk to children. In the non-residential scenario, children are not generally directly exposed, but fetuses carried by female workers can be exposed.

The USEPA has developed models to predict blood lead concentrations in children and pregnant women and provide information on the percentage of the population exceeding 10 µg/dL. The Integrated Exposure Uptake Biokinetic (IEUBK) Model predicts the risk of elevated blood lead (PbB) in children under the age of seven who are exposed to environmental lead from various sources, while the adult lead methodology (ALM) predicts the concentrations of lead in the blood of fetuses carried by women exposed to lead contaminated sites.

The blood lead concentration used in the IEUBK and ALM models is 10µg/dL since it is the level of concern above which significant health risks occur, although the developmental effects of lead have been demonstrated at levels below 10 µg/dL. According to the US Center for Disease Control, no threshold for adverse health effects in young children has been demonstrated and no safe blood level has been identified.

The California Office of Environmental Health Hazard Assessment proposed soil screening levels based on a child specific health guidance value for lead, defined as a benchmark incremental increase in blood lead (PbB) of up to 1 µg/dL. This benchmark change in blood lead concentration is a health-protective estimate, based on risk to children, and whereas the previous target blood lead levels was based on a “level of concern” that did not incorporate recent scientific information.

Based on the above, the soil levels in the IRBCA process are:

Residential land use soil (direct contact with soil)	80 mg/kg
Non-residential land use soil (direct contact with soil)	320 mg/kg

The RP can choose to perform a site specific (Tier 3) RA for lead if concentrations exceed these levels.

The above soil concentrations do not account for leaching to groundwater. At sites where this pathway is complete or potentially complete, the authorities may require a site-specific analysis. The use of a leaching test using water with a pH similar to that of infiltrating water may be used to determine the potential for lead to impact groundwater.

E.11 TARGET LEVEL CALCULATION FOR LNAPL OR DNAPL

The IRBCA process allows for the calculation of risk and target levels when LNAPL or DNAPL is present. Under this condition, the primary routes of exposure are indoor inhalation for a residential or a non-residential receptor, and the protection of a current or potential future POE groundwater well. For these pathways, the key step is the calculation of the vapor concentration and the dissolved concentration emanating from the LNAPL and/or DNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in Sections E.2 to E.8 above.

The soil vapor concentration in equilibrium with LNAPL or DNAPL is the effective soil vapor concentration. This concentration depends on (i) the chemical-specific saturated soil vapor concentration, and (ii) the mole fraction of the chemical in the LNAPL or DNAPL for which the soil vapor concentration is being calculated. If the mole fraction of a COC is not known, default mole fractions, calculated using the weight fraction of a specific COC in the LNAPL or DNAPL, may be used if the NAPL can be analyzed and its components determined. Alternatively, the evaluator may sample the LNAPL/DNAPL for laboratory analysis to determine site-specific values for the weight and mole fractions. The specific equations used to calculate the effective soil vapor or effective dissolved

concentrations are presented in Appendix E.

In the forward mode of risk assessment, the effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration at the POD and POE wells. If DNAPL is located below the water table, pathways related to inhalation of vapors generated from the DNAPL will be considered incomplete, as vapors will not penetrate the overlying column of saturated soil.

E.12 REFERENCES

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IRBCA Equation	Description
E-1	INDOOR INHALATION OF VAPORS (CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)
E-2	OUTDOOR INHALATION OF VAPORS
E-3	INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-4	DERMAL CONTACT WITH CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-5	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-6	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-7a, E-7b	INDOOR AND OUTDOOR AIR CONCENTRATION ESTIMATED FROM SUBSURFACE SOIL VAPOR CONCENTRATIONS
E-8	DERMAL CONTACT WITH CHEMICALS IN WATER (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-9	DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)
E-10	INDOOR AIR CONCENTRATION ESTIMATED FROM GROUNDWATER CONCENTRATION
E-11	OUTDOOR AIR CONCENTRATION ESTIMATED FROM GROUNDWATER CONCENTRATION
E-12	INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

IRBCA Equation	Description
E-13	OUTDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)
E-14	DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)
E-15	DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)
E-16	INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-17	DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-18	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-19	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

IRBCA Equation E-1	INDOOR INHALATION OF VAPORS (CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)
Carcinogenic effects $IELCR_{ininh} = \frac{C \times ET_{in} \times ED \times EF \times IUR}{AT_c \times 365 \times 24}$ Non-carcinogenic effects $HQ_{ininh} = \frac{C \times ET_{in} \times ED \times EF}{AT_{nc} \times 365 \times RfC \times 24 \times 1000}$ Source: RAGS Vol. I Part F, 2009	where: C = Contaminant concentration in indoor air [µg/m^3] $IELCR_{ininh}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in indoor air [-] HQ_{ininh} = Hazard quotient for individual constituents in indoor air [-] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ET_{in} = Indoor exposure time [hr/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfC = Chemical-specific reference concentration [mg/m^3] IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 1000 = Converts C in mg to µg [1000 µg/mg] 24 = Converts ET_{in} hours to day [24 hrs/day]

IRBCA Equation E-2	OUTDOOR INHALATION OF VAPORS
Carcinogenic effects $IELCR_{outinh} = \frac{C \times ET_{out} \times ED \times EF \times IUR}{AT_c \times 365 \times 24}$ Non-carcinogenic effects $HQ_{outinh} = \frac{C \times ET_{out} \times ED \times EF}{AT_{nc} \times 365 \times RfC \times 24 \times 1000}$ Source: RAGS Vol. I Part F, 2009	where: C = Contaminant concentration in outdoor air [µg/m^3] $IELCR_{outinh}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in outdoor air [-] HQ_{outinh} = Hazard quotient for individual constituents in outdoor air [-] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ET_{out} = Outdoor exposure time [hr/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfC = Chemical-specific reference concentration [mg/m^3] IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 1000 = Converts C in mg to µg [1000 µg/mg] 24 = Converts ET_{in} hours to day [24 hrs/day]

IRBCA Equation E-3	INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $IELCR_{sing} = \frac{C \times EF \times ED \times SF_o \times 10^{-6} \times IR_{soil}}{BW \times AT_c \times 365}$ Non-carcinogenic effects $HQ_{sing} = \frac{C \times EF \times ED \times 10^{-6} \times IR_{soil}}{BW \times AT_{nc} \times 365 \times RfD_o}$	where: C = Contaminant concentration in soil [mg/kg] $IELCR_{sing}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-] HQ_{sing} = Hazard quotient for individual constituents [-] THQ = Target hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] IR_{soil} = Soil ingestion rate [mg/day] SF_o = Oral cancer slope factor [(mg/kg-day)$^{-1}$] RfD_o = Chemical-specific oral reference dose [mg/kg-day] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^{-6} = Converts kg to mg [kg/mg]

IRBCA Equation E-4	DERMAL CONTACT WITH CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $$IELCR_{sdc} = \frac{C \times EF \times ED \times SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times ABS_d}{BW \times AT_c \times 365}$$ Non-carcinogenic effects $$HQ_{sdc} = \frac{C \times EF \times ED \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times ABS_d}{BW \times AT_{nc} \times 365 \times RfD_d}$$ Source: Modified from RAGS, Vol. I, Part E, 2004.	where: C = Contaminant concentration in soil [mg/kg] $IELCR_{sdc}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-] HQ_{sdc} = Hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] SA_{soil} = Skin surface area available for contact with soil [cm^2] EV_{soil} = Event frequency [event/day] AF = Soil to skin adherence factor [mg/cm^2-event] ABS_d = Chemical-specific dermal absorption factor [-] SF_d = Dermal cancer slope factor [$(mg/kg\text{-}day)^{-1}$] RfD_d = Chemical-specific oral reference dose [mg/kg-day] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^{-6} = Converts kg to mg [kg/mg]

IRBCA Equation E-5	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $IELCR_{signh} = \frac{C \times ET_{out} \times ED \times EF \times IUR \times 1000 \times (\frac{1}{VF_{ss}} + \frac{1}{VF_p})}{AT_c \times 365 \times 24}$ Non-carcinogenic effects $HQ_{sinh} = \frac{C \times ET_{out} \times ED \times EF \times (\frac{1}{VF_{ss}} + \frac{1}{VF_p})}{AT_{nc} \times 365 \times RfC \times 24}$ Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.	where: C = Contaminant concentration in soil [mg/kg] $IELCR_{sinh}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in surficial soil [-] HQ_{sinh} = Averaging time for carcinogens [year] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ET_{out} = Outdoor exposure time [hr/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfC = Chemical-specific reference concentration [mg/m^3] IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 1000 = Converts C in mg to µg [1000 µg/mg] 24 = Converts ET_{in} hours to day [24 hrs/day] VF_p = Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)] VF_{ss} = Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)] *Note: The depth to surficial soil for a construction worker is up to the typical construction depth.*

IRBCA Equation E-6	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$IELCR_{ssoil} = IELCR_{sdc} + IELCR_{\sin g} + IELCR_{\sinh}$$

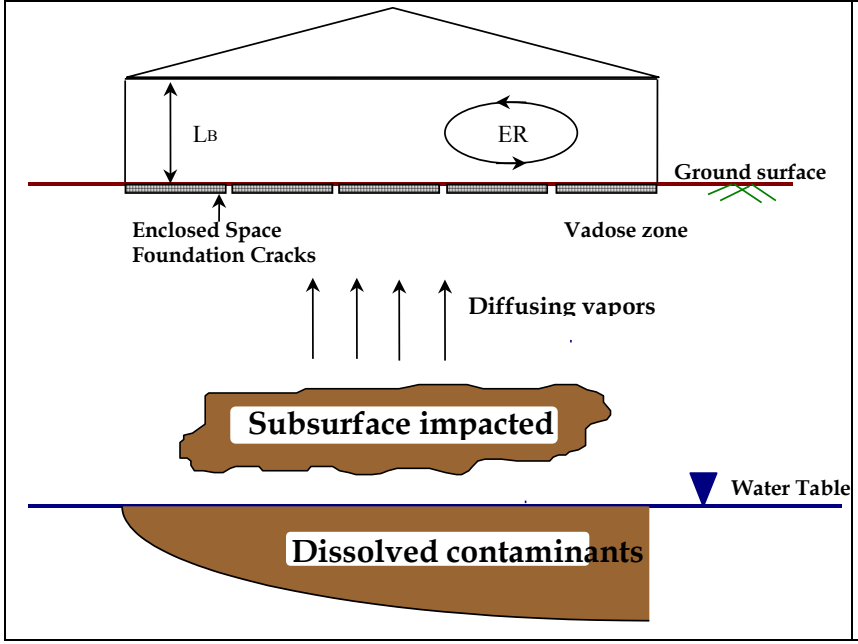
Non-carcinogenic effects

$$HQ_{ssoil} = HQ_{sdc} + HQ_{\sin g} + HQ_{\sinh}$$

where,

$IELCR_{ssoil}$ = Risk or the increased chance of developing cancer over a lifetime due to ingestion of vapors and particulates, inhalation of, and dermal contact with chemical in surficial soil [-]

HQ_{ssoil} = Hazard quotient for ingestion of, inhalation of vapors and particulates, and dermal contact with surficial soil [-]

IRBCA Equation E-7	INDOOR AIR CONCENTRATION ESTIMATED FROM SUBSURFACE SOIL VAPOR CONCENTRATIONS
	$$C_{ai} = C_{svi} \times \alpha_{sv}$$ where: C_{ai} = Indoor air concentration [µg/m^3-air] C_{svi} = Soil vapor concentration [µg/m^3-air] α_{sv} = Attenuation factor from subsurface soil vapor to indoor (enclosed space) air [-] Source: ASTM E1739-95

IRBCA Equation E-7b	OUTDOOR AIR CONCENTRATION ESTIMATED FROM SOIL VAPOR CONCENTRATION

$$C_{ao} = C_{sv} \times VF_{SV-out}$$

where:

C_{ai} = Outdoor air concentration [µg/m^3-air]
C_{sv} = Soil Vapor Concentration [µg/m^3-water]
$VF_{sv\text{-}out}$ = Volatilization factor from soil vapor to outdoor air [dimensionless]

Source: ASTM E1739-95

IRBCA Equation E-8	DERMAL CONTACT WITH CHEMICALS IN WATER (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $IELCR = \frac{C \times SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}{BW \times AT_c \times 365 \times 10^6}$ Non-carcinogenic effects $HQ = \frac{C \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}{BW \times AT_{nc} \times 365 \times RfD_d \times 10^6}$ For organic chemicals, If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$ If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$ For inorganic chemicals, $Z = K_p \times t_{event}$	where: C = Contaminant concentration for dermal contact with water [µg/L] $IELCR$ = 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_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] SA_{gw} = Skin surface area available for contact with water [cm^2] EV_{gw} = Event frequency [event/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfD_d = Chemical-specific dermal reference dose [mg/kg-day] SF_d = Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$ 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^6 = Conversion factor t_{event} = Event duration [hr/event] t^* = Chemical-specific time to reach steady-state [hr] Z = Chemical-specific dermal factor [cm/event] K_p = Chemical-specific dermal permeability coefficient [cm/hr] FA = Chemical-specific fraction absorbed in water [-] τ_{event} = Chemical-specific lag time [hr/event] B = Chemical-specific relative contribution of permeability coefficient [-]

$$B = K_P \frac{\sqrt{MW}}{2.6}$$

$$\log K_P = -2.80 + 0.66 \log K_{OW} - 0.0056 MW$$

If B<0.6 or B=0.6, then, $t^* = 2.4\tau_{event}$

If B>0.6 then, $t^* = 6\tau_{event} \times (b - \sqrt{b^2 - c^2})$

where,

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)}$$

$$b = 2 \times \frac{(1 + B)^2}{\pi} - c$$

$$\tau_{event} = 0.105 \times 10^{(0.0056 MW)}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

MW = Molecular weight [g/mole]
K_{ow} = Octanol water partition coefficient [L/kg]
b, c = Correlation coefficient which have been fitted to the data from Flynn, G.L. (1990)

$$b = 2 \times \frac{(1 + B^2)}{\pi} - c$$

IRBCA Equation E-9	DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)

Carcinogenic effects (Ingestion and Dermal Contact)

$$IELCR_{w(ing+dc)} = \frac{C \times ED \times EF \times \left[(SF_o \times IR_W) + \left(\frac{SF_d}{1000} \times SA_{wb} \times EV_{wb} \times Z_{wb}\right)\right]}{BW \times AT_c \times 365 * 1000}$$

Carcinogenic effects (Inhalation of Vapors Due to Water Use)

$$IELCR_{winh} = \frac{C \times ED \times EF \times ET_{in} \times K_f \times IUR}{AT_c \times 365 * 24}$$

Non-carcinogenic effects (Ingestion and Dermal Contact)

$$HQ_{w(ing+dc)} = \frac{C \times ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w\right) + \left(\frac{SA_{wb} \times EV_{wb} \times Z_{wb}}{RfD_d \times 1000}\right)\right]}{BW \times AT_{nc} \times 365 \times 1000}$$

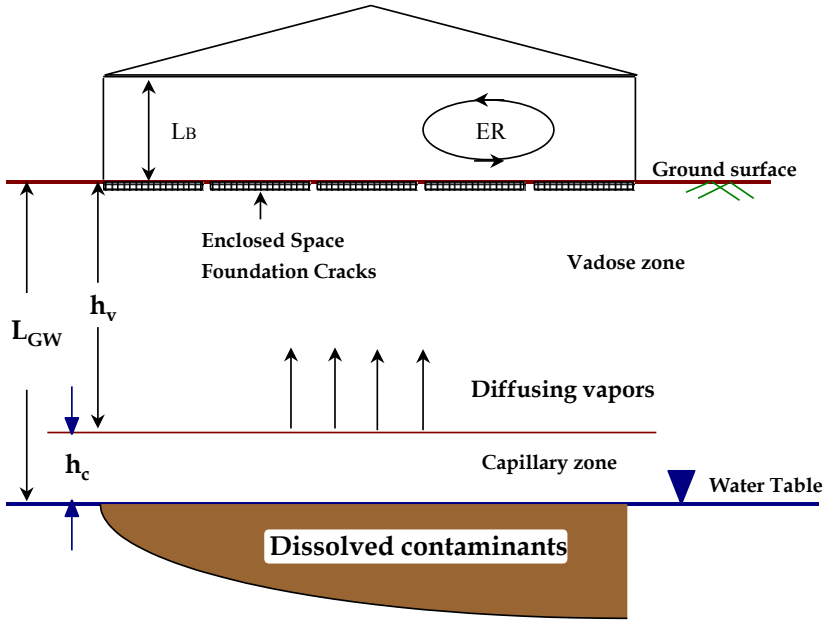
Non-carcinogenic effects (Inhalation of Vapors Due to Water Use)

$$HQ_{winh} = \frac{C \times ED \times EF \times ET_{in} \times K_f}{AT_c \times 365 \times RfC \times 24 \times 1000}$$

where:

$IELCR_{w(ing+dc)}$	=	Risk or the increased chance of developing cancer over a lifetime due to ingestion and dermal exposure to a chemical in domestic water use [-]
$IELCR_{winh}$	=	Risk or the increased chance of developing cancer over a lifetime due to inhalation exposure to a chemical in domestic water use [-]
$HQ_{w(ing+dc)}$	=	Hazard quotient due to ingestion and dermal exposure to an individual constituent in domestic water use [-]
HQ_{winh}	=	Hazard quotient due to inhalation exposure to an individual constituent in domestic water use [-]
C	=	Contaminant concentration in domestic water [µg/L]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
IR_w	=	Water ingestion rate [L/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
K_f	=	Volatilization factor [L/m^3]
ET_{in}	=	Inhalation exposure time [hr/day]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfC	=	Chemical-specific inhalation reference concentration [mg/m^3]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
IUR	=	Chemical-specific inhalation unit risk $[(\mu g/m^3)^{-1}]$
SF_d	=	Chemical-specific dermal cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L] and mg to µg [µg/mg]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
24	=	Conversion factor from hrs to day [hr/day]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]

FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

IRBCA Equation E-10	INDOOR AIR CONCENTRATION ESTIMATED FROM GROUNDWATER CONCENTRATION
$$C_{ai} = C_{wi} \times VF_{wesp}$$ where: C_{ai} = Indoor air concentration [µg/m^3-air] C_{wi} = Groundwater concentration [µg/L-water] VF_{wesp} = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-water)] Source: ASTM E1739-95	

IRBCA Equation E-11	OUTDOOR AIR CONCENTRATION ESTIMATED FROM GROUNDWATER CONCENTRATION

$$C_{ao} = C_{wi} \times VF_{wamb}$$

where:

C_{ao} = Outdoor air concentration [µg/m^3-air]
C_{wi} = Groundwater concentration [µg/L-water]
VF_{wamb} = Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)]

Source: ASTM E1739-95

IRBCA Equation E-12	INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IELCR_{ininh} = \frac{C \times \left((ED_{child} \times EF_{\ child} \times ET_{in-child}) + (ED_{adult} \times EF_{adult} \times ET_{in-adult})\right) \times IUR}{AT_c \times 365 \times 24}$$

Non-carcinogenic effects

$$HQ_{ininh} = \frac{C \times ((ED_{child} \times EF_{\ child} \times ET_{in-child}) + (ED_{adult} \times EF_{adult} \times ET_{in-adult}))}{AT_{nc} \times 365 \times RfC \times 24 \times 1000}$$

Source: RAGS Vol. I Part F, 2009

where:

$IELCR_{ai\text{-}aa}$= Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in indoor air [-]
$HQ_{ai\text{-}aa}$ = Hazard quotient for individual constituents due to exposure to indoor air [-]
C = Chemical concentration in indoor air [mg/m^3]
ED_{adult} = Exposure duration for an adult [year]
ED_{child} = Exposure duration for a child [year]
AT_c = Averaging time for carcinogenic effects [year]
AT_{nc} = Averaging time for non-carcinogenic effects [year]
EF_{child} = Exposure frequency for child [days/year]
EF_{adult} = Exposure frequency for adult [days/year]
$ET_{in\text{-}child}$ = Indoor exposure time for child [year]
$ET_{in\text{-}adult}$ = Indoor exposure time for adult [year]
365 = Converts years to days [days/year]
24 = Converts hours to day [hours/day]
1000 = Converts mg to µg [µg/mg]

IRBCA Equation E-13	OUTDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IELCR_{ininh} = \frac{C \times \left((ED_{child} \times EF_{\ child} \times ET_{out-child}) + (ED_{adult} \times EF_{adult} \times ET_{out-adult})\right) \times IUR}{AT_c \times 365 \times 24}$$

Non-carcinogenic effects

$$HQ_{ininh} = \frac{C \times ((ED_{child} \times EF_{\ child} \times ET_{out-child}) + (ED_{adult} \times EF_{adult} \times ET_{out-adult}))}{AT_{nc} \times 365 \times RfC \times 24 \times 1000}$$

Source: RAGS Vol. I Part F, 2009

where:

$IELCR_{ai\text{-}aa}$ = Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in outdoor air [-]
$HQ_{ai\text{-}aa}$ = Hazard quotient for individual constituents due to exposure to outdoor air [-]
C = Chemical concentration in outdoor air [µg/m^3]
ED_{adult} = Exposure duration for an adult [year]
ED_{child} = Exposure duration for a child [year]
AT_c = Averaging time for carcinogenic effects [year]
AT_{nc} = Averaging time for non-carcinogenic effects [year]
EF_{child} = Exposure frequency for child [days/year]
EF_{adult} = Exposure frequency for adult [days/year]
$ET_{out\text{-}child}$ = Outdoor exposure time for child [year]
$ET_{out\text{-}adult}$ = Outdoor exposure time for adult [year]
365 = Converts years to days [days/year]
24 = Converts hours to day [hours/day]
1000 = Converts mg to µg [µg/mg]

IRBCA Equation E-14	DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)
Carcinogenic effects $IELCR_{ininh} = \frac{C \times SF_d \times (DC_{w-c} \times Z_c + DC_{w-a} \times Z_a)}{AT_c \times 365 \times 10^6}$ Non-carcinogenic effects $HQ = \frac{C \times (DC_{w-c} \times Z_c + DC_{w-a} \times Z_a)}{AT_c \times 365 \times 10^6 \times RfD_d}$ where : $DC_{w\text{-}c} = \frac{ED_c \times EF_c \times SA_{gw-c} \times EV_{gw-c}}{BW_c}$ $DC_{w\text{-}a} = \frac{ED_a \times EF_a \times SA_{gw-a} \times EV_{gw-a}}{BW_a}$	For organic chemicals, If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$ If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$ For inorganic chemicals, $Z = K_p \times t_{event}$ Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

C	=	Contaminant concentration in groundwater from dermal contact [µg/L]
$IELCR$	=	Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
HQ	=	Hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
t_{event}	=	Event duration [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]
$DC_{w\text{-}c}$	=	Child dermal contact rate with groundwater [cm^2-event/kg]
$DC_{w\text{-}a}$	=	Adult dermal contact rate with groundwater [cm^2-event/kg]
$EV_{gw\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{gw\text{-}a}$	=	Resident adult event frequency [event/day]
Z_c	=	Resident child chemical-specific dermal factor [cm/event]
Z_a	=	Resident adult chemical-specific dermal factor [cm/event]
$SA_{gw\text{-}c}$	=	Resident child skin surface area available for contact with water [cm^2]
$SA_{gw\text{-}a}$	=	Resident adult skin surface area available for contact with water [cm^2]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]

IRBCA Equation E-15	DOMESTIC WATER USE (Age-Adjusted Resident)

Carcinogenic effects (Ingestion and Dermal Contact)

$$IELCR_{(ing+dc)} = C \times \frac{\left[\left(SF_o \times IR_{w-aa}\right) + \left(\frac{SF_d}{1000} \times \left(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}\right)\right)\right]}{AT_c \times 365}$$

Carcinogenic effects (Inhalation of Water Vapors)

$$IELCR_{inh} = \frac{C \times IUR \times ED_{aa} \times EF_a \times ET_{in\text{-}a} \times K_f \times 1000}{AT_c \times 365 \times 24}$$

Non-carcinogenic effects(Ingestion and Dermal Contact)

$$HQ_{(ing+dc)} = C \times \frac{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa}\right) + \left(\frac{\left(DC_{wb-c} Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}\right)}{RfD_d \times 1000}\right)\right]}{THQ \times AT_{nc} \times 365}$$

Non-carcinogenic effects(Inhalation of Water Vapors)

$$HQ_{inh} = \frac{C \times ED_{aa} \times EF_a \times ET_{in\text{-}a} \times K_f}{AT_{nc} \times 365 \times RfC \times 24}$$

where:

$$ED_{aa} = ED_c + ED_a$$

$$DC_{wb\text{-}c} = \frac{ED_c \times EF_c \times SA_{wb-c} \times EV_{wb-c}}{BW_c} \quad \text{and} \quad DC_{wb\text{-}a} = \frac{ED_a \times EF_a \times SA_{wb-a} \times EV_{wb-a}}{BW_a}$$

For organic chemicals,

If $t_{wb\text{-}event} \le t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: $K_f = 0$ for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

C_w	=	Contaminant concentration in domestic water [µg/L-H2O]
$IELCR_{(ing+dc)}$	=	Risk or the increased chance of developing cancer over a lifetime due to ingestion and dermal exposure to a chemical in domestic water [-]
$IELCR_{inh}$	=	Risk or the increased chance of developing cancer over a lifetime due to inhalation of vapors from domestic water use [-]

$HQ_{(ing+dc)}$	=	Hazard quotient for to ingestion and dermal exposure to a chemical in domestic water [-]
HQ_{inh}	=	Hazard quotient for exposure to inhalation of chemical vapors due to domestic water use [-]
AT_c	=	Averaging time for non-carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfC	=	Chemical-specific inhalation reference concentration [mg/m^3]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
IUR	=	Chemical-specific inhalation unit risk [$(\mu g/m^3)^{-1}$]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [$mg/(kg\text{-}day)]^{-1}$
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident child groundwater ingestion rate [L/day]
$IR_{w\text{-}a}$	=	Resident adult groundwater ingestion rate [L/day]
$DC_{wb\text{-}c}$	=	Child dermal whole-body contact rate with groundwater [cm^2-event/kg]
$DC_{wb\text{-}a}$	=	Adult dermal whole-body contact rate with groundwater [cm^2-event/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
ED_{aa}	=	Resident age-adjusted exposure duration [year]
EF_a	=	Exposure frequency for an adult [day/year]
ET_a	=	Exposure frequency for an adult [day/year]
K_f	=	Volatilization factor [L/m^3]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
365	=	Conversion factor [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]; and mg µg [µg/mg]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]

FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

For inhalation of vapors, dermal contact with, and ingestion of chemicals in water (domestic water use combined pathway) by age-adjusted resident,

$$IELCR_{w-aa} = IELCR_{(ing+dc)} + IELCR_{inh}$$

$$HQ_{w-aa} = HQ_{(ing+dc)} + HQ_{inh}$$

where,

$IELCR_{w\text{-}aa}$	=	Risk or increased chance of developing cancer over a lifetime due to ingestion, dermal contact with, and inhalation of chemicals in domestic water [-]
$HQ_{w\text{-}aa}$	=	Hazard quotient for ingestion of, dermal contact with, and inhalation of chemicals in domestic water [-]

IRBCA Equation E-16	INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IELCR_{sing-aa} = \frac{C \times SF_o \times IR_{s-aa} \times 10^{-6}}{AT_c \times 365}$$

Non-carcinogenic effects

$$HQ_{sing-aa} = \frac{C \times IR_{s-aa} \times 10^{-6}}{AT_{nc} \times 365 \times RfD_o}$$

where :

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

where:

C	=	Contaminant concentration in soil [mg/kg-wet soil]
$IELCR_{sing-aa}$	=	Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$HQ_{sing-aa}$	=	Hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
IR_{s-aa}	=	Age-adjusted soil ingestion rate [mg/kg]
IR_{s-c}	=	Resident child soil ingestion rate [mg/day]
IR_{s-a}	=	Resident adult soil ingestion rate [mg/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]

ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

IRBCA Equation E-17	DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IELCR_{sd\text{-}aa} = \frac{C \times SF_d \times SA_{soil-aa} \times ABS_d \times 10^{-6}}{AT_c \times 365}$$

Non-carcinogenic effects

$$HQ_{sd\text{-}aa} = \frac{C \times SA_{soil-aa} \times ABS_d \times 10^{-6}}{AT_{nc} \times 365 \times RfD_d}$$

where:

$$SA_{soil-aa} = \frac{ED_c \times EF_c \times AF_c \times SA_{soil-c} \times EV_{soil-c}}{BW_c} + \frac{ED_a \times EF_a \times AF_a \times SA_{soil-a} \times EV_{soil-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

C	=	Contaminant concentration in soil [mg/kg]
$IELCR_{sd\text{-}aa}$	=	Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
$HQ_{sd\text{-}aa}$	=	Hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
ABS_d	=	Chemical-specific dermal absorption factor [-]

AF_c	=	Resident child soil to skin adherence factor [mg/cm^2-event]
AF_a	=	Resident adult soil to skin adherence factor [mg/cm^2-event]
RfD_d	=	Chemical-specific dermal reference dose [(mg/kg-day)]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day)$^{-1}$]
SA_{aa}	=	Age-adjusted skin surface area [mg/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
$SA_{soil\text{-}c}$	=	Resident child skin surface area available for contact with soil [cm^2]
$SA_{soil\text{-}a}$	=	Resident adult skin surface area available for contact with soil [cm^2]
$EV_{soil\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{soil\text{-}a}$	=	Resident Child event frequency [event/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

IRBCA Equation E-18	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IECLR_{sinh-aa} = \frac{C \times ((ET_{out-c} \times ED_c \times EF_c) + (ET_{out-a} \times ED_a \times EF_a)) \times IUR \times 1000 \times (\frac{1}{VF_{ss}} + \frac{1}{VF_p})}{AT_c \times 365 \times 24}$$

Non-carcinogenic effects

$$HQ_{sinh-aa} = \frac{C \times ((ET_{out-c} \times ED_c \times EF_c) + (ET_{out-a} \times ED_a \times EF_a)) \times (\frac{1}{VF_{ss}} + \frac{1}{VF_p})}{AT_c \times 365 \times RFC \times 24}$$

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.

where:

$IELCR_{sinh\text{-}aa}$=Risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical in surficial soil [-]
$HQ_{sinh\text{-}aa}$ = Averaging time for carcinogens [year]
C = Contaminant concentration in soil [mg/kg]
AT_c = Averaging time for carcinogens [year]
AT_{nc} = Averaging time for non-carcinogens [year]
$ET_{out\text{-}r}$ = Outdoor exposure time for resident [hr/day]
ED_{aa} = Exposure duration for age-adjusted resident [year]
ED_c = Exposure duration for child [year]
ED_a = Exposure duration for adult [year]
EF_r = Exposure frequency for resident [day/year]
RfC = Chemical-specific reference concentration [mg/m^3]
IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$]
365 = Converts AT_c, AT_{nc} in years to days [day/year]
1000 = Converts C in mg to µg [1000 µg/mg]
24 = Converts ET_{in} hours to day [24 hrs/day]
VF_{ss} = Volatilization factor for vapor emissions from surficial soil[kg-soil/m^3-air]
VF_p = Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]

IRBCA Equation E-19	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$IELCR_{s-aa} = IELCR_{\sin g-aa} + IELCR_{sd-aa} + IELCR_{sout-aa}$$

Non-carcinogenic effects

$$HQ_{s-aa} = HQ_{\sin g-aa} + HQ_{sd-aa} + HQ_{sout-aa}$$

Where,

$IELCR_{s\text{-}aa}$ = Excess cancer risk over a lifetime due to exposure to ingestion of, inhalation of vapors and particulates and dermal contact with chemicals in surficial soil [-]

$HQ_{s\text{-}aa}$ = Hazard quotient for exposure to ingestion of, inhalation of vapors and particulates and dermal contact with chemicals in surficial soil [-]

Note: All parameters are defined under the individual pathway equations.

Note: $VF_s = 0$ for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.

IRBCA Equation	Description
E-20	INDOOR INHALATION OF VAPORS (CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)
E-21	OUTDOOR INHALATION OF VAPORS
E-22	INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-23	DERMAL CONTACT WITH CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-24	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-25	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-26	SOIL VAPOR CONCENTRATION PROTECTIVE OF INDOOR INHALATION OF VAPORS
E-27	SOIL VAPOR CONCENTRATION PROTECTIVE OF OUTDOOR INHALATION OF VAPORS
E-28	DERMAL CONTACT WITH CHEMICALS IN WATER (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
E-29	DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)

IRBCA Equation	Description
E-30	GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION OF VAPORS
E-31	GROUNDWATER CONCENTRATION PROTECTIVE OF OUTDOOR INHALATION OF VAPORS
E-32	INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)
E-33	OUTDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)
E-34	INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-35	DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-36	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-37	DIRECT SOIL CONTACT - INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)
E-38	DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)
E-39	DOMESTIC WATER USE (AGE-ADJUSTED RESIDENT)

IRBCA Equation E-20	INDOOR INHALATION OF VAPORS (CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)
Carcinogenic effects $$RBTL_{c-ininh} = \frac{TR \times AT_c \times 365 \times 24}{ET_{in} \times ED \times EF \times IUR}$$ Non-carcinogenic effects $$RBTL_{nc-ininh} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{ET_{in} \times ED \times EF}$$ Source: RAGS Vol. I Part F, 2009	where: $RBTL_{c\text{-}ininh}$= Carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] $RBTL_{nc\text{-}ininh}$= Non-carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] TR = Target risk [-] THQ = Target hazard quotient [-] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ET_{in} = Indoor exposure time [hr/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfC = Chemical-specific reference concentration [mg/m^3] IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 1000 = Converts µg to mg [1000 µg/mg] 24 = Converts ET_{in} hours to day [24 hrs/day]

IRBCA Equation E-21	OUTDOOR INHALATION OF VAPORS
Carcinogenic effects $$RBTL_{c-outinh} = \frac{TR \times AT_c \times 365 \times 24}{ET_{out} \times ED \times EF \times IUR}$$ Non-carcinogenic effects $$RBTL_{nc-outinh} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{ET_{out} \times ED \times EF}$$ Source: RAGS Vol. I Part F, 2009	where: $RBTL_{c\text{-}outinh}$ = Carcinogenic risk based target level for outdoor inhalation of vapors [µg/m^3] $RBTL_{nc\text{-}outinh}$ = Non-carcinogenic risk based target level for outdoor inhalation of vapors [µg/m^3] TR = Target risk [-] THQ = Target hazard quotient [-] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ET_{out} = Outdoor exposure time [hr/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfC = Chemical-specific reference concentration [mg/m^3] IUR = Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 1000 = Converts mg to µg [1000 µg/mg] 24 = Converts ET_{in} hours to day [24 hrs/day]

IRBCA Equation E-22	INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $$RBTL_{c-sing} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_o \times 10^{-6} \times IR_{soil}}$$ Non-carcinogenic effects $$RBTL_{nc-sing} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_o}{EF \times ED \times 10^{-6} \times IR_{soil}}$$	where: $RBTL_{c\text{-}sing}$= Carcinogenic risk based target level for ingestion of chemicals in soil [mg/kg] $RBTL_{nc\text{-}sing}$= Non-carcinogenic risk based target level for ingestion of chemicals in soil [mg/kg] TR = Target risk [-] THQ = Target hazard quotient [-] THQ = Target hazard quotient for individual constituents [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] IR_{soil} = Soil ingestion rate [mg/day] SF_o = Oral cancer slope factor [(mg/kg-day)$^{-1}$] RfD_o = Chemical-specific oral reference dose [mg/kg-day] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^{-6} = Converts kg to mg [kg/mg]

IRBCA Equation E-23	DERMAL CONTACT WITH CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $$RBTL_{c-sdc} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times ABS_d}$$ Non-carcinogenic effects $$RBTL_{nc-sdc} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_d}{EF \times ED \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times ABS_d}$$ Source: Modified from RAGS, Vol. I, Part E, 2004.	where: $RBTL_{c\text{-}sdc}$ = Carcinogenic risk based target level for dermal contact with chemicals in soil [mg/kg] $RBTL_{nc\text{-}sdc}$ = Non-carcinogenic risk based target level for dermal contact with chemicals in soil [mg/kg] TR = Target risk [-] THQ = Target hazard quotient [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] ED = Exposure duration [year] EF = Exposure frequency [day/year] SA_{soil} = Skin surface area available for contact with soil [cm^2] EV_{soil} = Event frequency [event/day] AF = Soil to skin adherence factor [mg/cm^2-event] ABS_d = Chemical-specific dermal absorption factor [-] SF_d = Dermal cancer slope factor [$(mg/kg\text{-}day)^{-1}$] RfD_d = Chemical-specific oral reference dose [mg/kg-day] 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^{-6} = Converts kg to mg [kg/mg]

IRBCA Equation E-24	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $RBTL_{c-sinh} = \frac{\frac{RBTL_{c-outinh}}{1000}}{\frac{1}{VF_{ss}} + \frac{1}{VF_p}}$ Non-carcinogenic effects $RBTL_{c-sinh} = \frac{\frac{RBTL_{nc-outinh}}{1000}}{\frac{1}{VF_{ss}} + \frac{1}{VF_p}}$ Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.	where: $RBTL_{c\text{-}sinh}$ = Carcinogenic risk based target level for inhalation of vapors and particulates in soil [mg/kg] $RBTL_{nc\text{-}sinh}$ = Non-carcinogenic risk based target level for inhalation of vapors and particulates in soil [mg/kg] $RBTL_{c\text{-}outinh}$ = Carcinogenic risk based target levels for outdoor inhalation of vapors [µg/m^3] $RBTL_{nc\text{-}outinh}$ = Non-carcinogenic risk based target levels for outdoor inhalation of vapors [µg/m^3] VF_p = Volatilization factor for particulate emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)] VF_{ss} = Volatilization factor for vapor emissions from surficial soil [(mg/m^3-air)/(mg/kg-soil)] *1000* = Converts µg to mg [1000 µg/mg] *Note: The depth to surficial soil for a construction worker is up to the typical construction depth.*

IRBCA Equation E-25	DIRECT SOIL CONTACT INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{c-ssoil} = \frac{1}{\frac{1}{RBTL_{c-sdc}} + \frac{1}{RBTL_{c-\sin g}} + \frac{1}{RBTL_{c-\sinh}}}$$

Non-carcinogenic effects

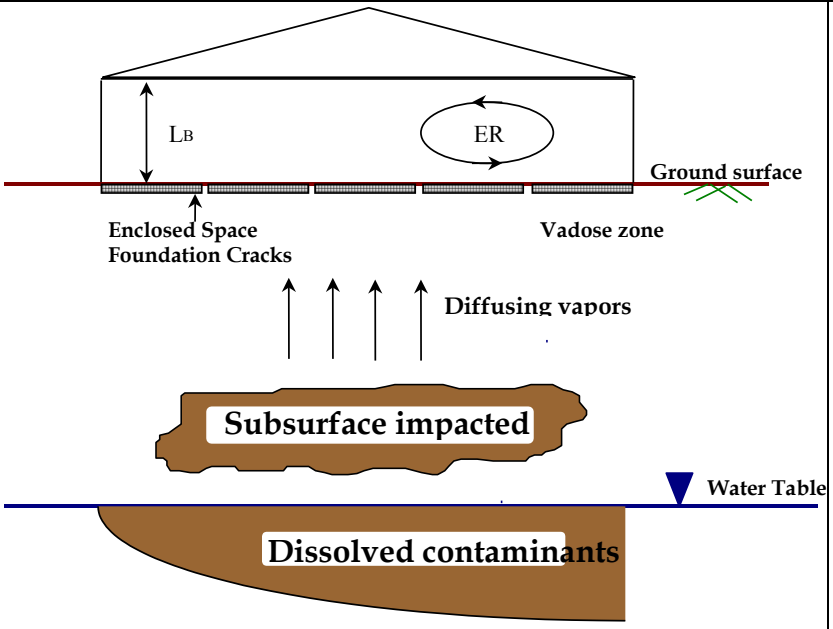
$$RBTL_{nc-ssoil} = \frac{1}{\frac{1}{RBTL_{nc-sdc}} + \frac{1}{RBTL_{nc-\sin g}} + \frac{1}{RBTL_{nc-\sinh}}}$$

where,

$RBTL_{c\text{-}ssoil}$ = Carcinogenic risk based target level for inhalation of vapors and particulates, inhalation of, and dermal contact with chemical in surficial soil [mg/kg]

$RBTL_{nc\text{-}ssoil}$ = Non-carcinogenic risk based target level for inhalation of vapors and particulates, inhalation of, and dermal contact with chemical in surficial soil [mg/kg]

Note: All other parameters are defined under the individual pathway equations.

IRBCA Equation E-26	SOIL VAPOR CONCENTRATION PROTECTIVE OF INDOOR INHALATION OF VAPORS
	$$RBTL_{svi} = \frac{RBTL_{ininh}}{\alpha_{sv}}$$ where: $RBTL_{svi}$ = Risk based target level for indoor inhalation of vapors from soil vapor [µg/m^3-air] $RBTL_{ininh}$ = Risk based target level for indoor inhalation of air [µg/m^3-air] α_{sv} = Attenuation factor from subsurface soil vapor to indoor (enclosed space) air [-] Source: ASTM E1739-95

IRBCA Equation E-27	OUTDOOR AIR CONCENTRATION ESTIMATED FROM SOIL VAPOR CONCENTRATION

$$RBTL_{svout} = \frac{RBTL_{outinh}}{VF_{SV-out}}$$

where:

C_{ai} = Outdoor air concentration [µg/m^3-air]
C_{sv} = Soil Vapor Concentration [µg/m^3-water]
$VF_{sv\text{-}out}$ = Volatilization factor from soil vapor to outdoor air [dimensionless]

Source: ASTM E1739-95

IRBCA Equation E-28	DERMAL CONTACT WITH CHEMICALS IN WATER (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)
Carcinogenic effects $RBTL_{c-dw} = \frac{TR \times BW \times AT_c \times 365 \times 10^6}{SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$ Non-carcinogenic effects $RBTL_{nc-dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 10^6 \times RfD_d}{SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$ For organic chemicals, If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$ If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$ For inorganic chemicals, $Z = K_p \times t_{event}$	where: $RBTL_{c-dw}$ = Carcinogenic risk based target level for dermal contact with water [µg/L] $RBTL_{nc-dw}$ = Non-carcinogenic risk based target level for dermal contact with water [µg/L] TR = Target risk [-] THQ = Target hazard quotient [-] BW = Body weight [kg] AT_c = Averaging time for carcinogens [year] AT_{nc} = Averaging time for non-carcinogens [year] SA_{gw} = Skin surface area available for contact with water [cm^2] EV_{gw} = Event frequency [event/day] ED = Exposure duration [year] EF = Exposure frequency [day/year] RfD_d = Chemical-specific dermal reference dose [mg/kg-day] SF_d = Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$ 365 = Converts AT_c, AT_{nc} in years to days [day/year] 10^6 = Conversion factor t_{event} = Event duration [hr/event] t^* = Chemical-specific time to reach steady-state [hr] Z = Chemical-specific dermal factor [cm/event] K_p = Chemical-specific dermal permeability coefficient [cm/hr] FA = Chemical-specific fraction absorbed in water [-] τ_{event} = Chemical-specific lag time [hr/event] B = Chemical-specific relative contribution of permeability coefficient [-]

$$B = K_P \frac{\sqrt{MW}}{2.6}$$

$$\log K_P = -2.80 + 0.66 \log K_{OW} - 0.0056 MW$$

If B<0.6 or B=0.6, then, $t^* = 2.4\tau_{event}$

If B>0.6 then, $t^* = 6\tau_{event} \times (b - \sqrt{b^2 - c^2})$

where,

$$c = \frac{1 + 3B + 3B^2}{3(1 + B)}$$

$$b = 2 \times \frac{(1 + B)^2}{\pi} - c$$

$$\tau_{event} = 0.105 \times 10^{(0.0056 MW)}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

MW = Molecular weight [g/mole]
K_{ow} = Octanol water partition coefficient [L/kg]
b, c = Correlation coefficient which have been fitted to the data from Flynn, G.L. (1990)

$$b = 2 \times \frac{(1 + B^2)}{\pi} - c$$

IRBCA Equation E-29	DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)

Carcinogenic effects (Ingestion and Dermal Contact)

$$RBTL_{c-w(ing+dc)} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{ED \times EF \times \left[(SF_o \times IR_w) + \left(\frac{SF_d}{1000} \times SA_{wb} \times EV_{wb} \times Z_{wb}\right)\right]}$$

Carcinogenic effects (Inhalation of Vapors Due to Water Use)

$$RBTL_{c-winh} = \frac{TR \times AT_c \times 365 \times 24}{ED \times EF \times ET_{in} \times K_f \times IUR}$$

Non-carcinogenic effects (Ingestion and Dermal Contact)

$$RBTL_{nc-w(ing+dc)} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000}{ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w\right) + \left(\frac{SA_{wb} \times EV_{wb} \times Z_{wb}}{RfD_d \times 1000}\right)\right]}$$

Non-carcinogenic effects (Inhalation of Vapors Due to Water Use)

$$RBTL_{nc-winh} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{ED \times EF \times ET_{in} \times K_f}$$

where:

$RBTL_{c\text{-}w(ing+dc)}$	=	Carcinogenic risk based target level for ingestion and dermal exposure to a chemical in domestic water use [µg/L]
$RBTL_{nc\text{-}w(ing+dc)}$	=	Non-carcinogenic risk based target level for ingestion and dermal exposure to a chemical in domestic water use [µg/L]
$RBTL_{c\text{-}winh}$	=	Carcinogenic risk based target level for inhalation exposure to a chemical in domestic water use [µg/L]
$RBTL_{nc\text{-}winh}$	=	Non-carcinogenic risk based target level for inhalation exposure to a chemical in domestic water use [µg/L]
TR	=	Target risk [-]
THQ	=	Target hazard quotient [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
IR_w	=	Water ingestion rate [L/day]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
K_f	=	Volatilization factor [L/m^3]
ET_{in}	=	Inhalation exposure time [hr/day]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfC	=	Chemical-specific inhalation reference concentration [mg/m^3]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
IUR	=	Chemical-specific inhalation unit risk $[(\mu g/m^3)^{-1}]$
SF_d	=	Chemical-specific dermal cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L] and mg to µg [µg/mg]

$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
24	=	Conversion factor from hrs to day [hr/day]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

For inhalation of vapors, dermal contact with, and ingestion of chemicals in water (domestic water use combined pathway) by child and adult resident,

Carcinogenic Effects

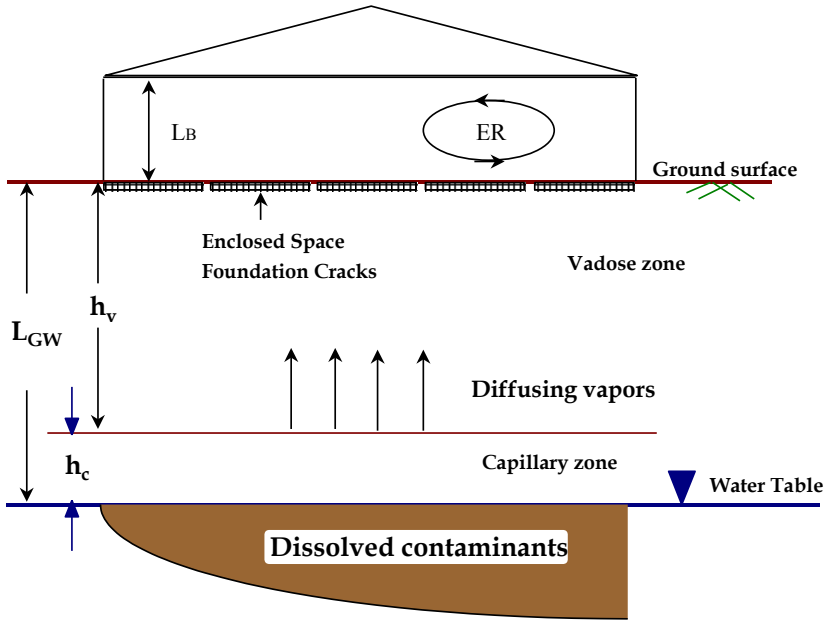
$$RBTL_{c-w} = \frac{1}{\frac{1}{RBTL_{c\text{-}(ing+dc)}} + \frac{1}{RBTL_{c\text{-}inh}}}$$

Non-Carcinogenic Effects

$$RBTL_{nc-w} = \frac{1}{\frac{1}{RBTL_{nc\text{-}(ing+dc)}} + \frac{1}{RBTL_{nc\text{-}inh}}}$$

where,

$RBTL_{c\text{-}w}$	=	Carcinogenic risk based target level for domestic water use [mg/L]
$RBTL_{nc\text{-}w}$	=	Non-carcinogenic risk based target level for domestic water use [mg/L]

IRBCA Equation E-30	GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION OF VAPORS
$$RBTL_{wi} = \frac{RBTL_{ininh}}{VF_{wesp}}$$ where: $RBTL_{wi}$ = Risk based target level protective of indoor inhalation of vapors from groundwater [µg/L-water] $RBTL_{ininh}$= Risk based target level for indoor inhalation of air [µg/m^3-air] VF_{wesp} = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-water)] Source: ASTM E1739-95	

IRBCA Equation E-31	GROUNDWATER CONCENTRATION PROTECTIVE OF OUTDOOR INHALATION OF VAPORS

$$RBTL_{wi} = \frac{RBTL_{inhout}}{VF_{wamb}}$$

where:

$RBTL_{wi}$ = Risk based target level protective of outdoor inhalation of vapors from groundwater [µg/L-water]
$RBTL_{inhout}$ = Risk based target level protective of outdoor inhalation of air [µg/m^3-air]
VF_{wamb} = Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)]

Source: ASTM E1739-95

IRBCA Equation E-32	INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)
Carcinogenic effects $RBTL_{c-ininh-aa} = \frac{TR \times AT_c \times 365 \times 24}{(ET_c \times ED_c \times EF_c) + (ET_a \times ED_a \times EF_a) \times IUR}$ Non-carcinogenic effects $RBTL_{nc-ininh-aa} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{(ET_{in-c} \times ED_c \times EF_c) + (ET_{in-a} \times ED_a \times EF_a)}$ Source: RAGS Vol. I Part F, 2009	where: $RBTL_{c\text{-}ininh\text{-}aa}$=Carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] $RBTL_{nc\text{-}ininh\text{-}aa}$=Non-carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] TR = Target risk [-] THQ = Target hazard quotient [-] ED_c = Exposure duration for a child [year] ED_a = Exposure duration for an adult [year] AT_c = Averaging time for carcinogenic effects [year] AT_{nc} = Averaging time for non-carcinogenic effects [year] EF_c = Exposure frequency for a child [days/year] EF_a = Exposure frequency for a adult [days/year] $ET_{in\text{-}c}$ = Indoor exposure time for a child [hours/day] $ET_{in\text{-}a}$ = Indoor exposure time for a resident [hours/day] *365* = Converts years to days [days/year] *24* = Converts hours to day [hours/day] *1000* = Converts mg to µg [µg/mg]

IRBCA Equation E-33	OUTDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)
Carcinogenic effects $RBTL_{c-outinh-aa} = \frac{TR \times AT_c \times 365 \times 24}{(ET_{out-c} \times ED_c \times EF_c) + (ET_{out-a} \times ED_a \times EF_a) \times IUR}$ Non-carcinogenic effects $RBTL_{nc-outinh} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{(ET_{out-c} \times ED_c \times EF_c + ET_{out-a} \times ED_a \times EF_a)}$ Source: RAGS Vol. I Part F, 2009	where: $RBTL_{c\text{-}outinh\text{-}aa}$=Carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] $RBTL_{nc\text{-}outinh\text{-}aa}$=Non-carcinogenic risk based target level for indoor inhalation of vapors [µg/m^3] TR = Target risk [-] THQ = Target hazard quotient [-] ED_a = Exposure duration for an adult [year] AT_c = Averaging time for carcinogenic effects [year] AT_{nc} = Averaging time for non-carcinogenic effects [year] EF_c = Exposure frequency for a child [days/year] EF_a = Exposure frequency for a adult [days/year] $ET_{in\text{-}c}$ = Outdoor exposure time for a child [hours/day] $ET_{in\text{-}a}$ = Outdoor exposure time for a resident [hours/day] 365 = Converts years to days [days/year] 24 = Converts hours to day [hours/day] 1000 = Converts mg to µg [µg/mg]

IRBCA Equation E-34	INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{c-\sin g-aa} = \frac{TR \times AT_c \times 365}{SF_o \times IR_{s-aa} \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{nc-\sin g-aa} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{IR_{s-aa} \times 10^{-6}}$$

where :

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part A, 1989

where:

$RBTL_{c\text{-}sing\text{-}aa}$	=	Carcinogenic risk based target level for ingestion of soil [mg/kg]
$RBTL_{nc\text{-}sing\text{-}aa}$	=	Non-carcinogenic risk based target level for ingestion of soil [mg/kg]
TR	=	Target risk [-]
THQ	=	Target hazard quotient [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
$IR_{s\text{-}aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s\text{-}c}$	=	Resident child soil ingestion rate [mg/day]
$IR_{s\text{-}a}$	=	Resident adult soil ingestion rate [mg/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

IRBCA Equation E-35	DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{c\text{-}sd\text{-}aa} = \frac{TR \times AT_c \times 365}{SF_d \times SA_{soil-aa} \times ABS_d \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{nc\text{-}sd\text{-}aa} = \frac{THQ \times AT_{nc} \times 365 \times RfD_d}{SA_{soil-aa} \times ABS_d \times 10^{-6}}$$

where:

$$SA_{soil-aa} = \frac{ED_c \times EF_c \times AF_c \times SA_{soil-c} \times EV_{soil-c}}{BW_c} + \frac{ED_a \times EF_a \times AF_a \times SA_{soil-a} \times EV_{soil-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

IRBCA Equation E-36	INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{c-sinh-aa} = \frac{\frac{RBTL_{c-outinh-aa}}{1000}}{\frac{1}{VF_{ss}} + \frac{1}{VF_p}}$$

Non-carcinogenic effects

$$RBTL_{nc-sinh-aa} = \frac{\frac{RBTL_{nc-outinh-aa}}{1000}}{\frac{1}{VF_{ss}} + \frac{1}{VF_p}}$$

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.

where:

$RBTL_{c\text{-}sinh\text{-}aa}$ = Carcinogenic risk based target level for inhalation of vapors and particulates from soil [mg/kg]
$RBTL_{nc\text{-}sinh\text{-}aa}$ = Non-carcinogenic risk based target level for inhalation of vapors and particulates from soil [mg/kg]
$RBTL_{c\text{-}outinh\text{-}aa}$ = Carcinogenic risk based target level for outdoor inhalation of vapors [µg/m^3]
$RBTL_{nc\text{-}outinh\text{-}aa}$ = Non-carcinogenic risk based target level for outdoor inhalation of vapors [µg/m^3]
VF_{ss} = Volatilization factor for vapor emissions from surficial soil[kg-soil/m^3-air]
VF_p = Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]

IRBCA Equation E-37	DIRECT SOIL CONTACT INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{c-ssoil-aa} = \frac{1}{\frac{1}{RBTL_{c-sd-aa}} + \frac{1}{RBTL_{c-\sin g-aa}} + \frac{1}{RBTL_{c-\sinh-aa}}}$$

Non-carcinogenic effects

$$RBTL_{nc-ssoil-aa} = \frac{1}{\frac{1}{RBTL_{nc-sd-aa}} + \frac{1}{RBTL_{nc-\sin g-aa}} + \frac{1}{RBTL_{nc-\sinh-aa}}}$$

where,

$RBTL_{c\text{-}ssoil\text{-}aa}$ = Carcinogenic risk based target level for dermal contact and ingestion of soils and inhalation of vapors and particulates from soil [mg/kg]

$RBTL_{nc\text{-}ssoil\text{-}aa}$ = Non-carcinogenic risk based target level for dermal contact and ingestion of soils and inhalation of vapors and particulates from soil [mg/kg]

Note: All parameters are defined under the individual pathway equations.

Note: $VF_{ss} = 0$ for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg.

where:

$RBTL_{c\text{-}sd\text{-}aa}$	=	Carcinogenic risk based target level for dermal contact with soil [mg/kg]
$RBTL_{nc\text{-}sd\text{-}aa}$	=	Non-carcinogenic risk based target level for dermal contact with soil [mg/kg]
TR	=	Target risk [-]
THQ	=	Target hazard quotient [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
ABS_d	=	Chemical-specific dermal absorption factor [-]
AF_c	=	Resident child soil to skin adherence factor [mg/cm^2-event]
AF_a	=	Resident adult soil to skin adherence factor [mg/cm^2-event]
RfD_d	=	Chemical-specific dermal reference dose [(mg/kg-day)]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day)$^{-1}$]
SA_{aa}	=	Age-adjusted skin surface area [mg/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
$SA_{soil\text{-}c}$	=	Resident child skin surface area available for contact with soil [cm^2]
$SA_{soil\text{-}a}$	=	Resident adult skin surface area available for contact with soil [cm^2]
$EV_{soil\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{soil\text{-}a}$	=	Resident Child event frequency [event/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

IRBCA Equation E-38	DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)
Carcinogenic effects $RBTL_{c-dw-aa} = \frac{TR \times AT_c \times 365 \times 10^6}{SF_d \times (DC_{w-c} \times Z_c + DC_{w-a} \times Z_a)}$ Non-carcinogenic effects $RBTL_{nc-dw-aa} = \frac{TR \times AT_{nc} \times 365 \times 10^6 \times RfD}{(DC_{w-c} \times Z_c + DC_{w-a} \times Z_a)}$ where : $DC_{w\text{-}c} = \frac{ED_c \times EF_c \times SA_{gw-c} \times EV_{gw-c}}{BW_c}$ $DC_{w\text{-}a} = \frac{ED_a \times EF_a \times SA_{gw-a} \times EV_{gw-a}}{BW_a}$	For organic chemicals, If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$ If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$ For inorganic chemicals, $Z = K_p \times t_{event}$ Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{c\text{-}dw\text{-}aa}$	=	Carcinogenic risk based target level for dermal contact with chemicals in groundwater [µg/L]
$RBTL_{nc\text{-}dw\text{-}aa}$	=	Non-carcinogenic risk based target level for dermal contact with chemicals in groundwater [µg/L]
TR	=	Target risk [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [$(mg/kg\text{-}day)^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
10^6	=	Conversion factor from cm^3 to L [cm^3/L] and mg to µg
t_{event}	=	Event duration [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]
$DC_{w\text{-}c}$	=	Child dermal contact rate with groundwater [cm^2-event/kg]
$DC_{w\text{-}a}$	=	Adult dermal contact rate with groundwater [cm^2-event/kg]
$EV_{gw\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{gw\text{-}a}$	=	Resident adult event frequency [event/day]
Z_c	=	Resident child chemical-specific dermal factor [cm/event]
Z_a	=	Resident adult chemical-specific dermal factor [cm/event]
$SA_{gw\text{-}c}$	=	Resident child skin surface area available for contact with water [cm^2]
$SA_{gw\text{-}a}$	=	Resident adult skin surface area available for contact with water [cm^2]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]

IRBCA Equation E-39	DOMESTIC WATER USE (AGE-ADJUSTED RESIDENT)

Carcinogenic effects (Ingestion and Dermal Contact)

$$RBTL_{c-(ing+dc)} = \frac{TR \times AT_c \times 365 \times 1000}{\left[(SF_o \times IR_{w-aa}) + \left(\frac{SF_d}{1000} \times (DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}\right)\right]}$$

Carcinogenic effects (Inhalation of Water Vapors)

$$RBTL_{c-inh} = \frac{TR \times AT_c \times 365 \times 24}{(ED_c \times EF_c \times ET_{in-c} + ED_a \times EF_a \times ET_{in-a}) \times K_f \times IUR}$$

Non-carcinogenic effects(Ingestion and Dermal Contact)

$$RBTL_{nc-(ing+dc)} = \frac{THQ \times AT_{nc} \times 365 \times 1000}{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa}\right) + \left(\frac{DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}}{RfD_d \times 1000}\right)\right]}$$

Non-carcinogenic effects(Inhalation of Water Vapors)

$$RBTL_{nc-inh} = \frac{THQ \times AT_{nc} \times 365 \times RfC \times 24 \times 1000}{(ED_c \times EF_c \times ET_{in-c} + ED_a \times EF_a \times ET_{in-a}) \times K_f}$$

$$DC_{wb\text{-}c} = \frac{ED_c \times EF_c \times SA_{wb-c} \times EV_{wb-c}}{BW_c} \quad \text{and} \quad DC_{wb\text{-}a} = \frac{ED_a \times EF_a \times SA_{wb-a} \times EV_{wb-a}}{BW_a}$$

For organic chemicals,

If $t_{wb\text{-}event} \leq t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: K_f = 0 for non-volatile chemicals (i.e., chemicals with a Henry's Law constant less than or equal to 1 x 10-5 atm-m3/mole or a vapor pressure less than or equal to 1 mm Hg)

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{c\text{-}(ing+dc)}$	=	Carcinogenic risk based target level for ingestion and dermal contact with domestic water [µg/L]
$RBTL_{c\text{-}inh}$	=	Non-carcinogenic risk based target level for inhalation of vapors from domestic water [µg/L]
$RBTL_{nc\text{-}(ing+dc)}$	=	Carcinogenic risk based target level for ingestion and dermal contact with domestic water [µg/L]
$RBTL_{nc\text{-}inh}$	=	Non-carcinogenic risk based target level for inhalation of vapors from domestic water [µg/L]
TR	=	Target risk [-]
THQ	=	Target hazard quotient [-]
AT_c	=	Averaging time for non-carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfC	=	Chemical-specific inhalation reference concentration [mg/m^3]
RfD_d	=	Chemical-specific dermal reference dose [mg/kg-day]
SF_o	=	Chemical-specific oral cancer slope or potency factor [(mg/kg-day)$^{-1}$]
IUR	=	Chemical-specific inhalation unit risk [(µg/m^3)$^{-1}$]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident child groundwater ingestion rate [L/day]
$IR_{w\text{-}a}$	=	Resident adult groundwater ingestion rate [L/day]
$DC_{wb\text{-}c}$	=	Child dermal whole-body contact rate with groundwater [cm^2-event/kg]
$DC_{wb\text{-}a}$	=	Adult dermal whole-body contact rate with groundwater [cm^2-event/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
ED_{aa}	=	Resident age-adjusted exposure duration [year]
EF_a	=	Exposure frequency for an adult [day/year]
ET_a	=	Exposure frequency for an adult [day/year]
K_f	=	Volatilization factor [L/m^3]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]

EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
365	=	Conversion factor [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]; and mg µg [µg/mg]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

For inhalation of vapors, dermal contact with, and ingestion of chemicals in water (domestic water use combined pathway) by age-adjusted resident,

Carcinogenic Effects

$$RBTL_{c-w-aa} = \frac{1}{\frac{1}{RBTL_{c\text{-}(ing+dc)}} + \frac{1}{RBTL_{c\text{-}inh}}}$$

Non-Carcinogenic Effects

$$RBTL_{nc-w-aa} = \frac{1}{\frac{1}{RBTL_{nc\text{-}(ing+dc)}} + \frac{1}{RBTL_{nc\text{-}inh}}}$$

where,

$RBTL_{c\text{-}w\text{-}aa}$	=	Carcinogenic risk based target level for domestic water use [mg/L]
$RBTL_{nc\text{-}w\text{-}aa}$	=	Non-carcinogenic risk based target level for domestic water use [mg/L]

IRBCA Equation	Description
E-49	VOLATILIZATION FACTORS (SURFICIAL SOIL TO OUTDOOR AIR)
E-50	VOLATILIZATION FACTORS (PARTICULAR EMISSIONS FROM SURFICIAL SOIL)
E-51	VOLATILIZATION/ATTENUATION FACTORS (SUBSURFACE SOIL VAPOR TO INDOOR AIR)
E-52	VOLATILIZATION FACTORS (SOIL VAPOR TO OUTDOOR AIR)
E-53	VOLATILIZATION FACTORS (GROUNDWATER TO INDOOR AIR)
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E-56	EFFECTIVE DIFFUSION COEFFICIENTS
E-57	SUBSURFACE SOIL CONCENTRATION PROTECTIVE OF LEACHING TO GROUNDWATER
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E-61	DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE
E-62	ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION
E-63	ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION FOR RESIDENT AND NON-RESIDENTIAL WORKER
E-64	STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

IRBCA Equation	Description
E-65	STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POD

IRBCA Equation E-49	VOLATILIZATION FACTORS (SURFICIAL SOIL TO OUTDOOR AIR)
$VF_{ss} = Q/C \times \frac{(3.14 \times D_A \times \tau)^{1/2}}{(2 \times \rho_s \times D_A)} \times 10^{-4}$ where: $D_A = \frac{\left(\theta_{as}^{10/3} \times D^a \times H + \theta_{ws}^{10/3} \times D^w\right)/\theta_T^2}{\rho_s \times K_{sv} + \theta_{ws} + \theta_{as} \times H}$ Source: USEPA, 2011. RST – User's Guide. USEPA, 1996. SSL: Technical Background Document	where: VF_{ss} = Volatilization factor from surficial soil to outdoor (ambient) air [kg-soil/m^3-air] Q/C = Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)] D_A = Apparent diffusivity [cm^2/s] τ = Averaging time for vapor flux [s] ρ_s = Vadose zone dry soil bulk density of surficial soil [g-soil/cm^3-soil] K_{sv} = Chemical-specific solid-water sorption coefficient [cm^3-water/g-soil] D_a = Chemical-specific diffusion coefficient in air [cm^2/s] D_w = Chemical-specific diffusion coefficient in water [cm^2/s] θ_T = Total soil porosity in the surficial soils [cm^3/cm^3-soil] θ_{as} = Volumetric air content in the surficial soils [cm^3-air/cm^3-soil] θ_{ws} = Volumetric water content in the surficial soils [cm^3-water/cm^3-soil] H = Chemical-specific Henry's Law constant [(L-water)/(L-air)] 10^{-4} = Conversion factor [m^2/cm^2] *Note: Surficial soil properties are assumed same as the vadose zone properties.*

IRBCA Equation E-50	VOLATILIZATION FACTORS (PARTICULAR EMISSIONS FROM SURFICIAL SOIL)
$$VF_p = \left[Q/C \times \frac{3600}{0.036 \times (1 - V) \times \left(U_m / U_t\right)^3 \times F(x)} \right]^{-1}$$ Source: Soil Screening Guidance, 1996	where: VF_p = Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air] Q/C = Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)] V = Fraction of vegetative cover [-] U_m = Mean annual wind speed [m/s] U_t = Equivalent threshold value of wind speed at 7 m [m/s] $F(x)$ = Function dependent on U_m/U_t derived using Cowherd *et al.* 1985 [-] 0.036 = Empirical constant [g/m^2-hr]

IRBCA Equation E-51	VOLATILIZATION/ATTENUATION FACTORS (SUBSURFACE SOIL VAPOR TO INDOOR AIR)
For advection and diffusion, $$\alpha_{sv} = \frac{\left[\left(\frac{D_T^{eff} \times A_B}{Q_{bldg} \times L_T}\right) \times \exp\left(\frac{Q_{soil} \times L_{crack}}{D_{crack}^{eff} \times A_{crack}}\right)\right]}{\left[\exp\left(\frac{Q_{soil} \times L_{crack}}{D_{crack}^{eff} \times A_{crack}}\right) + \left(\frac{D_T^{eff} \times A_B}{Q_{bldg} \times L_T}\right) + \left(\frac{D_T^{eff} \times A_B}{Q_{soil} \times L_T}\right)\left[\exp\left(\frac{Q_{soil} \times L_{crack}}{D_{crack}^{eff} \times A_{crack}}\right) - 1\right]\right]}$$ where, $$L_T = D_{source} - L_F$$ If $L_F > L_{crack}$, $A_B = (L_B \times W_B) + (2 \times L_F \times L_B) + (2 \times L_F \times W_B)$ If $L_F \leq L_{crack}$, $A_B = (L_B \times W_B)$ $$Q_{bldg} = \left(\frac{L_B \times W_B \times H_B \times ER}{3600}\right)$$ $$A_{crack} = 2 \times (L_B + W_B) \times w$$ $$Q_{soil} = \frac{2\pi \times \Delta P \times k_v \times X_{crack}}{\mu \times \ln\left(\frac{2Z_{crack}}{r_{crack}}\right)}$$	where, α_{sv} = Attenuation factor for soil vapor to indoor air [-] D_T^{eff} = Total overall effective diffusion coefficient [cm^2/s] A_B = Area of enclosed space below grade [cm^2] Q_{bldg} = Building ventilation rate [cm^3/s] L_T = Source to building separation [cm] Q_{soil} = Volumetric flow rate of soil-vapor into the enclosed space [cm^3/s] L_{crack} = Slab thickness [cm] D_{crack}^{eff} = Effective diffusion coefficient through the cracks [cm^2/s] A_{crack} = Area of total cracks [cm^2] D_{source} = Depth below grade to top of contamination [cm] L_F = Depth below grade to bottom of enclosed space floor [cm] L_B = Length of building [cm] W_B = Width of building [cm] Q_{bldg} = Building ventilation rate [cm^3/s] H_B = Height of building [cm] ER = Air exchange rate [l/h] 3600 = Conversion factor [sec/h] ΔP = Soil-building pressure differential [$g/cm\text{-}s^2$] k_v = Soil gas permeability[cm^2] X_{crack} = Floor-wall seam perimeter [cm] μ = Viscosity of air at soil temperature [g/cm-s] r_{crack} = Equivalent crack radius [cm] Z_{crack} = Crack depth below grade [cm]

$X_{crack} = 2 \times (L_B + W_B)$ $r_{crack} = \left(\frac{A_{crack}}{X_{crack}} \right)$ Source: USEPA, 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings.	

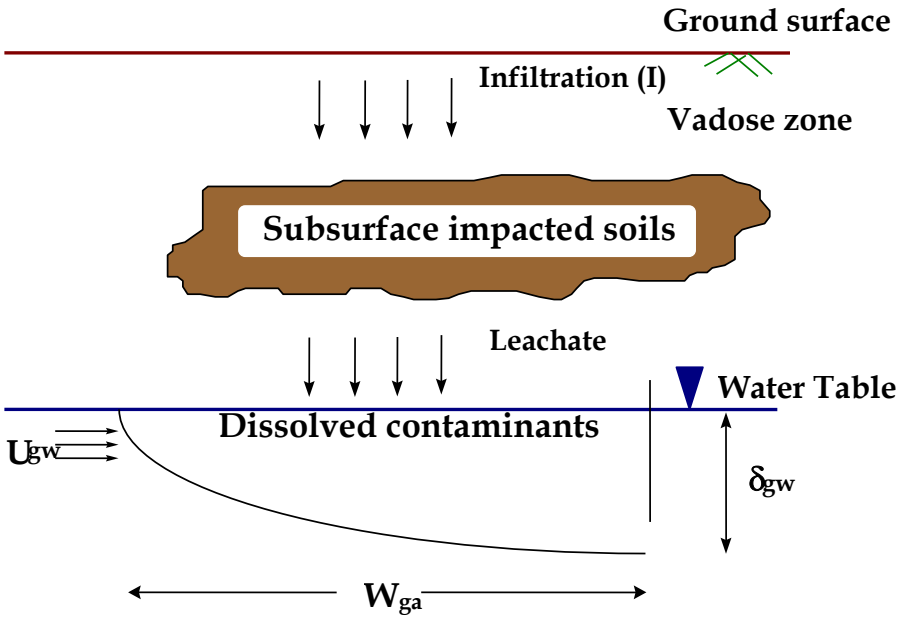
IRBCA Equation E-52	VOLATILIZATION FACTORS (SUBSURFACE SOIL VAPOR TO OUTDOOR AIR)
$$VF_{sv-out} = \left(1 + \frac{d_{sv} \times U_m \times \delta_a \times 100}{D_s^{eff} \times W_{sv}}\right)^{-1}$$ Source: Equation A-13 CCME 2014	where: $VF_{sv\text{-}out}$ = Volatilization factor from soil vapor to outdoor air [(mg/m^3-air)/(mg/L-water)] U_m = Mean annual wind speed [m/s] δ_a = Breathing zone height [cm] d_{sv} = Depth to soil vapor measurement [cm] D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] W_{sv} = Dimension of soil vapor source area parallel to wind direction [cm] *100* = Conversion factor [cm/m]

IRBCA Equation E-53	VOLATILIZATION FACTORS (GROUNDWATER TO INDOOR AIR)
$VF_{wesp} = H \times \alpha_{gw} \times 10^3$ Note: α_{gw} is calculated using equation for α_{sv} with depth to groundwater. Source: USEPA, 2004. User's Guide for Evaluating Subsurface Vapor Intrusion into Buildings.	where, VF_{wesp} = Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-water)] H = Vadose zone chemical specific Henry's Law constant [L-water/L-air] α_{gw} = Attenuation factor from groundwater to indoor 10^3 = Conversion factor [L/m^3]

IRBCA Equation E-55	VOLATILIZATION FACTORS (GROUNDWATER TO OUTDOOR AIR)
$$VF_{wamb} = \frac{H}{1 + \left(\frac{100 \times U_m \times \delta_a \times L_{GW}}{W_{ga} \times D_{ws}^{eff}} \right)} \times 10^3$$ Source: ASTM E1739-95	where: VF_{wamb} = Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)] H = Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)] U_m = Mean annual wind speed [m/s] δ_a = Breathing zone height [cm] L_{GW} = Depth to groundwater [cm] D_{ws}^{eff} = Effective diffusion coefficient between groundwater and soil surface [cm^2/s] W_{ga} = Dimension of soil source area parallel to wind direction [cm] 100 = Conversion factor [cm/m] 10^3 = Conversion factor [L/m^3]

IRBCA Equation E-56	EFFECTIVE DIFFUSION COEFFICIENTS
D_s^{eff} : effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] $$D_s^{eff} = D^a \times \frac{\theta_{as}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{ws}^{3.33}}{\theta_T^2}$$ where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil] θ_{ws} = Volumetric water content in vadose zone soils [cm^3-water/cm^3-soil] θ_T = Total soil porosity in the impacted zone [cm^3/cm^3-soil] H = Chemical-specific Henry's Law constant [L-water/L-air]	D_{ws}^{eff} : effective diffusion coefficient between groundwater and surface soil [cm^2/s] $$D_{ws}^{eff} = (h_{cap} + h_v) \times \left[\frac{h_{cap}}{D_{cap}^{eff}} + \frac{h_v}{D_s^{eff}} \right]^{-1}$$ where: h_{cap} = Thickness of capillary fringe [cm] h_v = Thickness of vadose zone [cm] D_{cap}^{eff} = Effective diffusion coefficient through capillary fringe [cm^2/s] D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s] L_{GW} = Depth to groundwater ($h_{cap} + h_v$) [cm]
D_{cap}^{eff} : effective diffusion coefficient for the capillary fringe [cm^2/s] $$D_{cap}^{eff} = D^a \times \frac{\theta_{acap}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcap}^{3.33}}{\theta_T^2}$$ where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] θ_{acap} = Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil] θ_{wcap} = Volumetric water content in capillary fringe soils [cm^3-water/cm^3-soil] θ_T = Total soil porosity [cm^3/cm^3-soil] H = Chemical-specific Henry's Law constant [L-water/L-air]	D_{crack}^{eff} : effective diffusion coeff. through foundation cracks [cm^2/s] $$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^2} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^2}$$ where: D^a = Chemical-specific diffusion coefficient in air [cm^2/s] D^w = Chemical-specific diffusion coefficient in water [cm^2/s] θ_{acrack} = Volumetric air content in foundation/wall cracks [cm^3-air/cm^3-total volume] θ_{wcrack} = Volumetric water content in foundation/wall cracks [cm^3-water/cm^3-total volume] θ_T = Total soil porosity [cm^3/cm^3-soil] H = Chemical-specific Henry's Law constant [L-water/L-air]

Source: ASTM E1739-95

IRBCA Equation E-57	SUBSURFACE SOIL CONCENTRATION PROTECTIVE OF LEACHING TO GROUNDWATER
	$$RBTL_{SL} = \frac{RBTL_w}{LF_{sw} \times 1000}$$ 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 [ug/L-water] LF_{SW} = Leaching factor (from subsurface soil to groundwater) [(mg/L-water)/(mg/kg-soil)] 1000 – Conversion Factor [µg to mg] Source: ASTM E1739-95

IRBCA Equation E-58	LEACHING FACTOR FROM SUBSURFACE SOIL TO GROUNDWATER

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

where:

LF_{SW}	=	Leaching factor from subsurface soil to groundwater [(mg/L-water)/(mg/kg-soil)]
ρ_s	=	Vadose zone dry soil bulk density [g-soil/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-water/cm^3- soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-water/g-soil]
H	=	Chemical-specific Henry's Law constant [L-water/L-air]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw}	=	Ki = Groundwater Darcy velocity [cm/yr]
K	=	Hydraulic conductivity of the saturated zone [cm/year]
i	=	Hydraulic gradient in the saturated zone [-]
δ_{gw}	=	Groundwater mixing zone thickness [cm]
I	=	Infiltration rate of water through vadose zone [cm/year]
W_{ga}	=	Groundwater dimension parallel to groundwater flow direction [cm]

This equation consists of two parts (i) the Summer's model and (ii) equilibrium conversion of the leachate concentration to a soil concentration on a dry weight basis.

Source: ASTM E1739-95

IRBCA Equation E-59	SOIL CONCENTRATION AT WHICH DISSOLVED PORE WATER AND VAPOR PHASES BECOME SATURATED

Single Component

$$C_s^{SAT} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv} \times \rho_s]$$

where:

C_s^{SAT} = Soil concentration at which dissolved pore water and vapor phases become saturated [(mg/kg-soil)]
S = Pure component solubility in water [mg/L-water]
S_{ei} = Effective solubility of component i in water = $x_i \times S$ [mg/L-water]
x_i = Mole fraction of component $i = (w_i \times MW_{avg})/MW_i$ [-]
w_i = Weight fraction of component i [-]
MW_{avg} = Average molecular weight of mixture [g/mole]
MW_i = Molecular weight of component i [g/mole]
ρ_s = Vadose zone dry soil bulk density [g-soil/cm^3-soil]
H = Chemical-specific Henry's Law constant [L-water/L-air]
θ_{as} = Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-water/cm^3- soil]
K_{sv} = $f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-water/g-soil]
f_{ocv} = Fraction organic carbon in vadose zone [g-C/g-soil]

Source: ASTM E1739-95

IRBCA Equation E-60	SOIL VAPOR CONCENTRATION AT WHICH VAPOR PHASE BECOMES SATURATED

Single Component

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

where:

C_v^{SAT}	=	Soil vapor concentration at which vapor phase become saturated [mg/m^3-air]
P^s	=	Saturated vapor pressure [atm]
P_i^s	=	Effective vapor pressure of component *i* in water = $x_i \times P^s$ [atm]
R	=	Ideal gas constant [0.08206 atm•L/mol•K]
T	=	Temperature [K]
S_{ei}	=	Effective solubility of component *i* in water = $x_i \times S$ [mg/L-water]
x_i	=	Mole fraction of component *i* = $(w_i \times MW_{avg})/MW_i$ [-]
w_i	=	Weight fraction of component *i* [-]
MW	=	Molecular weight of the chemical [g/mole]
ρ_s	=	Vadose zone dry soil bulk density [g-soil/cm^3-soil]
10^6	=	Conversion factor [(g/L)/(mg/m^3)]

Source: ASTM E1739-95

IRBCA Equation E-61	DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-vt)\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]}{2\sqrt{\alpha_x\times v\times t}}\right]\times$$

$$\left[erf\left[\frac{(y+Y/2)}{2\sqrt{\alpha_y x}}\right]-erf\left[\frac{(y-Y/2)}{2\sqrt{\alpha_y x}}\right]\right]\times\left[erf\left[\frac{(z+Z)}{2\sqrt{\alpha_z x}}\right]-erf\left[\frac{(z-Z)}{2\sqrt{\alpha_z x}}\right]\right]$$

where:

C	=	Dissolved-phase concentration [mg/L]
C_o	=	Dissolved-phase concentration at the source (at x=y=z=0) [mg/L]
v	=	Retarded seepage velocity [m/sec]
λ	=	Overall first order bio-decay rate [1/day]
α_x	=	Longitudinal dispersivity [m]
α_y	=	Lateral dispersivity [m]
α_z	=	Vertical dispersivity [m]
x, y, z	=	Spatial coordinates [m]
t	=	Time [day]
x	=	Distance along the centerline measured from the downgradient edge of the groundwater source [m]
Y	=	GW source dimension perpendicular to GW flow direction [m]
Z	=	GW source (mixing zone) thickness [m]
DA F_{sat}	=	$C_o/C(x)$

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]\right]\times erf\left[\frac{Y}{4\sqrt{\alpha_y x}}\right]\times erf\left[\frac{Z}{2\sqrt{\alpha_z x}}\right]$$

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

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

Note: Compare to ASTM E1739-95, p. 31, where $Y = S_w$ $Z = S_d$, $v = u$, and $C_o = C_{source}$

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

IRBCA Equation E-62	ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target groundwater concentration at the POE} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

IRBCA Equation E-63	ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION FOR RESIDENT AND NON-RESIDENTIAL WORKER

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{DAF_{POD}}$$

where:

POD	=	Point of demonstration
DAF_{bldg}	=	Dilution attenuation factor between the on/off-site building and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration below on/off-site building is expressed in mg/L-water

IRBCA Equation E-64	STREAM PROTECTION: ALLOWABLE GROUNDWATER CONCENTRATION AT THE POINT OF DISCHARGE

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

$$Q_{gw} = \left(Z + \sqrt{\alpha_z X_s}\right) \times \left(Y + 2\sqrt{\alpha_y X_s}\right) \times U_{gw}$$

where:

Q_{gw}	=	Impacted groundwater discharge into the stream [ft^3/day]
C_{gw}	=	Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
Q_{sw}	=	Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft^3/day]
C_{sw}	=	Allowable concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
C_{su}	=	The COCs' concentration upstream of the groundwater plume discharge [mg/L]
Y	=	GW source dimension perpendicular to GW flow direction [ft]
Z	=	GW source (mixing zone) thickness [ft]
α_y	=	Lateral dispersivity [ft]
α_z	=	Vertical dispersivity [ft]
X_s	=	Distance from the downgradient edge of the groundwater source to the stream [ft]
U_{gw}	=	Darcy velocity [ft/day]

IRBCA Equation E-65	STREAM PROTECTION: ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION AT THE SOURCE & POD

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target concentration at the POE [mg/L]} \times \frac{DAF_{POE}}{DAF_{POD}}$$

where:

POE	=	Point of exposure
POD	=	Point of demonstration
DAF_{POE}	=	Dilution attenuation factor between the point of exposure and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and the source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

For calculation of DAF_{POE} and DAF_{POD}, please refer to Domenico's model.

Active Remediation: Actions taken to reduce the concentrations and mass of chemical(s) of concern.

Activity and Use Limitations (AULs): Mechanisms or controls that ensure that exposure pathways to COCs, through current or reasonable future uses, are not complete for as long as the COCs pose an unacceptable risk to human health or the environment.

Acute Exposure: A single, brief exposure, usually less than 24 hours in duration.

Acute Toxicity: The ability of a substance to cause adverse health effects as a result of an acute exposure.

Additivity of Risk: Sum of risk for all complete pathways for each chemical.

Bioconcentration Factor: The ratio of the concentration of a chemical in a given organism to its 'concentration in the surrounding medium (water, soil, etc.).

Bioavailibility: The rate and extent of systemic absorption of a chemical.

Chronic exposure: Repeated or continuous exposure occurring over an extended period.

Chronic Toxicity: The ability of a substance to cause adverse health effects as a result of chronic exposure.

Contaminant: Any undesired physical, chemical, biological, or radiological substance that is present in the air, water, soil, soil gas or sediment due to anthropogenic activities.

Natural Attenuation: The reduction in concentrations of chemical(s) of concern in the environment due to naturally occurring processes such as diffusion, dispersion, absorption, chemical degradation, biodegradation etc.

Cancer Slope Factors (CSF): A conservative dose-response metric derived from human or animal studies used to calculate cancer risk. CSFs are typically developed by USEPA and represent the increase in lifetime cancer risk per unit dose, with the CSF in units of 1/ (mg/kg-day).

Chemical(s) of Concern: Specific contaminants that are identified for quantitative evaluation in the risk assessment process and are deemed to be related to anthropogenic activities at the site.

Conceptual Site Model: A graphical or a descriptive representation of all the complete routes of exposure, impacted media and the chemicals of concern.

Corrective Action: The sequence of actions that include site assessment, interim remedial action, remedial action, operation and maintenance of equipment, monitoring of progress, and termination of the remedial action.
7Q10: The average minimum flow of a stream during seven consecutive days that has a probable recurrence interval of once- in-ten years.

Cumulative site-wide risk: Sum of risk for all chemicals and all complete routes of exposure.

Dermal Absorption: The process by which a chemical penetrates the skin and enters the body.

Dermal Exposure: Contact between a chemical and the skin.

Dermal Toxicity: Adverse effects of a toxicant on the skin.

Detection Limit: The lowest concentration of a chemical that can be distinguished from zero or background for a specific analytical method.

Dilution Attenuation Factor (DAF): Represents the reduction in the concentration due to the influence of natural attenuation processes as a chemical migrates through the media. The numerical factor by which a contaminant concentration is diminished as the contaminant moves through soil and groundwater from its source to the point of contact. Attenuating effects include adsorption of the contaminant onto soil and aquifer media, chemical transformation, biological degradation, and dilution from mixing of the leachate with ambient groundwater, etc.

Direct Exposure Pathway: An exposure pathway where the point of exposure is at the source, without a release to any other medium.

Ecological Assessment: A qualitative appraisal of the actual or potential effects of chemical(s) of concern on the ecological receptors: plants and animals and their habitats.

Ecological receptor: A living organism e.g. fauna and flora other than a human being and domestic species.

Engineering Controls: Modifications to a site or facility (for example, slurry walls, capping, and point of use water treatment) to reduce or eliminate the potential for exposure to a chemical(s) of concern.

Exposure: Contact of an organism with chemical(s) of concern at the exchange boundaries (for example, skin, lungs, and liver) and available for absorption.

Exposure Area: Geographical areas located within a larger site that has similar exposure characteristics. Typically, within an exposure area, a receptor would be exposed to COCs by multiple exposure pathways.

Exposure Assessment: The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.

Exposure Pathway: Physical migration of contaminants from sources to the receptor. An exposure pathway describes a unique mechanism by which an individual or population (human and ecological receptor or ecological habitat) is exposed to a chemical(s) of concern and its byproducts originating from a site. Each exposure pathway includes a source or release from a source, a point of exposure, an exposure route and a receptor. If the exposure point is distant from the source, a transport/exposure medium (for example, air) or media also is included.

Exposure Route: The manner in which a chemical(s) of concern comes in contact with an organism (for example, ingestion, inhalation, and dermal contact).

Facility: The property containing the source of the chemical(s) of concern where a release has occurred.

Habitat: A place where an ecological receptor such as an animal or plant normally lives, reproduces, and hibernates.

Hazard Index: The sum of two or more hazard quotients (HQ) for multiple chemical(s) of concern or multiple exposure pathways, or both and can be used to predict the non-cancer risk of simultaneous exposure of a receptor to several chemicals.

Hazard Quotients: The ratio of the dose to the reference dose for that chemical.

Hot Spot: Highly contaminated areas which present a potential risk to human health and the environment. In some cases the hot-spot is the location of the source of pollution or the area with the highest concentrations at the site.

Hydraulic Conductivity: The volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hyporheic Zone: Region beneath and adjacent to streams and rivers where surface and groundwater mix.

Incremental Carcinogenic Risk Levels: The potential for incremental carcinogenic human health effects due to exposure to the chemical(s) of concern.

Indirect Exposure Pathways: An exposure pathway where there exists at least one media (soil, groundwater, air) between the source and the point(s) of exposure. To quantify dose and risk evaluation for such a pathway requires the application of a model.

Institutional Controls: The restriction on use or access (for example, fences, deed restrictions, restrictive zoning) to a site or facility to eliminate or minimize potential exposure to a chemical(s) of concern.

Interim Remedial Action: The course of action to mitigate fire and safety hazards and to prevent further migration of hydrocarbons in their vapor, dissolved, or liquid phase.

Integrated Exposure Uptake Biokinetic Model- IEUBK: A model developed by the USEPA to predict blood lead concentrations in children resulting from exposure to lead in soil and other sources.

Integrated Risk Information System (IRIS): A USEPA electronic database containing toxicity values (e.g., reference doses and slope factors) and other details for each chemical.

Karst: A distinctive set of geomorphic landforms resulting from the development of extensive subsurface solution channels and caves in carbonate rocks (Boulding, 1995).

K_d: Soil-water organic partition coefficient for organics.

LC50: Median Lethal Concentration. The concentration of a toxicant that is lethal to 50 percent of the test organisms within a designated period of time.

LD50: Median Lethal Dose. The dose of a toxicant that is lethal to 50 percent of the test organisms within a designated period of time.

Lowest Observable Adverse Effect Level (LOAEL): The lowest dose of a chemical observed to cause an adverse effect.

Long-Term Stewardship: An appropriate system of controls, institutions and information necessary to fully protect human health and the environment into perpetuity with demonstrated ability and feasible registration, long-term control by the authorities, including municipal authorities and their enforcement.

Maximum Contaminant Level (MCL): A standard for drinking water established by USEPA under the Safe Drinking Water Act, which is the maximum permissible level of chemical(s) of concern in water that is delivered to any user of a public water supply. In Israel these levels are called: IWDS- Israeli Water Drinking Standard.

Mixing Zone: An area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met.

Natural Biodegradation: The reduction in concentration of chemical(s) of concern through naturally occurring microbial activity.

Non-Residential "Commercial/Industrial Land Use": The use of land for the primary purpose of buying, selling or trading of merchandise or services including, without limitation, shopping malls, office complexes, restaurants, hotels, motels, grocery stores, automobile service stations, petroleum distribution operations, dry cleaning operations, municipal yards, warehouses, law courts, museums, golf courses, government offices, air and sea terminals, bus and railway stations, and storage associated with these uses.

No Observable Adverse Effect Level (NOAEL): The highest dose of a chemical that does not produce an observable adverse health effect.

Off-site: Areas beyond the site that can potentially become contaminated.
Point of Demonstration: A point located between the source and the point of exposure where measurements are made to predict the concentrations at the POE.

Point of Exposure: The point where exposure occurs i.e., the location where chemicals enter the human body or the body of the ecological receptor or its habitat.

Practical Quantitation Limit: Lowest concentration that can be reliably quantified within specified limits of precision and accuracy during routine laboratory operating conditions.

Preliminary Remediation Goals (PRGs): risk-based concentrations developed by USEPA R IX. These were replaced by Regions 3/6/9 Regional Screening Levels (RSLs).

Qualitative Risk Analysis: A nonnumeric evaluation of a site to determine potential exposure pathways and receptors based on known or readily available information.

Reasonable Maximum Exposure (RME): The highest exposure that is reasonably expected to occur at a site. RMEs are estimated for individual pathways or a combination of exposure pathways.

Reasonable Potential Exposure Scenario: A situation with a credible chance of occurrence where a receptor may become directly or indirectly exposed to the chemical(s) of concern without considering extreme or essentially impossible circumstances.

Reasonably Anticipated Future Use: Future use of a site or facility that can be predicted with a high degree of certainty given current use, local government planning, and zoning.

Receptor: Human, structures, utilities, surface waters, seawater, sediments and ecological risk receptors (flora and fauna and their habitats) which may be adversely affected by a release and potentially be subject to damage by exposure to COCs and/or their by products via ingestion, inhalation, or absorption or dermal contact. This definition also specifically includes water-supply wells because it must be assumed that humans will be ingesting the water from these wells.

Residential Land Use: The use of land for the primary purpose of (a) a residence by persons on a permanent, temporary or seasonal basis, including, without limitation, single family dwellings, cabins, apartments, condominiums or townhouses, or (b) institutional facilities, including, without limitation, schools, hospitals, daycare operations, prisons, community centers, places of worship (synagogues, mosques, churches).

Reference Concentration (RfC): An estimate of the concentration of a toxicant that is likely to be without appreciable risk of adverse effects during a lifetime of continuous exposure.

Reference Dose (RfD): A preferred toxicity value for evaluating potential non-carcinogenic effects in humans resulting from exposure to a chemical(s) of concern. If the threshold for the most sensitive health effect can be identified - the effect that occurs at the lowest dose - limiting exposure to produce doses below that threshold should protect against all of the effects of the chemical. This concept is the basis for the USEPA reference dose (RfD).

Remediation/Remedial Action: Activities conducted to protect human health, safety, and the environment. These activities include evaluating risk, site cleanup, making no-further-action determinations, monitoring controls, engineering controls, and designing and operating cleanup equipment.

Remediating Party: All entities and their designees, collectively and generically, such as responsible parties, development interests, landowners and others directly involved in the remediation of a particular contaminated site

Representative Concentration: The concentration that represents the effective concentration to which a receptor is exposed by a specified pathway.

Risk Assessment: An analysis of the potential for adverse health effects caused by chemical(s) of concern at a site to determine the need for remedial action or the need to develop target levels to design remedial action.

Risk Reduction: The lowering or elimination of the level of risk posed to human health or the environment through interim remedial action, remedial action, or institutional or engineering controls.

Risk-Based Screening Level/Screening Levels (RBSLs): Risk-based site-specific corrective action target levels for chemical(s) of concern developed under the Tier 1 evaluation.

Route of Exposure: The manner or mechanism by which a COC affects a receptor, for example, ingestion or inhalation

Sensitivity Analysis: Evaluation of the calculated risk or target levels for different alternatives of possible input parameters.

Site: The area(s) defined by the extent of migration of the chemical(s) of concern - areal extent of contamination.

Site Assessment: An evaluation of subsurface geology, hydrology, and surface characteristics to determine if a release has occurred, the levels of the chemical(s) of concern, and the extent of the migration of the chemical(s) of concern. The site assessment collects data on groundwater quality and potential receptors and generates information to support remedial action decisions.

Site Classification: A qualitative evaluation of a site based on known or readily available information to identify the need for interim remedial actions and further information gathering. Site classification is intended to specifically prioritize sites.

Site Specific Target Levels (SSTLs): Risk-based remedial action target levels for chemical(s) of concern developed for a particular site under the Tier 2 and Tier 3 evaluations.

Site-Specific: Activities, information, and data unique to a particular site.

Sources: Points of entry of contaminants into possible exposure pathways. In the case of hydrocarbons and chlorinated organic compounds releases, the non-

aqueous phase liquid (NAPL) which can either dissolve into the aqueous phase or volatilize into the gaseous phase constitutes a source. Primary sources include underground tanks and associated piping, lagoons, landfills etc. For risk assessment purposes, as an example, the dissolved plume in groundwater may be the source for the inhalation exposure pathway.

Source Area(s): Either the location of liquid hydrocarbons or the location of highest soil and groundwater concentrations of the chemical(s) of concern.

Surficial Soil: The upper layer of the soil, between ground level and a predetermined depth (see text).

Subsurface Soil: The soil layer between the bottom of the surficial soil layer and the water table.

Target Levels: Numeric values or other performance criteria that are protective of human health, safety, and the environment.

Tier 1 Risk Assessment: A risk-based analysis to develop non-site-specific values for direct and indirect exposure pathways utilizing conservative exposure factors and fate and transport for potential pathways and various property use categories (for example, residential, commercial, and industrial uses). Values established under Tier 1 will apply to all sites that fall into a particular category.

Tier 2 Risk Assessment: A risk-based analysis applying the direct exposure values established under a Tier 1 risk assessment at the point(s) of exposure developed for a specific site and development of values for potential indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

Tier 3 Risk Assessment: A risk-based analysis to develop values for potential direct and indirect exposure pathways at the point(s) of exposure based on site-specific conditions.

95% UCL: Upper confidence limit of the average. Several methods are available for calculating a 95% UCL on the mean for a set of data. However, the performance of these methods varies dramatically and is dependent on the nature of the data set (e.g., number of values, their distribution and variability, the extent of censoring). For calculating 95% UCL values, IRBCA recommends using the most recent version of USEPAs ProUCL tool.

User: An individual or group involved in the RBCA process including owners, operators, regulators, underground storage tank (UST) fund managers, attorneys, consultants, legislators, and so forth.

Very Strict Levels (VSLs): The MoEP default cleanup levels that allow unrestricted land use. They are determined according to land use.

Volatilization Factor: A measure of the process of transfer of a chemical from the aqueous or liquid phase to the gas phase under specific environmental conditions and exposure durations.

APPENDIX G
GUIDELINES FOR CALCULATING UPPER CONFIDENCE LIMITS (UCL) FOR AN ENVIRONMENTAL DATA SET

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APPENDIX G
GUIDELINES FOR CALCULATING UPPER CONFIDENCE LIMITS FOR AN ENVIRONMENTAL DATA SET

1. Background

This document describes the general approach to calculate the representative concentration of chemicals of concern in environmental media. The IRBCA guidance document allows the representative concentrations to be calculated using the 95% upper confidence limit (UCL) of the arithmetic mean of the data set, provided that the data set is comprised of a sufficient number and quality of samples. The IRBCA Guidance documents recommends the use of USEPA ProUCL software and accompanying user guide and guidance documents to calculate 95% upper confidence limit of an environmental data set. Please note that the ProUCL is periodically updated and the user should use the most current software version.

2. Definitions

Background Measurements – Measurements that are not site-related or impacted by site activities. Background sources can be naturally occurring or anthropogenic (man-made).

Bias – The systematic or persistent distortion of a measured value from its true value (this can occur during sampling design, the sampling process, or laboratory analysis).

Bootstrap Method – The bootstrap method is a computer-based method for assigning measures of accuracy to sample estimates. This technique allows estimation of the sample distribution of almost any statistic using only very simple methods. Bootstrap methods are generally superior to

ANOVA for small data sets or where sample distributions are non-normal.

Confidence Limit – The lower or an upper boundary of a confidence interval. For example, the 95% upper confidence limit (UCL) is given by the upper bound of the associated confidence interval.

Coverage, Coverage Probability – The coverage probability (e.g., = 0.95) of an upper confidence limit (UCL) of the population mean represents the confidence coefficient associated with the UCL.

Detection Limit – A measure of the capability of an analytical method to distinguish samples that do not contain a specific analyte from samples that contain low concentrations of the analyte. It is the lowest concentration or amount of the target analyte that can be determined to be different from zero by a single measurement at a stated level of probability. Detection limits are analyte and matrix-specific and may be laboratory-dependent.

Exposure Point Concentration (EPC) – The constituent concentration within an exposure unit to which the receptors are exposed. Estimates of the EPC represent the concentration term used in exposure assessment.

Level of Significance (α) – The error probability (also known as false positive error rate) tolerated of falsely rejecting the null hypothesis and accepting the alternative hypothesis.

Mean – The sum of all the values of a set of measurements divided by the number of values in the set; a measure of central tendency.

Median – The middle value for an ordered set of n values. It is represented by the central value when n is odd or by the average of the two most central

values when n is even. The median is the 50th percentile.

Non-Detect (ND) Values – Samples being reported below the laboratory analytical detection limits. Non-Detects may correspond to values that are zero (0) or the analytical reporting limit.

Normal Distribution – An arrangement of a data set in which most values cluster in the middle of the range and the rest taper off symmetrically toward either extreme (bell-curve shaped graph).

Outliers – Values in a data set that are not representative of the set as a whole, usually because they are very large relative to the rest of the data. The presence of outliers distorts most statistics if used in any calculations.

Probability Values (p-value) – In statistical hypothesis testing, the p-value associated with an observed value, tobserved of some random variable T used as a test statistic is the probability that, given that the null hypothesis is true, T will assume a value as or more unfavorable to the null hypothesis as the observed value tobserved. The null hypothesis is rejected for all levels of significance, α greater than or equal to the p-value.

3. Downloading and Running ProUCL

ProUCL Version 5.1 User Guide: Proucl_5.1_user-guide.pdf

ProUCL Software Download: ProUCL Software Download

Installation Instructions

{Requires the use of Winzip or equivalent to unzip the files}

1. Download and save SETUP.zip to any directory. Note: You can delete this file when the installation is complete if desired and always re-download the latest version of ProUCL 5.1 from this website.

2. Run SETUP.zip Double-Click on SETUP.zip or using Run option (Start gets you to that option), browse to the directory setup.zip was saved to and run it by finding it using the "all files" (not Programs) choices of files to open.

3. Unzip and install from SETUP.zip to a Root Directory or Folder where you wish to install ProUCL 5.1. This will create a directory named ProUCL 5.1; add all the necessary files; create two subdirectories, adding sample data to one and documentation to the other.

4. You can create a shortcut by dragging the program (ProUCL.exe) to where you want the shortcut

5. Run ProUCL 5.1 by double clicking the program or the shortcut if you created one (You can now delete the file SETUP.exe if desired).

Minimum Hardware Requirements

- Intel Pentium 1.0 GHz
- 45 MB of hard drive space
- 512 MB of memory (RAM)
- CD-ROM drive or internet connection
- Windows XP (with SP3), Vista (with SP1 or later), and Windows 7

ProUCL 5.1.00 will function but some titles and some Graphical User Interfaces (GUIs) will need to be scrolled. Definition without color will be marginal.

- Minimum graphics display of 800 by 600 pixels
- Basic Color is preferred

4. Frequently Asked Questions

What are the minimum sample size requirements to calculate 95% UCL of the arithmetic mean of the data set?

The ProUCL guidance documents suggest a minimum data set size of 10 when the calculating the upper limits.

Can I calculate 95% UCL on a data set representing site background values?

Yes, however, a few elevated statistical outliers present in a background data set may actually represent potentially contaminated locations within the site. Those elevated outliers may not be coming from the background population under evaluation. Since the presence of outliers in a data set tend to yield distorted or misleading values of the decision making statistics (eg. UCL), elevated outliers should not be included in the background data sets and estimation of site background values. The objective here is to compute background statistics based upon a data set which represents the main background population without outliers. A background data set should have a minimum of 10 observations, however more observations is preferable.

Should the data set include sample concentrations from different soil depths and soil types?

Yes. The data set collected from a site population (eg. Exposure area) should be representative of the population under investigation. Depending upon the areas under investigation, different soil depths and soil types may be considered as representing different statistical populations. In such cases, background versus site comparisons may have to be conducted separately for each of those sub-populations (surface soil, sub-surface layers, soil types etc…). Comparing depths and soil types should be considered in the planning stages when

developing sampling plan. Specifically, the availability of an adequate amount of representative data is required from each of those sub-populations/strata defined by the sample depth, soil types or other characteristics.

Should ProUCL be used to calculate 95%UCL of the mean on discrete samples or composite samples?

ProUCL can be used for discrete sample data sets as well as on composite sample data sets. However, in a data set (background or site), samples should be either all discrete or all composite.

Can I calculate 95%UCL of the mean on a data set that contains non-detect observations?

Yes, non-detect (ND) observations are inevitable in most environmental data sets. In practice, ND values are replaced with analytical detection limits or reporting limits.

How should I calculate representative concentration when there is a low frequency of detection at my site?

When the number of detected values is small, it is preferable to use other methods rather than using statistical methods to compute representative concentrations. Specifically, for data sets considting of <4 detects and for small data sets (sample size <10) with low detection frequency, the risk assessor should use an alternative method to calculate the representative concentration on a site-specific basis (eg. maximum concentration).

Should field duplicates be included in the data set?

ProUCL does not pre-process field duplicates. The risk assessor should determine how field duplicates are used. Documentation should be provided to the MoEP. The user is advised to refer to the appropriate MoEP guidance documents related to collection and use of field duplicates.

Can ProUCL be used for other environmental applications?

The use of ProUCL for other environmental applications must be approved by the MoEP and Water Authority prior to its use. The ProUCL has been used to determine compliance assessment of groundwater monitoring well, contaminated pile sampling, verification sampling after excavation, identification of hot spots etc… Users should refer to the ProUCL guidance and technical documents for instruction.

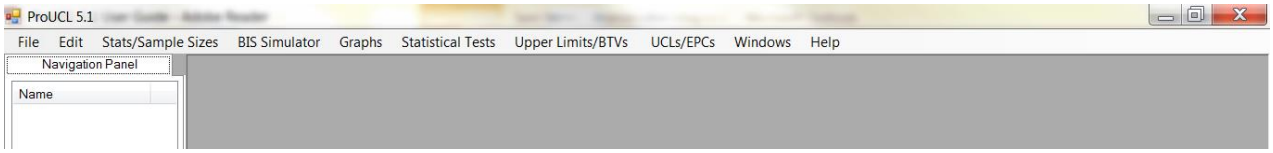
What if my Data Set is not Normal?

The ProUCL software can calculate UCL for a data set that is normally distributed **(**i.e. symmetrical about the mean following a bell curve) and not-normally distributed. The user is responsible for selecting an appropriate choice for the data distribution: Normal, Gamma, Lognormal, or Nonparametric (non-discernible distribution). It is desirable that user determines data distribution using the Goodness-of-Fit test option prior to using the UCL option. The UCL output sheet also informs the user if data are normal, gamma, lognormal, or a non-discernible distribution. Program computes statistics depending on the user selection.

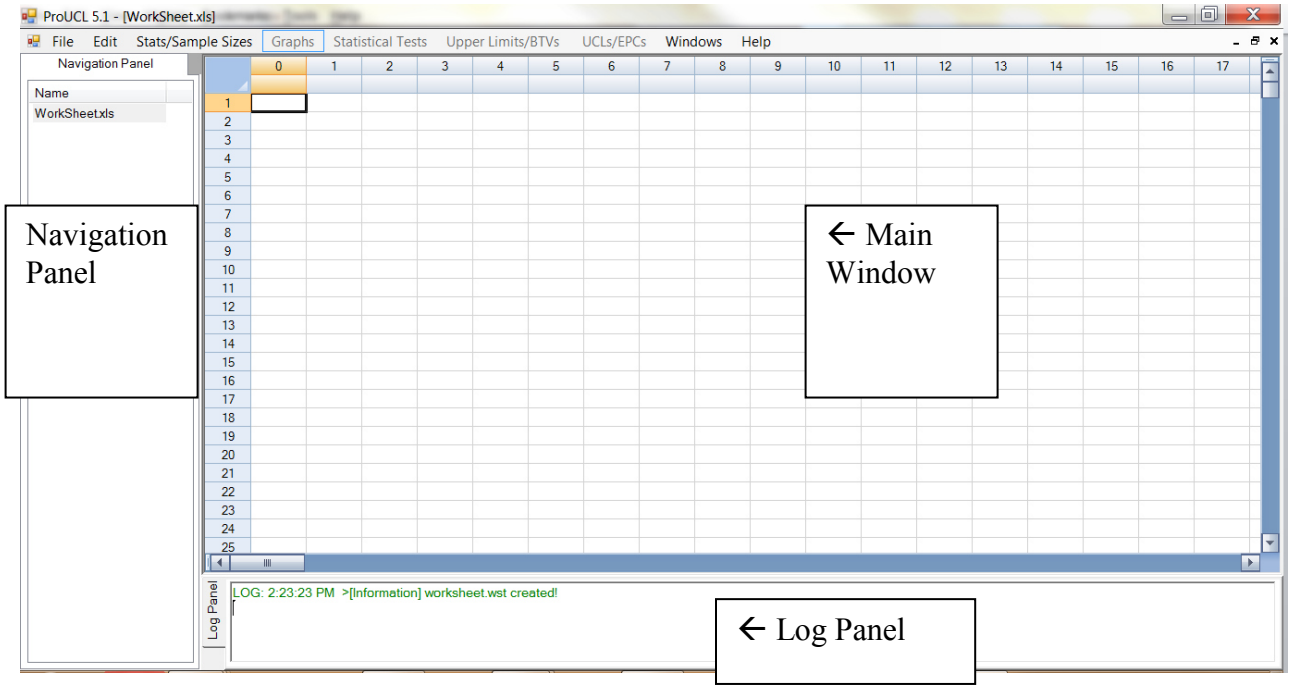
Using ProUCL Software[1]

Creating a New Data Set

The following file options will appear when the ProUCL software is executed.



By choosing the **File ► New** option, a new worksheet shown below will appear. The user enters variable names and data following the ProUCL input file format requirements described below.



The above screen consists of three main window panels:

The **MAIN WINDOW** displays data sheets and outputs results from the procedure used.

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[1] *ProUCL 5.1 User Guide, Statistical Software for Environmental Applications for Data Sets with and without Nondetect Observations, USEPA, EPA/600/R-07/041, October 2015*

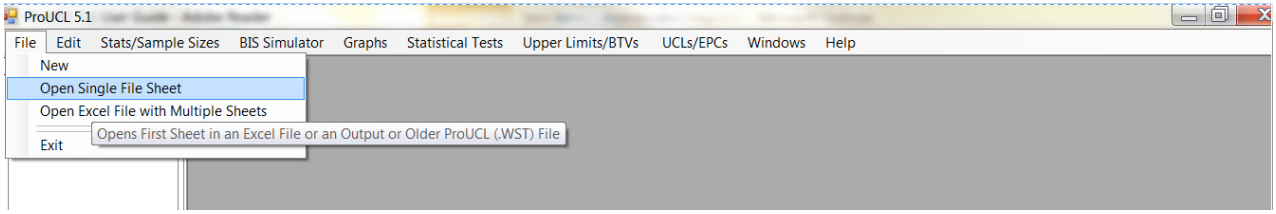
The **NAVIGATION PANEL** displays the name of data sets and all generated outputs.

The **LOG PANEL** displays transactions in green, warning messages in orange, and errors in red. For an example, when one attempts to run a procedure meant for left-censored data sets on a full-uncensored data set, ProUCL 5.1 will output a warning in orange in this panel.

Should both panels be unnecessary, you can choose **Configure ► Panel ON/OFF**.

Opening an Existing Data Set

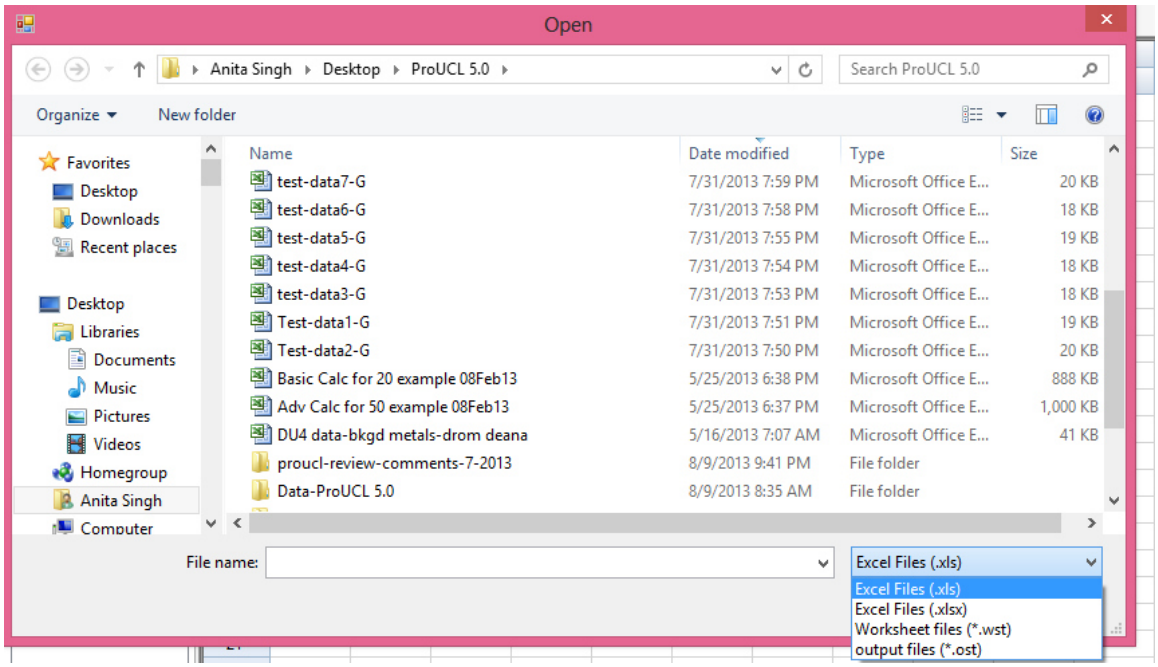
The user can open an existing worksheet (*.xls, *.xlsx, *.wst, and *.ost) by choosing the **File ► Open Single File Sheet** option. The following drop down menu will appear:



Choose a file by selecting the type of file such as **.xls** as shown below. This option can also be used to read in a *.wst worksheet and *.ost output sheet generated by earlier versions (e.g., ProUCL 4.1 and older) of ProUCL.

By choosing the **File ► Excel Multiple Sheets** option, the user can open an Excel file consisting of multiple sheets. Each sheet will be opened as a separate file to be processed individually by ProUCL.

Caution: If you are editing a file (e.g., an excel file using Excel), make sure to close the file before importing the file into ProUCL using the file open option.



Input File Formats

- The program can read Excel files. The user can also perform typical Cut, Paste, and Copy operations available under the Edit Menu Option.

- The first row in all input data files consist of alphanumeric (strings of numbers and characters) names representing the header row. Those header names may represent meaningful variable names such as Arsenic, Chromium, Lead, Group-ID, and so on.

Number Precision

- The user may turn "Full Precision" on or off by choosing **Configure ► Full Precision On/OFF**

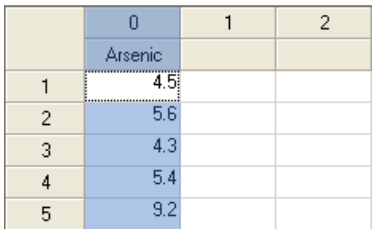
- By leaving “Full Precision” turned **off**, ProUCL will display numerical values using an appropriate (default) decimal digit option; and by turning “Full Precision” **off**, all decimal values will be rounded to the nearest thousandths place.

- The “Full Precision” **on** option is specifically useful when dealing with data sets consisting of small numerical values (e.g., < 1) resulting in small values of the various estimates and test statistics. These values may become so small with several leading zeros (e.g., 0.00007332) after the

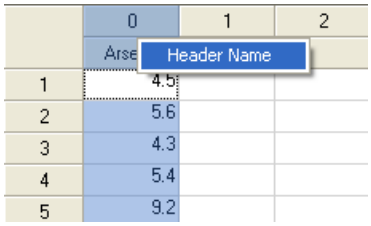
decimal. In such situations, one may want to use the "Full Precision" **on** option to see nonzero values after the decimal.

Entering and Changing a Header Name

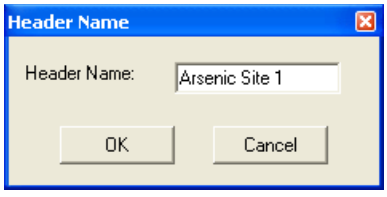
1. The user can change variable names (Header Name) using the following process. Highlight the column whose header name (variable name) you want to change by clicking either the column number or the header as shown below.



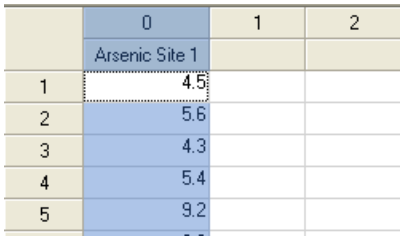
2. Right-click and then click **Header Name**.



3. Change the Header Name.



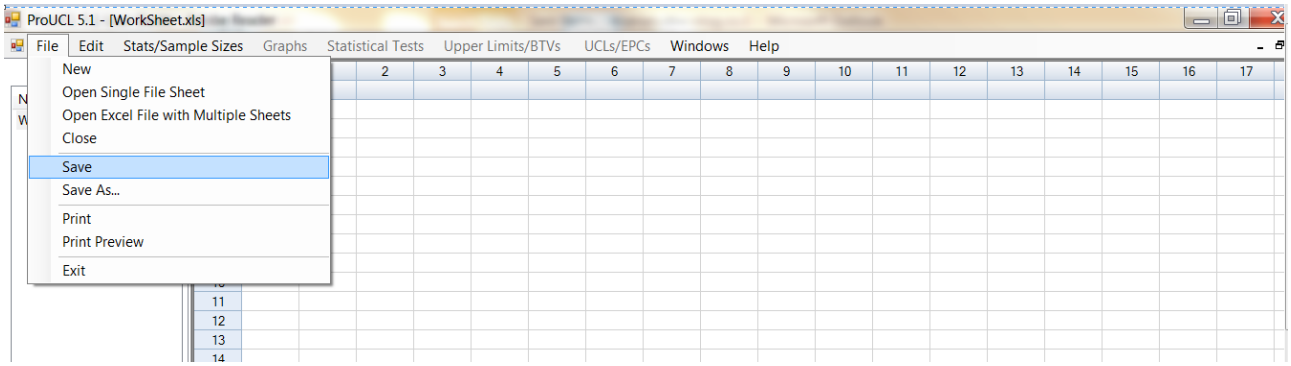
4. Click the **OK** button to get the following output with the changed variable name.



Saving Files

The **Save** option allows the user to save the active window in Excel 2003 or Excel 2007.

The **Save As** option also allows the user to save the active window. This option follows typical Windows standards, and saves the active window to a file in .xls or .xlsx format. All modified/edited data files, and output screens (excluding graphical displays) generated by the software can be saved as .xls or .xlsx files.



Handling Non-Detect (ND_ Observations and Generating Files with Non-Detects

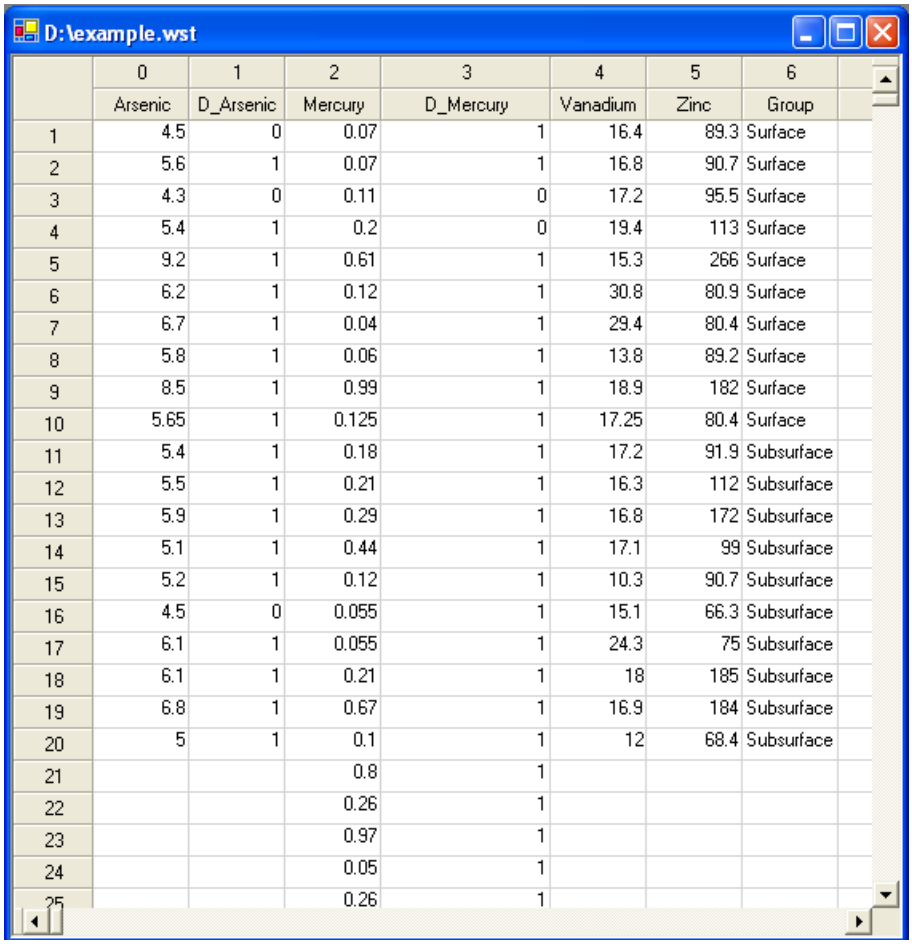
- Several modules of ProUCL (e.g., Statistical Tests, Upper limits/BackgroundVaules, UCLs/EPCs) handle data sets containing ND observations with single and multiple detection limits.

- The user informs the program about the status of a variable consisting of NDs. For a variable with ND observations (e.g., arsenic), the detected values, and the numerical values of the associated detection limits (for less than values) are entered in the appropriate column associated with that variable. No qualifiers or flags (e.g., J, B, U, UJ, X) should be entered in data files with ND observations.

- Data for variables with ND values are provided in two columns. One column consists of numerical values of detected observations and numerical values of detection limits (or reporting limits) associated with observations reported as NDs; and the second column represents their detection status consisting of only 0 (for ND values) and 1 (for detected values) values. The name of the corresponding variable representing the detection status should start with d_, or D_ (not case sensitive) and the

variable name. The detection status column with variable name starting with a D_ (or a d_) should have only two values: 0 for ND values, and 1 for detected observations.

- For example, the header name, D_Arsenic is used for the variable, Arsenic having ND observations. The variable D_Arsenic contains a 1 if the corresponding Arsenic value represents a detected entry, and contains a 0 if the corresponding entry represents a ND entry. If this format is not followed, the program will not recognize that the data set has NDs. An example data set illustrating these points is given as follows. ProUCL does not distinguish between lowercase and uppercase letters.



	0	1	2	3	4	5	6
	Arsenic	D_Arsenic	Mercury	D_Mercury	Vanadium	Zinc	Group
1	4.5	0	0.07	1	16.4	89.3	Surface
2	5.6	1	0.07	1	16.8	90.7	Surface
3	4.3	0	0.11	0	17.2	95.5	Surface
4	5.4	1	0.2	0	19.4	113	Surface
5	9.2	1	0.61	1	15.3	266	Surface
6	6.2	1	0.12	1	30.8	80.9	Surface
7	6.7	1	0.04	1	29.4	80.4	Surface
8	5.8	1	0.06	1	13.8	89.2	Surface
9	8.5	1	0.99	1	18.9	182	Surface
10	5.65	1	0.125	1	17.25	80.4	Surface
11	5.4	1	0.18	1	17.2	91.9	Subsurface
12	5.5	1	0.21	1	16.3	112	Subsurface
13	5.9	1	0.29	1	16.8	172	Subsurface
14	5.1	1	0.44	1	17.1	99	Subsurface
15	5.2	1	0.12	1	10.3	90.7	Subsurface
16	4.5	0	0.055	1	15.1	66.3	Subsurface
17	6.1	1	0.055	1	24.3	75	Subsurface
18	6.1	1	0.21	1	18	185	Subsurface
19	6.8	1	0.67	1	16.9	184	Subsurface
20	5	1	0.1	1	12	68.4	Subsurface
21			0.8	1			
22			0.26	1			
23			0.97	1			
24			0.05	1			
25			0.26	1			

Caution

- Care should be taken to avoid any misrepresentation of detected and non-detected values. Specifically, do not include any missing values (blanks, characters) in the D_column (detection status column). If a missing value is located in the D_column (and not in the associated variable column), the corresponding value in the variable column is treated as a ND, even if this might not have been the intention of the user.

- It is mandatory that the user makes sure that only a 1 or a 0 are entered in the detection status D_column. If a value other than a 0 or a 1 (such as qualifiers) is entered in the D_ column (the detection column), results may become unreliable, as the software defaults to any number other than 0 or 1 as a ND value.

- When computing statistics for full uncensored data sets without any ND values, the user should select only those variables (from the list of available variables) that contain no ND observations. Specifically, ND values found in a column chosen for the summary statistics (full-uncensored data set) will be treated as a detected value; whatever value (e.g., detection limit) is entered in that column will be used to compute summary statistics for a full-uncensored data set without any ND values.

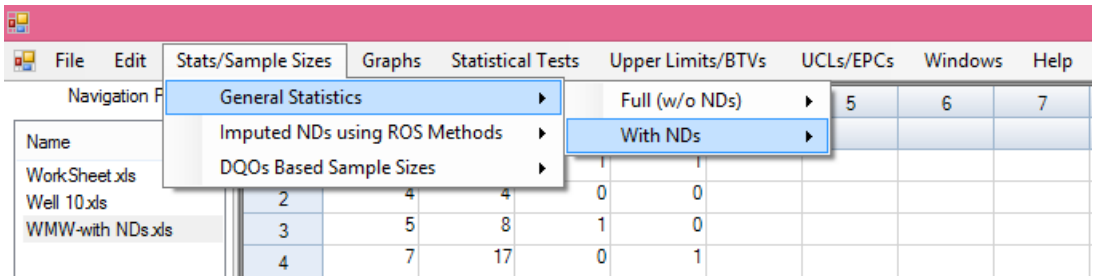
- It is mandatory that the header name of a non-detect column associated with a variable such as XYZ should be D_XYZ (or d_Xyz). No other characters or blanks are allowed. However, the header (column) names are not case sensitive. If the nondetect column is not labeled properly, methods to handle non-detect data will not be activated and shown.

Summary Statistics for Data Sets with Non-Detect Observations

- To compute statistics of interest (e.g., background statistics, Goodness of Fit (GOF) test, UCLs, etc..) for variables with ND values, one should choose the ND option, **"With NDs"**, from the available menu options such as S**tats/Sample Sizes**, **Graphs**, **Statistical Tests**, **Upper Limits/BTVs**, and **UCLs/EPCs**.

- The NDs option of these modules gets activated only when your data set contains NDs.

- For data sets with NDs, the **Stats/Sample Sizes** module of ProUCL 5.0 computes summary statistics and other general statistics such as the KM mean and KM standard deviation based upon raw as well as log-transformed data.



The **General Statistics/With NDs** option also provides simple statistics (e.g., % NDs, Max detect, Min detect, Mean) based upon detected values. The statistics computed in log-scale (e.g., *sd* of log-transformed detected values) may help a user to determine the degree of skewness (e.g., mild, moderate, high) of a data set based upon detected values. These statistics may also help the user to choose the most appropriate method (e.g., KM bootstrap-t UCL or KM percentile bootstrap UCL) to compute UCLs, UPLs, and other limits used to compute decision statistics.

- All other parametric and nonparametric statistics and estimates of population mean, variance, percentiles (e.g., KM, and ROS estimates) for variables with ND observations are provided in other menu options such as **Upper Limits/BTVs** and **UCLs/EPCs**.

Warning Messages and Recommendations for Data Sets with an Insufficient Amount of Data

- ProUCL provides warning messages and recommendations for data sets with an insufficient amount of data for calculating meaningful estimates and statistics of interest. For example, it is not desirable to compute an estimate of the exposure concentration value based upon a discrete (as opposed to composite or other sampling methodology) data set of size less than 5, especially when NDs are also present in the data set.

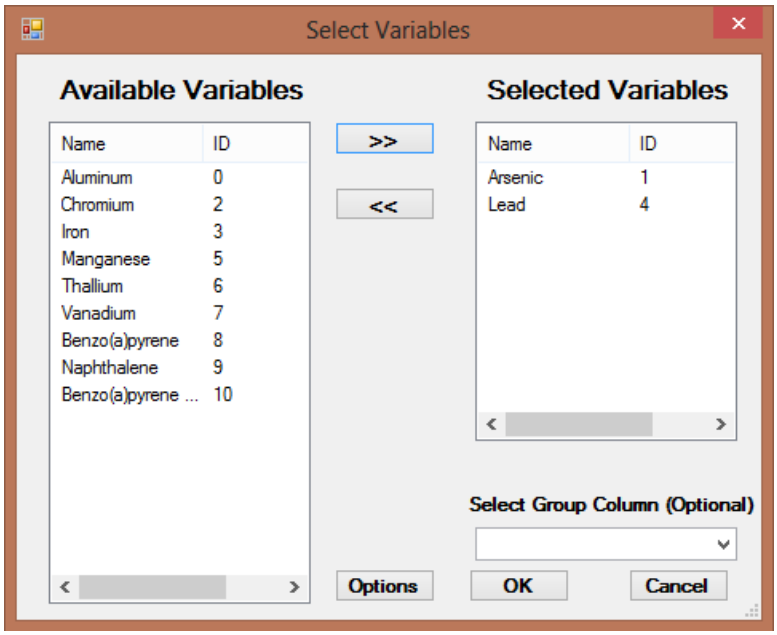
- It is suggested that for data sets composed of observations resulting from discrete sampling, at least 10 observations should be collected to compute UCLs and various other limits.

Select Variables Screen

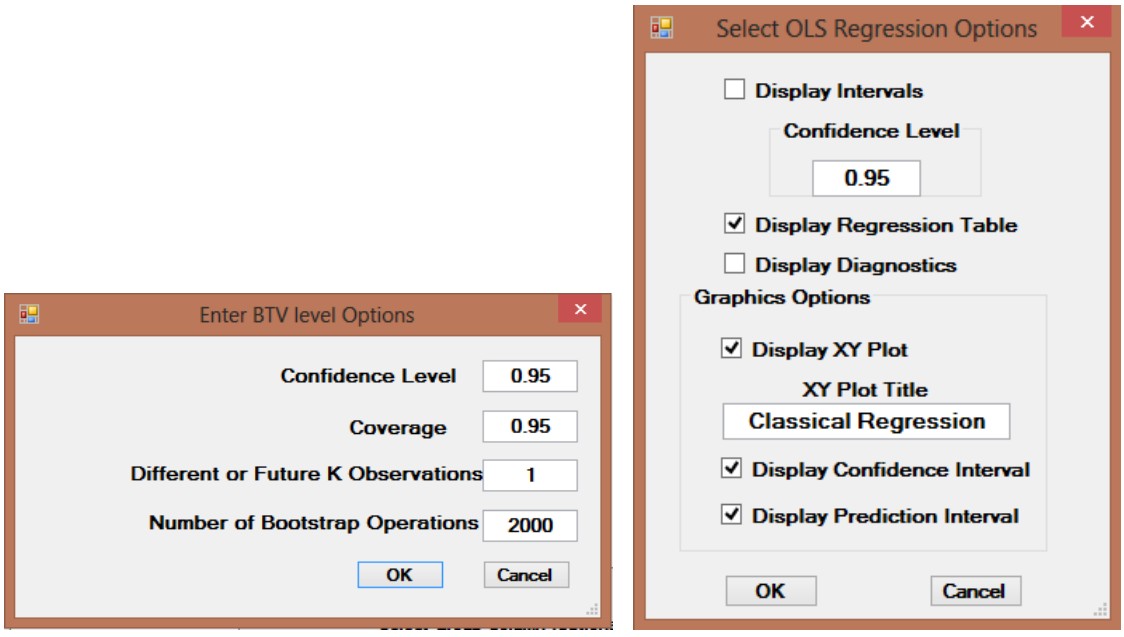
- The **Select Variable** screen is associated with all modules of ProUCL.

- Variables need to be selected to perform statistical analyses.

- When the user clicks on a drop-down menu for a statistical procedure (e.g., UCLs), the following window will appear.



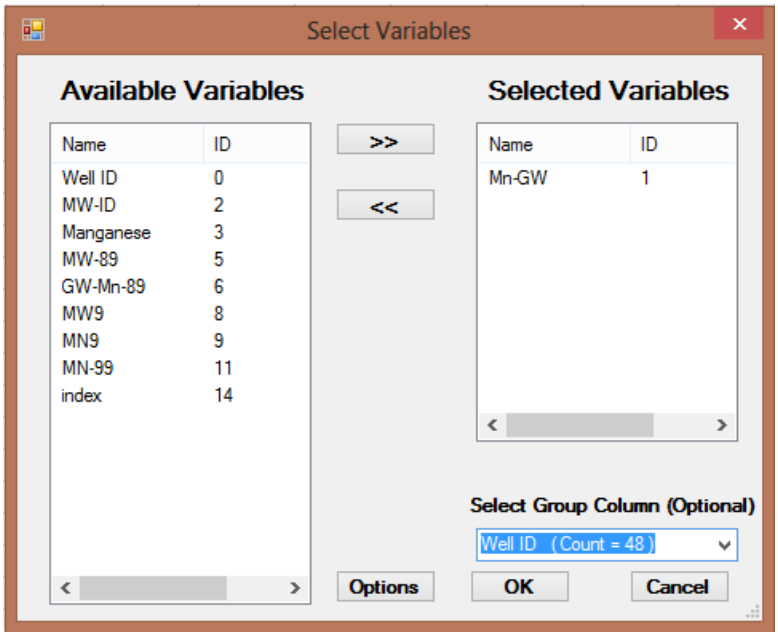
- The **Options** button is available in certain menus. The use of this option leads to another pop-up window such as shown below. This window provides the options associated with the selected statistical method (e.g., BTVs, OLS Regression).



- ProUCL can process multiple variables simultaneously. ProUCL software can generate graphs, and compute UCLs, and background statistics

simultaneously for all selected variables shown in the right panel of the screen shot displayed on the previous page.

- If the user wants to perform statistical analysis on a variable (e.g., manganese) by a Group variable, click the arrow below the **Select Group Column (Optional)** to get a drop-down list of available variables from which to select an appropriate group variable. For example, a group variable (e.g., Well ID) can have alphanumeric values such as MW8, MW9, and MW1. Thus in this example, the group variable name, Well ID, takes 3 values: MW1, MW8, and MW9. The selected statistical method (e.g., GOF test) performs computations on data sets for all the groups associated with the selected group variable (e.g., Well ID)



- The Group variable is useful when data from two or more samples need to be compared.

- Any variable can be a group variable. However, for meaningful results, only a variable, that really represents a group variable (categories) should be selected as a group variable.

General Statistics

The **General Statistics** option is available under the **Stats/Sample Sizes** module of ProUCL 5.1. This option is used to compute general statistics including simple summary statistics (e.g., mean, standard deviation) for all selected variables. In addition to simple summary statistics, several other statistics are computed for full uncensored data sets (**Full w/o NDs**), and for data sets with non-detect (**with NDs**) observations (e.g., estimates based upon the KM method). Two Menu options: **Full w/o NDs** and **With NDs** are available.

- **Full (w/o NDs)**: This option computes general statistics for all selected variables.

- **With NDs**: This option computes general statistics including the KM method based mean and standard deviations for all selected variables with ND observations.

Each menu option (**Full (w/o NDs)** and **With NDs**) has two sub-menu options:

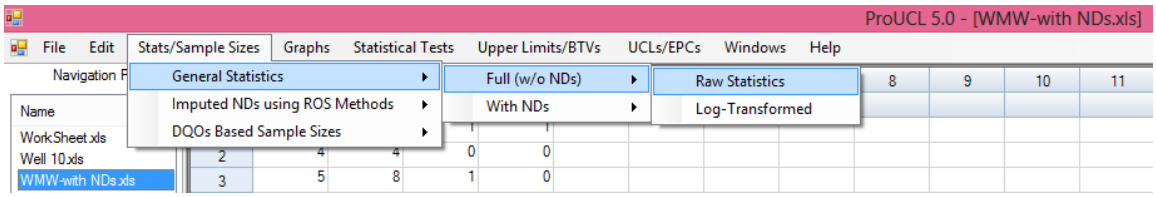
- Raw Statistics

- Log-Transformed

When computing general statistics for raw data, a message will be displayed for each variable that contains non-numeric values. The **General Statistics** option computes log-transformed (natural log) statistics only if all of the data values for the selected variable(s) are positive real numbers. A message will be displayed if non-numeric characters, zero, or negative values are found in the column corresponding to a selected variable.

General **Statistics for Full Data Sets without NDs**

1. Click **General Statistics ► Full (w/o NDs)**



2. Select either **Log-Transformed** or **Raw Statistics** option.

3. The **Select Variables** screen will appear. Select one or more variables from the **Select Variables** screen.

4. Click on the **OK** button to continue or on the **Cancel** button to cancel the **General Statistics** option.

Raw Statistics

User Selected Options	
From File	FULLIRIS-nds.xls
Full Precision	OFF

From File: FULLIRIS-nds.xls

Summary Statistics for Uncensored Data Sets

Variable	NumObs	# Missing	Minimum	Maximum	Mean	SD	SEM	MAD/0.675	Skewness	Kurtosis	CV
sp-length (1)	50	0	4.3	5.8	5.006	0.352	0.0498	0.297	0.12	-0.253	0.0704
sp-length (2)	50	0	4.9	7	5.936	0.516	0.073	0.519	0.105	-0.533	0.087
sp-length (3)	50	0	4.9	7.9	6.588	0.636	0.0899	0.593	0.118	0.0329	0.0965

Percentiles for Uncensored Data Sets

Variable	NumObs	# Missing	10%ile	20%ile	25%ile(Q1)	50%ile(Q2)	75%ile(Q3)	80%ile	90%ile	95%ile	99%ile
sp-length (1)	50	0	4.59	4.7	4.8	5	5.2	5.32	5.41	5.61	5.751
sp-length (2)	50	0	5.38	5.5	5.6	5.9	6.3	6.4	6.7	6.755	6.951
sp-length (3)	50	0	5.8	6.1	6.225	6.5	6.9	7.2	7.61	7.7	7.802

Log-Transformed Statistics

User Selected Options	
From File	FULLIRIS-nds.xls
Full Precision	OFF

From File: FULLIRIS-nds.xls

Summary Statistics for Uncensored Log-Transformed Data Sets

Variable	NumObs	# Missing	Minimum	Maximum	Mean	Variance	SD	MAD/0.675	Skewness	Kurtosis	CV
sp-length (1)	50	0	1.459	1.758	1.608	0.00497	0.0705	0.0605	-0.0553	-0.291	0.0438
sp-length (2)	50	0	1.589	1.946	1.777	0.00761	0.0872	0.0873	-0.0852	-0.463	0.0491
sp-length (3)	50	0	1.589	2.067	1.881	0.00943	0.0971	0.0885	-0.196	0.492	0.0516

Percentiles for Uncensored Log-Transformed Data Sets

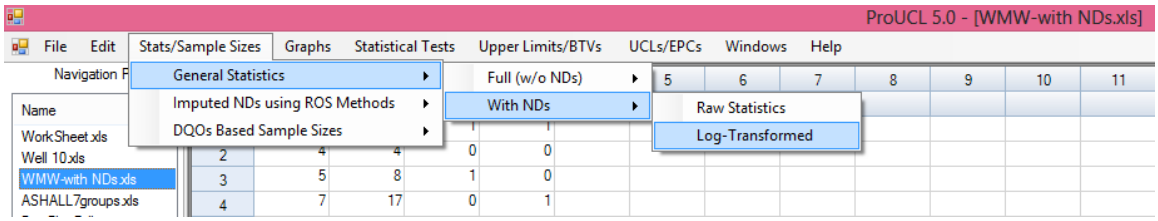
Variable	NumObs	# Missing	10%ile	20%ile	25%ile(Q1)	50%ile(Q2)	75%ile(Q3)	80%ile	90%ile	95%ile	99%ile
sp-length (1)	50	0	1.524	1.548	1.569	1.609	1.649	1.671	1.688	1.724	1.749
sp-length (2)	50	0	1.683	1.705	1.723	1.775	1.841	1.856	1.902	1.91	1.939
sp-length (3)	50	0	1.758	1.808	1.829	1.872	1.932	1.974	2.029	2.041	2.054

The **General Statistics** screen (and all other output screens generated by other modules) shown above can be saved as an Excel 2003 (.xls) or 2007 (.xlsx) file. Click **Save** from the file menu.

On the output screen shown above, most of the statistics are self explanatory and described in the ProUCL Technical Guide.

General Statistics with NDs

1. As above, Click **General Statistics ► With NDs**



2. Select either **Log-Transformed** or **Raw Statistics** option.

3. The **Select Variables** screen (Chapter 3) will appear. Select variable(s) from the list of variables.

- Only those variables that have ND values will be shown. The user should make sure that the variables with NDs are defined properly including the column showing the detection status of the various observations.

Computing Upper Confidence Limits (UCLs) of the Mean with Non-Detects

In ProUCL, two choices are available for computing UCL statistics:

- Full (w/o NDs): Computes UCLs for full-uncensored data sets without any nondetects.

- With NDs: Computes UCLs for data sets consisting of ND observations with multiple DLs or reporting limits (RLs).

- For full data sets without NDs and also for data sets with NDs, the following options and choices are available to compute UCLs of the population mean.

    - The user specifies a confidence level; a number in the interval (0.5, 1), 0.5 inclusive. The default choice is 0.95.

    - The program computes several nonparametric UCLs using the CLT, adjusted CLT, Chebyshev inequality, jackknife, and bootstrap re-sampling methods.

    - The user is responsible for selecting an appropriate choice for the data distribution: normal, gamma, lognormal, or nonparametric. **It is desirable that user determines data distribution using the Goodness-of-Fit test option prior to using the UCL option**. The UCL output sheet also informs the user if data are normal, gamma,

lognormal, or a non-discernible distribution. Program computes statistics depending on the user selection.

- For data sets, which are not normal, one may try the gamma UCL next. The program will offer you advice if you chose the wrong UCL option.

- For data sets, which are neither normal nor gamma, one may try the lognormal UCL. The program will offer you advice if you chose the wrong UCL option.

- Data sets that are not normal, gamma, or lognormal are classified as distribution-free nonparametric data sets. The user may use nonparametric UCL option for such data sets. The program will offer you advice if you chose the wrong UCL option.

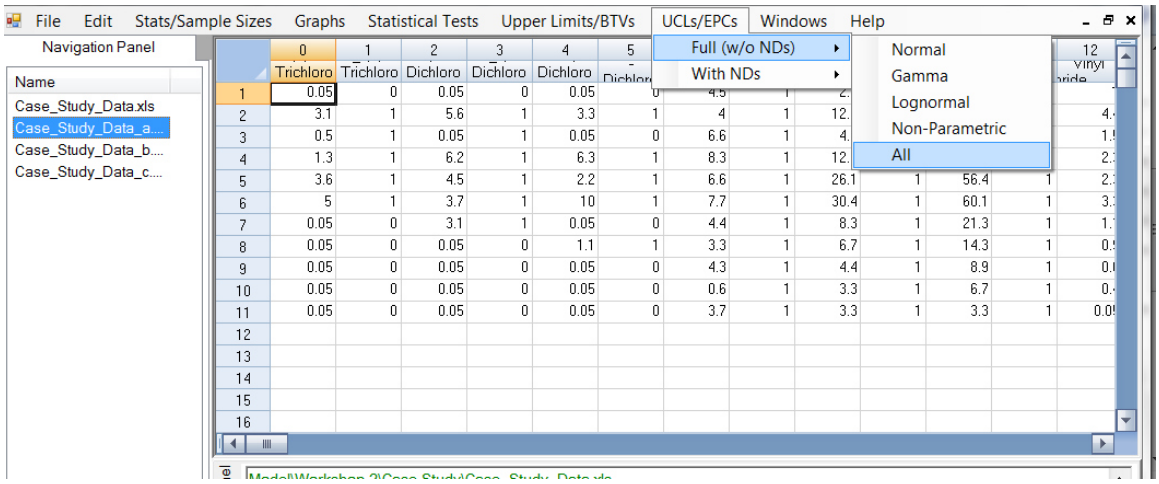
- The program also provides the **All** option. By selecting this option, ProUCL outputs most of the relevant UCLs available in ProUCL. The program informs the user about the distribution of the underlying data set, and offers advice regarding the use of an appropriate UCL.

For lognormal data sets, ProUCL can compute 90%, 95%, 97.5%, and 99% Land's statistic-based H-UCL of the mean. For all other methods, ProUCL can compute a UCL for any confidence coefficient (CC) in the interval (0.5, 1.0), 0.5 inclusive. If you have selected a distribution, then ProUCL will provide a recommended UCL method for 0.95, confidence level. Even though ProUCL can compute UCLs for any confidence coefficient level in the interval (0.5, 1.0), the recommendations are provided only for 95% UCL; as exposure point concentration term is estimated by a 95% UCL of the mean.

Notes: Like all other methods, it is recommended that the user identify a few low probability (coming from extreme tails) outlying observations that may be present in the data set. Outliers distort statistics of interest including summary statistics, data distributions, test statistics, UCLs and background concentrations. Decisions based upon distorted statistics may be misleading and incorrect. The objective is to compute decision statistics based upon the majority of the data set representing the main dominant population. The project team should decide about the disposition (to include or not to include) of outliers before computing estimates of Exposure point concentrations and Background concentrations. To determine the influence of outliers on UCLs and background statistics, the project team may want to compute statistics twice: once using the data set with outliers, and once using the data set without outliers.

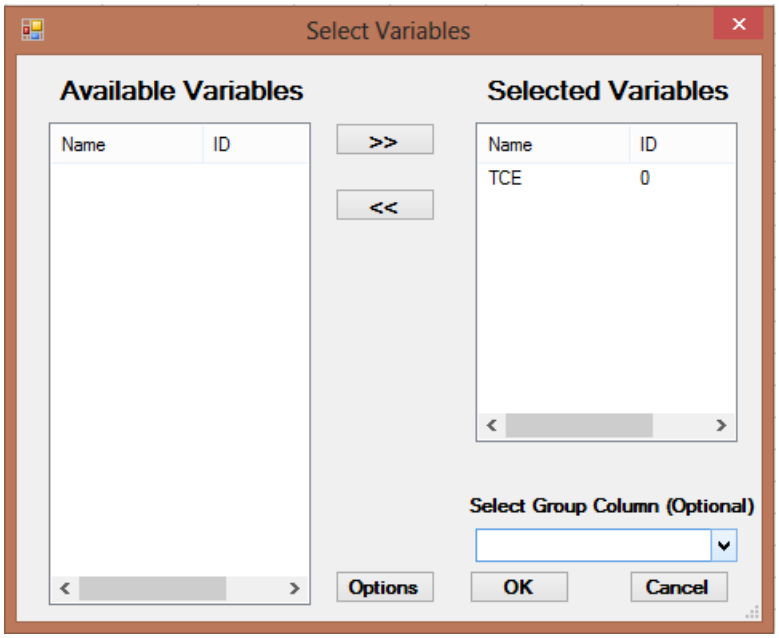
UCLs for Full (w/o NDs) Data Sets

1. Click **UCLs/EPCs ► Full (w/o NDs) ► All**

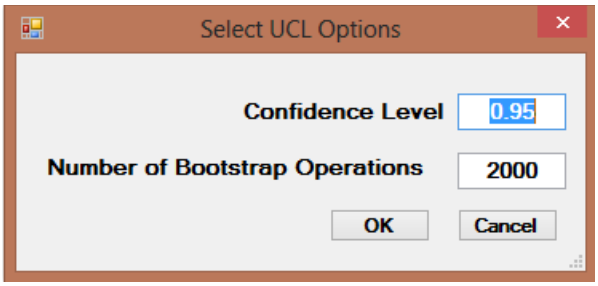


2. The **Select Variables** screen (Chapter 3) will appear.

- Select a variable(s) from the **Select Variables** screen.



- When the **Option** button is clicked, the following window will be shown.



- Specify the **Confidence Level**; a number in the interval (0.5, 1), 0.5 inclusive. The default choice is **0.95**.

- Click on **OK** button to continue or on **Cancel** button to cancel the option.

- Click on **OK** to continue or on **Cancel** to cancel the UCL computation option.

Output Screen for Normal Distribution (Full Data w/o NDs)

Normal UCL Statistics for Uncensored Full Data Sets

User Selected Options	
Date/Time of Computation	3/25/2013 3:53:05 PM
From File	SuperFund.xls
Full Precision	OFF
Confidence Coefficient	95%

Vanadium

General Statistics

Total Number of Observations	20	Number of Distinct Observations	17
		Number of Missing Observations	0
Minimum	7.2	Mean	17.34
Maximum	32	Median	16.5
SD	8.075	SD of logged Data	0.492
Coefficient of Variation	0.466	Skewness	0.429

Normal GOF Test

Shapiro Wilk Test Statistic	0.925	**Shapiro Wilk GOF Test**	
5% Shapiro Wilk Critical Value	0.905	Data appear Normal at 5% Significance Level	
Lilliefors Test Statistic	0.146	**Lilliefors GOF Test**	
5% Lilliefors Critical Value	0.198	Data appear Normal at 5% Significance Level	

Data appear Normal at 5% Significance Level

Assuming Normal Distribution

95% Normal UCL		**95% UCLs (Adjusted for Skewness)**	
95% Student's-t UCL	20.46	95% Adjusted-CLT UCL (Chen-1995)	20.49
		95% Modified-t UCL (Johnson-1978)	20.49

Suggested UCL to Use

95% Student's-t UCL	20.46		

Calculating UCL for Data Sets with NDs

1. Click **UCLs/EPCs ► With NDs**

2. Choose the **Normal, Gamma, Lognormal, Non-Parametric,** or **All** option.

3. Select a variable(s) from the **Select Variables** screen.

Ecological Risk Assessment
Screening Checklist for Potential Receptors and Habitat
Level 1, Checklist A

1. Is the boundary of the contaminated area less than 1 km (or more if local conditions and the authorities' request) to a surface water body (stream, river beds, pond, lake, etc.)?

2. Are wetlands (such as a significant winter pond) located on or within 1 km from the site?

3. Are contaminated soils uncovered or otherwise accessible to ecological receptors and the elements?

4. Are there karstic features on or within 1 km of the boundary of the contaminated area? Note: The 1 km criterion does not apply to situations where a hydrological connection exists between the onsite karstic features and a water body.

5. Are there rare, threatened, or endangered species on the site or within 1 km of the boundary of the contaminated area? Are there "red" listed species[1] present on the Site?

6. Are there environmentally sensitive areas within 1 km (or more if local conditions and the authorities request) of the contaminated area?

[1] The IUCN Red List of Threatened Species ™ (UN Red List)

7. Are commercially or recreationally important species (fauna or flora) on or within 1 km (or more if local conditions and the authorities dictate) of the contaminated area?

   If the answer is “Yes” to any of the above questions, then complete Ecological Risk Assessment Checklist B.

Ecological Risk Assessment
Screening Checklist for Potential Receptors and Habitat
Level 1, Checklist B

EVALUATION OF RECEPTOR-PATHWAY INTERACTIONS

Exposure to COCs to Surface Water

Are contaminants of concern (COCs) present or potentially present in surface waters?
AND
Are ecologically important species or habitats present?
AND
Could COCs reach these receptors via surface water?

When answering the above questions, consider the following:

- Known or suspected presence of COCs in surface waters
- Ability of contaminants to migrate to surface waters.
- Terrestrial organisms may be dermally exposed to water-borne contaminants as a result of wading or swimming in contaminated waters. Aquatic receptors may be exposed through osmotic exchange, respiration or ventilation of surface waters.
- Contaminants may be taken-up by terrestrial plants whose roots are in contact with surface waters.
- Terrestrial receptors may ingest water-borne contaminants if contaminated surface waters are used as a drinking water source.

Exposure to COCs in Sediments

Are COCs present or potentially present in sediments?
AND
Are ecologically important species or habitats present?

AND

Could COCs reach these receptors via contact with sediments?

When answering the above questions, consider the following:

- Known or suspected presence of COCs in sediment.
- Ability of COCs to leach or erode from surface soils and be carried into sediment via surface runoff.
- Potential for contaminated groundwater to upwell through, and deposit contaminants in, sediments.
- If sediments are present in an area that is only periodically inundated with water, terrestrial species may be dermally exposed during dry periods. Aquatic receptors may be directly exposed to sediments or may be exposed through osmotic exchange, respiration or ventilation of sediment pore waters.
- Terrestrial plants may be exposed to sediment in an area that is only periodically inundated with water.
- If sediments are present in an area that is only periodically inundated with water, terrestrial species may have direct access to sediments for the purposes of incidental ingestion. Aquatic receptors may regularly or incidentally ingest sediment while foraging.

Exposure to COCs in Dietary Food Items

Are COCs present or potentially present in prey or food items of ecologically important receptors?

AND

Are ecologically important species or habitats present?

AND

Could COCs reach these receptors via consumption of food items?

When answering the above questions, consider the following:

- Higher trophic level terrestrial and aquatic consumers and predators may be exposed through consumption of contaminated food sources.
- In general, organic contaminants with log Kow > 3.5 may accumulate in terrestrial mammals and those with a log Kow > 5 may accumulate in aquatic vertebrates.

Exposure to COCs in Surficial Soil

Are COCs present or potentially present in surficial soils?
AND
Are ecologically important species or habitats present?
AND
Could COCs reach these receptors via incidental ingestion of or dermal contact with surficial soils?

When answering the above questions, consider the following:

- Known or suspected presence of COCs in surficial (□1m depth) soils.
- Ability of COCs to migrate to surficial soils.
- Significant exposure via dermal contact would generally be limited to organic contaminants which are lipophilic and can cross epidermal barriers.
- Exposure of terrestrial plants to contaminants present in particulates deposited on leaf and stem surfaces by rain striking contaminated soils (i.e., rain splash).
- Contaminants in bulk soil may partition into soil solution, making them available to roots.
- Incidental ingestion of contaminated soil could occur while animals grub for food resident in the soil, feed on plant matter covered with contaminated soil or while grooming themselves clean of soil.

Exposure to COCs in Sub-Surface Soil

Are COCs present or potentially present in the sub-soils?

AND

Are ecologically important species or habitats present?

AND

Could COCs reach these receptors via vapors or fugitive dust carried in surface air or confined in burrows?

When answering the above questions, consider the following:

- Volatility of the COCs (volatile chemicals generally have Henry's Law constant > 10-5 atm-m3/mol and molecular weight < 200 g/mol).
- Exposure via inhalation is most important to organisms that burrow in contaminated soils, given the limited amounts of air present to dilute vapors and an absence of air movement to disperse gases.
- Exposure via inhalation of fugitive dust is particularly applicable to ground-dwelling species that could be exposed to dust disturbed by their foraging or burrowing activities or by wind movement.
- Foliar uptake of organic vapors would be limited to those contaminants with relatively high vapor pressures.
- Exposure of terrestrial plants to contaminants present in particulates deposited on leaf and stem surfaces.

Exposure to COCs in the Ambient Air

Are COCs present or potentially present in the ambient air?

AND

Are ecologically important species or habitats present?

AND

Could COCs reach ecological receptors via inhalation of volatile COCs aboveground or in subsurface burrows OR via COCs adhered to dust in ambient air?

5.a.) Are COCs present on the site volatile?

5.b.) Could COCs on the site be transported in air as dust or particulate matter?

Exposure to COCs from Erosional Transport

Could COCs from the site reach ecological receptors via erosional transport of impacted soils or via precipitation runoff or through sediments carried during flood flows?

And

Can COCs be leached from or be transported by erosion of surface soils?

Exposure to COCs through a Karst System

Are COCs present or potentially present in the groundwater?

Could COCs originating on the site reach ecological receptors and/or habitats via transport through a karst system?

If the answers to the above questions are "Yes", the MoEP may require further assessment to determine whether the site poses an unacceptable risk to ecological receptors.