Human Health Risk Assessment

In its 2000 session, the Wyoming Legislature created new opportunities, procedures, and standards for voluntary remediation of contaminated sites. These provisions, enacted as Articles 16, 17, and 18 of the Wyoming Environmental Quality Act and implemented by the Wyoming Department of Environmental Quality (DEQ), will govern future environmental cleanups in Wyoming.

This Fact Sheet provides procedures for use in preparing a site-specific human health risk assessment under the Voluntary Remediation Program (VRP).

Use of this Fact Sheet for methods and report presentation for VRP sites in Wyoming will:

- Foster a consistent and technically defensible approach to conducting site-specific risk assessments
- Expedite DEQ's review of risk assessments
- Minimize revision and resubmittal of risk assessment documents, thus reducing time and costs for Volunteers
- Assist in the site remediation decision-making process

This Fact Sheet also specifies when DEQ should be consulted during preparation of a risk assessment to ensure that the methodology used is as complete as possible and appropriate for the site.

Summary of Contents

This Fact Sheet is organized into five main sections:

1–Introduction: Provides an overview of the human health risk assessment process, applicable Wyoming requirements, the relationship of this Fact Sheet to other guidance documents, and limitations.

2–Problem Formulation: Describes the site information that should be obtained to conduct a site-specific human health risk assessment and the process of developing a conceptual site model and a conceptual human exposure model.

3–Site-Specific Risk Assessment: Describes how site data should be evaluated to develop site exposure concentrations and methods to be used in conducting the exposure assessment,
toxicity assessment, risk characterization, and uncertainty evaluation components of the site-specific human health risk assessment.

4–VRP Information: Explains how to obtain more information about the Voluntary Remediation Program.

5–References: Provides a citation of references used in developing this Fact Sheet.

Exposure equations and related technical information are contained in Appendix A.

1. Introduction

A risk assessment is a written document in which site-specific information from the site conceptual model and pertinent scientific information on toxicology, chemical environmental fate and transport, and exposure are assembled, critiqued, and interpreted. The risk assessment evaluates existing and future potential risks to human health from hazardous substances detected in soil, groundwater, sediments, surface waters, and (in some cases) air and biota that are at the site. The results of the risk assessment provide a basis for risk managers to determine whether, and to what extent, remediation of impacted media is warranted.

A. Applicable Wyoming Statutes

Procedures and standards for the VRP program, including those for conducting site-specific human health risk assessments, are in Articles 16, 17, and 18 of the Wyoming Environmental Quality Act. Results of a site-specific human health risk assessment are to be compared to the acceptable risk limits that have been established in Article 16 of the Environmental Quality Act (§35-11-1605[a][iii][B]). These limits state that the lifetime cancer risk to any exposed individual will not exceed one-in-one million (1 x 10^{-6}) to one-in-ten thousand (1 x 10^{-4}). Consistent with the statute and EPA guidance, DEQ will use an excess cancer risk at the one-in-one million level as a point of departure, or target risk level, for determining remediation goals. The risk limit for noncarcinogenic substances is a hazard index of 1.0. If total carcinogenic or noncarcinogenic risks for any given exposure scenario exceed these limits, further consultation with DEQ may be necessary, and some type of remediation or other action to reduce or control risk may be necessary. For further information, see section 3. C. Risk Characterization.

B. Relationship to Other Guidance Documents

A complete list of reference documents used to develop this Fact Sheet is provided in section 5. The primary Environmental Protection Agency (EPA) guidance document that this Fact Sheet supplements is Risk Assessment Guidance for Superfund; Volume I: Human Health Evaluation Manual (EPA, 1989). To conduct a site-specific human health risk assessment under the VRP, the Volunteer should have this document available for reference. This Fact Sheet is not meant to replace EPA guidance on risk assessment; rather it is meant to provide specific information in cases where it is not provided by EPA guidance, and to identify differences between EPA guidance and DEQ guidance for completing the site-specific human health risk assessment. Other EPA risk assessment guidance will also be referenced as appropriate, and it is
recommended that these referenced guidance documents be available when completing the risk assessment.

DEQ acknowledges that information, guidance documents, and references are constantly updated, as well as new information published. Volunteers are encouraged to bring new or updated information to the attention of DEQ. DEQ policy is to update its material on an as-needed basis, generally when major reference materials are updated or revised.

This Fact Sheet supplements other DEQ VRP Fact Sheets. Other Fact Sheets directly related to or cited in this Fact Sheet include:

- Fact Sheet #6 Independent Cleanup
- Fact Sheet #8 Site Characterization
- Fact Sheet #11 Risk Assessment
- Fact Sheet #12 Soil Cleanup Levels
- Fact Sheet #13 Groundwater Cleanup Levels
- Fact Sheet #14 Ecological Risk Assessment–Steps 1 and 2 Ecological Exclusion and Scoping Assessments
- Fact Sheet #15 Liability Assurances
- Fact Sheet #19 Ecological Risk Assessment–Steps 3 and 4 Screening and Baseline Ecological Risk Assessment
- Fact Sheet #23 Institutional Controls, Engineering Controls, and Use Control Areas
- Fact Sheet #24 Establishing Site-Specific Background Metals Concentrations in Soil
- Fact Sheet #25 Using Fate and Transport Models to Evaluate Cleanup Levels
- Fact Sheet #28 Data Quality Objectives

C. Limitations

This document is meant to assist in the development of site-specific human health risk assessments for sites under the Wyoming VRP. Its use for cleanup projects under other authorities should be discussed with DEQ.

Although this Fact Sheet includes a summary of how a site-specific human health risk assessment should be conducted, it is not intended to be a training manual on risk assessment, nor to provide a complete description of all VRP guidance and options. To effectively apply the information in this document, the user should have adequate knowledge of:

- Site assessment and remediation methods
- Toxicology and risk assessment principles and procedures
- Contaminant fate and transport processes
- Current VRP guidance documents
If the results of site characterization indicate that contaminants are limited to soil only (no contamination of groundwater or surface water is present), the site may be qualified to proceed under the VRP independent cleanup process (ICP). The ICP is a streamlined, standardized process in which a Volunteer will remove all contaminated soil so that cleanup levels appropriate for unrestricted site use are achieved. For more information on independent cleanup the Volunteer should consult Fact Sheet #6 *Independent Cleanup*.

All Volunteers should also consult Fact Sheet #12 *Soil Cleanup Levels*. This Fact Sheet provides a streamlined process for evaluating soil contamination to determine if further evaluation through a site-specific risk assessment is needed. The precalculated soil cleanup levels contained in Fact Sheet #12 are based on current toxicological data and conservative exposure assumptions. Volunteers are encouraged to use the precalculated soil cleanup levels in Fact Sheet #12 where appropriate; however, these levels are limited to soil. When the independent cleanup process or application of the soil cleanup level look-up table is not appropriate or preferred for site-specific circumstances, a more site-specific risk evaluation is needed. However, DEQ is continuing to make every effort to ensure that the risk assessment process is as streamlined as possible for any given set of site conditions. The next section of this document identifies steps that can be taken to potentially streamline site specific risk evaluations.

The VRP requires that all groundwater be cleaned up to promulgated levels or calculated risk-based levels (see Fact Sheet #13 *Groundwater Cleanup Levels*). When risk-based calculated levels are used, it is assumed that the use of groundwater will be as drinking water. Promulgated levels are, in some cases, the federally established Maximum Contaminant Levels (MCLs) (see DEQ Chapter 17 Water Quality Rules and Regulations). MCLs are established for chemicals based on risk and the ability to effectively remove the chemical from the water (technology limitations), and therefore, are not set based on a pre-set risk limit. It should be noted that for more complicated sites with multiple chemicals in soil and groundwater and multiple potential exposure pathways, the risk associated with an MCL used as a water cleanup level may need to be considered within the context of total site risk from all applicable contaminated media and associated pathways. This is the case even where cleanup levels are based on unrestricted site use exposure assumptions. This approach ensures that site specific cleanup levels will consider the additive health effects from multiple chemicals and determine the potential for additive risk over different media.

The information in this document is strictly for the evaluation of human health risks. Ecological risk evaluation is also required by the Wyoming Environmental Quality Act. Information for completing the ecological risk evaluation is provided in other DEQ guidance documents. DEQ Fact Sheet #14 *Ecological Risk Assessment–Steps 1 and 2 Ecological Exclusion and Scoping Assessments* provides a step-wise approach for this evaluation and should also be consulted for methods pertaining to this evaluation. For sites that do not screen out in Steps 1 and 2, Fact Sheet #19 contains information on Steps 3 and 4 related to ecological risk evaluation.
D. Streamlining the Risk Assessment Process for Multiple Contaminants

The potential opportunity to limit additional evaluation through the site-specific risk assessment process discussed in this section is applicable to certain types of sites. These sites have contamination limited to soil and groundwater, and have more than one contaminant present.

Fact Sheet #12 Soil Cleanup Levels provides instruction for evaluating sites with multiple contaminants present in soil to determine if further evaluation through site-specific risk assessment is necessary. In many cases, when a Volunteer conducts the multiple contaminant evaluation for soil, further risk evaluation is indicated to be necessary. The reason for this is that the process outlined in Fact Sheet #12 has been simplified for the purpose of providing an easy-to-implement first step, and this simplification requires the user to sum the risk posed by each chemical without consideration of the type of health effect each chemical may cause.

If further evaluation is indicated to be necessary after conducting the multiple chemical analysis outlined in Fact Sheet #12, the Volunteer may choose to conduct an interim step prior to starting a site-specific risk assessment, which involves identifying the basis of the toxicity criteria used to calculate the soil cleanup levels. For example, a hypothetical site has soil contaminated with both toluene and zinc at concentrations above levels provided in the Fact Sheet look-up table. Further evaluation of the toxicity criteria used in establishing the cleanup levels for toluene and zinc shows that the toxicity criterion for toluene is based on changes in liver and kidney weight, while the toxicity criterion for zinc is based on changes in enzyme activity in the blood. Since these health effects are not likely additive, the risk posed by the presence of both of these chemicals in soil is not additive. This analysis may allow the Volunteer to develop justification for why the risk posed by individual chemicals in soil is, in fact, not additive.

The procedures that should be used for conducting this interim step are outlined in the EPA guidance document Risk Assessment Guidance for Superfund; Volume I: Human Health Evaluation Manual (EPA, 1989), Chapter 8. This evaluation should only be conducted by a qualified environmental scientist.

2. Problem Formulation

The potential that a site-specific human health risk assessment would be needed should be considered when developing the approach for characterizing the nature and extent of contamination at any site. Considering the potential for conducting a human health risk assessment will ensure that the type and amount of data necessary to complete the assessment will be included in the site characterization efforts. Identifying the type and quantity of site information that will be necessary to complete the site-specific human health risk assessment will minimize the likelihood that additional field work will be necessary to collect needed data during the risk evaluation process and will assist in planning site investigation phases, if appropriate. Further information on conducting site characterization under the VRP is available in DEQ Fact Sheet #8 Site Characterization. Additional information on planning the site characterization process can be found in the following EPA guidance documents listed in
Fact Sheet #8 and the EPA guidance documents provide a summary of site information that should be considered in developing a plan for site characterization. They also define the process for developing a site conceptual model, which is one of the first steps in the risk assessment process. It is used in planning and implementing site characterization and other remedial activities and in defining the scope of the site-specific human health risk assessment. The process outlined in Fact Sheet #8 and EPA guidance should be followed to develop the site conceptual model, and the model should be refined as additional information about the site becomes available.

As described in Fact Sheet #11, site-specific risk assessments are required to calculate risk under conditions of unrestricted, current, and likely future land use. This typically requires two site conceptual models—one for current and likely future land use and one for unrestricted land use.

A. Developing a Site Conceptual Model

A site conceptual model is a summary that:

- Describes all of the known or suspected sources of contamination
- Considers how and where the contaminants are likely to move
- Identifies who is likely to be affected by them
- Identifies potential exposure pathways

It is a description of the surface and the subsurface of the site and the site environmental setting, including contaminant sources, release mechanisms, migration routes, potential human and ecological receptors, and exposure pathways. (The need for a site conceptual model for evaluation of ecological impacts is discussed in Fact Sheet #19 Ecological Risk Assessment–Steps 3 and 4 Screening and Baseline Ecological Risk Assessment.) A site conceptual model should be provided in the site-specific risk assessment work plan submitted to DEQ for review and approval. The risk assessment work plan is discussed in the next section of this document.

Risk to human health cannot exist unless the contamination at a site comes in contact with a human receptor and has the ability to cause an adverse effect. A site conceptual model establishes whether contamination that is at a site or that has migrated offsite will come into contact with human receptors. The site conceptual model is used as a planning tool to help design a site investigation to collect the type of information that will be needed to conduct the risk assessment. In developing the site conceptual model, the complete range of potential sources, pathways, and receptors should be considered. As the investigation proceeds, the data being collected can be used to narrow the focus to the exposure scenario/pathway combinations that are reasonably likely to result in risk.
Components of the site conceptual model (excluding consideration of ecological receptors) may include the following:

- Contamination sources (e.g., primary sources such as tanks, drums, and buried waste; secondary sources such as contaminated soil, groundwater, non-aqueous phase liquids)
- Release mechanisms (e.g., spill, leaks, direct discharge)
- Impacted media (e.g., soil, sediments, groundwater, surface water, air)
- Migration pathways (e.g., leaching, runoff, volatilization to atmosphere or to a confined space, fugitive dust, uptake by animals/fish/plants)
- Potential human receptors (e.g., residents, workers, site visitors)
- Exposure pathways (e.g., ingestion, dermal, inhalation)

B. Developing the Risk Assessment Work Plan

Prior to completing the site-specific human health risk assessment, a risk assessment work plan should be developed and submitted to DEQ for approval. The risk assessment work plan describes the methodologies for completing the human health risk assessment for the site. It identifies the tasks necessary to define the magnitude of threats to human health posed by contaminants at the site and the activities necessary to complete the tasks. The following information should be included in the risk assessment work plan:

- A summary of site conditions
- A complete site conceptual model
- A presentation of site data for use in the risk assessment, including:
  - A discussion about how data will be evaluated for adequacy and to determine if it is appropriate for use in the risk assessment.
  - A discussion about whether or not data were grouped as “exposure units” and, if so, how the data were grouped for analysis.
  - Methods that were used to screen data to identify contaminants of interest and the results of this screening.
  - Methods that were used to statistically analyze data to estimate exposure point concentrations and the results of these calculations.
  - See Fact Sheet #28 Data Quality Objectives (DQOs) for additional information.
- Equations that will be used to estimate chemical intake and input parameters to all equations
- Toxicity criteria that will be used with chemical intake information to estimate risk
- Methods that will be used to evaluate uncertainty in the risk assessment
- Methods that will be used to develop remediation goals (including natural background evaluation as appropriate)
- Methods that will be used to compare site conditions to risk-based remediation goals
Procedures outlined in the remainder of this Fact Sheet discuss the task elements of the site-specific human health risk assessment and identify specific procedures to use in development of the risk assessment work plan.

C. Site Information

Information on existing and historical site conditions, land and water uses, and the nature and extent of contamination is needed to complete the site-specific human health risk assessment. Land and water use information, combined with information on existing and historical site conditions, assists in the identification of potentially exposed human receptors (including any sensitive subpopulations, such as children). Information on the nature and extent of contamination and potentially exposed populations allows for the identification of site-specific exposure scenarios and exposure pathways. Information on contaminants, receptors, and exposure pathways is combined in a site conceptual model that summarizes the relevant site information and sets the stage for the site-specific human health risk assessment.

D. Use Control Area Determination

Use control areas are sites where some soil contamination remains in place, requiring that use of the property be restricted over the long term.

For a site conceptual model that is developed for an unrestricted use scenario, the exposure scenarios and exposure pathways evaluated in the site-specific human health risk assessment are based on unrestricted use, (i.e., no assumption that a use control area (UCA) would be in place in the future).

For a site conceptual model that is developed for current and likely future land use, the exposure scenarios and exposure pathways may be based on an assumption that a UCA would be in place.

A UCA is created by a local government, not by DEQ or the Volunteer. Before an owner and DEQ enter into a remedy agreement that includes long term restrictions on the use of the site, the owner must obtain a use control area designation by petitioning the appropriate governmental entity or entities. A UCA is a complement to remedy agreements, covenants not to sue, and certificates of completion. More information on UCAs is available in §35-11-1609, in DEQ Fact Sheet #15 Liability Assurances, and in Fact Sheet #23 Institutional Controls, Engineering Controls, and Use Control Areas.

E. Nature and Extent of Contamination

The nature (types of contaminants and their concentrations) and extent (horizontal and vertical spatial distribution) of contamination should be determined prior to initiating a risk assessment. The process to be used in planning and conducting a site investigation is discussed in section 2 of this document. Environmental sampling to provide data for a site-specific risk assessment should not be conducted until the DQO process has been completed. This will ensure that all environmental data collected in support of the risk assessment are of known and documented
quality and have been collected at locations and in media that are pertinent to the risk assessment. According to EPA (1993), DQOs are qualitative and quantitative statements established prior to data collection that specify the quality of the data necessary to support decisions during remedial response activities. Several key issues relative to data needs in completing a risk assessment should be addressed in scoping a site investigation. These issues include:

- The types of data needed (e.g., environmental, toxicological)
- How the data will be used (e.g., site characterization, nature and extent of the plume, risk evaluation, remedy evaluation)
- The desired level of certainty for the conclusions derived from the analytical data (e.g., what are the probabilities of false positive and false negative results as a function of risk and concentration)

DEQ has developed guidance on DQOs under the Voluntary Remediation Program (see Fact Sheet #28). In addition, Fact Sheet #8 Site Characterization and the following EPA guidance documents: (EPA, 1992a; EPA, 1993; and EPA, 2000) provide information to assist the Volunteer in identifying DQOs during investigation planning to address risk assessment information needs. The site conceptual model should also be used to guide the sampling design process.

F. Identification of Contaminants of Interest

Using data obtained from the nature and extent determinations, the data can then be pre-screened to identify contaminants of interest (COIs) that will be evaluated in the risk assessment. The identification of COIs should be conducted according to procedures outlined in the EPA Region VIII guidance document Evaluating and Identifying Contaminants of Concern for Human Health (EPA, 1994). Procedures outlined in this EPA guidance document should be modified as appropriate under Wyoming cleanup statutes and be consistent with DEQ guidance. According to the EPA Region VIII guidance document, contaminants should be screened based on the following criteria to determine whether they qualify as COIs that should be carried forward in the risk assessment:

- Essential nutrients
- Exceedance of natural background concentrations
- Detection frequency
- Mobility, persistence, and bioaccumulation
- Exceedance of soil cleanup levels provided in DEQ Fact Sheet #12 Soil Cleanup Levels and cleanup levels for groundwater referenced in DEQ Fact Sheet #13 Groundwater Cleanup Levels
- Historical evidence
- Concentration and toxicity in all applicable media
While the EPA Region VIII guidance allows for either the maximum detected site value or the 95% upper confidence level on the arithmetic mean value to be used in screening, DEQ’s policy is that the maximum detected value be used in all screening for contaminants of interest, unless the Volunteer can demonstrate the adequacy of the sample size, distribution, and statistical method to DEQ to calculate the 95 percent value. Volunteers interested in using the 95% UCL should contact DEQ prior to beginning the screening process, as well as consult Fact Sheet #28

**Data Quality Objectives.** Statistical software available at [http://www.epa.gov/nerlesd1/tsc/software.htm](http://www.epa.gov/nerlesd1/tsc/software.htm) covers a wide range of possible data distribution sets and includes recommendations on when it is appropriate to use the maximum detected value.

All procedures that will be used to screen data should be presented in the risk assessment work plan provided to DEQ for review. It should be noted that although the EPA Region VIII guidance allows for screening for COIs based on detection frequency, DEQ reserves approval of such a screening method. DEQ’s decision to approve screening based on detection frequency will be based on information presented by the Volunteer in the risk assessment work plan. For screening based on detection frequency to be approved, the risk assessment work plan should include demonstrations that (1) the site has been adequately characterized, and (2) screening based on detection frequency would not eliminate chemicals from additional analysis without adequate justification.

Additionally, the Volunteer is cautioned in planning his or her investigation to ensure that analytical detection limits for all constituents in soil and groundwater are below risk-based screening concentrations. Constituents with detection limits higher than screening concentrations will need to be carried through the site-specific risk assessment process, unless the Volunteer can present information in the risk assessment work plan adequate to support their elimination.

All contaminants that are not screened out through this process should be carried forward and evaluated in the site-specific human health risk assessment.

**G. Identification of Potentially Exposed Populations**

The characteristics of the human population at the site and in the site vicinity need to be identified in order to evaluate exposure. This is necessary to ensure that the exposure scenarios selected for evaluation best represent the characteristics of the potentially exposed population. Exposure scenarios (designated “residential”, “industrial”, etc.) are comprised of one or more exposure routes appropriate to the potentially exposed population. Estimation of exposure also involves the identification of exposure pathways. An exposure pathway is the way a chemical or physical agent comes in contact with a receptor (e.g., ingestion, inhalation, dermal contact).

The VRP statute requires that site cleanup be conducted in a manner that would allow future unrestricted land use, unless it can be demonstrated by the Volunteer that such a cleanup is technically impracticable or that alternative cleanup levels for soil can be implemented through
establishment of a UCA for the site. UCA petitions require that the site-specific human health risk assessment evaluate risk under an assumption of unrestricted land use. Since residential land use is the exposure scenario that typically results in the greatest degree of potential exposure at a site, the residential exposure scenario is most often selected to represent the greatest potential risk under unrestricted land use conditions. Therefore, DEQ will require that a residential exposure scenario be evaluated to support a UCA petition to the local government, in addition to exposure scenarios that are currently representative of site conditions or may best represent future site use. The UCA petition and information necessary to complete the petition are outlined only in the Wyoming statute (see §35-11-1609) and in Fact Sheet #23 *Institutional Controls, Engineering Controls, and Use Control Areas* and are not reflected in EPA guidance documents.

DEQ has defined three default exposure scenarios (residential, industrial, and excavation worker), and associated exposure factors, for use in site-specific human health risk assessments. Equations for estimating chemical intake for these exposure scenarios by their associated exposure pathways and input parameters are provided in Appendix A to this Fact Sheet. Risk evaluation of other exposure scenarios, for example, recreational, may be needed for some sites.

Specific subpopulations that are considered sensitive may be identified for evaluation in a site-specific human health risk assessment. A sensitive subpopulation is a group of individuals that, because of behavior or physiology, are at greater risk from exposure to site chemicals. Examples of sensitive subpopulations are pregnant women and children in a residential exposure scenario. Pregnant women often comprise a sensitive subpopulation, because some chemicals are developmental toxicants of special potential risk to a developing fetus. Children are considered a sensitive subpopulation for several reasons, including:

- They are likely to have greater contact with soil and a higher incidental soil ingestion rate than an adult.
- Their smaller body size and stage of development puts them at greater risk from exposure to some chemicals, because their organs are still developing.
- Their immune systems are less robust than an adult’s.
- Exposure early in life may alter the incidence of cancers observed later in life (EPA, 2003b).

### 3. Site-Specific Human Health Risk Assessment

This section of the Fact Sheet briefly outlines the steps in evaluating site-specific human health risk. These steps are explained in detail in EPA guidance documents, which are referenced as appropriate in this section. As previously discussed, this Fact Sheet is not meant to provide a step-by-step process for completing a site-specific risk assessment, since EPA guidance documents provide this detailed information. The information provided in this section is intended to supplement EPA guidance as necessary and to identify specific preferences recommended by Wyoming DEQ for completing the assessment.
A. Exposure Assessment

The objective of the exposure assessment is to estimate the type and magnitude of exposures to the COIs that are present at or migrating from a site. The results of the exposure assessment are combined with chemical-specific toxicity information (described in section 3.A. of this Fact Sheet) to characterize potential risks (described in section 3.C. of this Fact Sheet).

The first step in evaluating the type and magnitude of exposure at a site is to group soil data into appropriate “exposure units”, if grouping the data in this manner is appropriate for risk evaluation at a site. For many sites, only one exposure unit is present at the site, and sub-grouping of the data into smaller site segments is not necessary or appropriate. Grouping soil data into exposure units is appropriate if the site could be subdivided in the future or if different types of exposure are associated with different areas of the site. The concept of an exposure unit does not apply to groundwater, because the VRP requires that all groundwater be cleaned up to promulgated levels or risk-based calculated levels. In general, subdividing air and surface water data into discreet exposure units is not appropriate, and all data would be grouped together by media into one overall site exposure unit for estimating exposure point concentrations. However, if a Volunteer believes that subdividing these site data into discrete exposure units is warranted, the rationale and methods used should be presented in the risk assessment work plan for DEQ review.

The next step is to develop contaminant concentrations (referred to as “exposure point concentrations”) that are representative of the environmental concentrations to which an individual may be exposed in that exposure unit. An exposure point concentration is developed for each COI in each environmental medium in each exposure unit identified in the conceptual site model. The exposure point concentrations are developed by statistically evaluating the data in accordance with procedures approved by DEQ to identify values for use in the risk assessment.

In some cases, data may not be available at the anticipated point of contact to estimate an exposure point concentration. For example, a potential point of contact with groundwater may be offsite, and actual data from the location offsite where this contact may occur would not be available. Another example could be evaluation of indoor air concentrations of solvent vapors that may result from the presence of contaminated soil or groundwater under a building (i.e., vapor intrusion). Although air concentrations can be measured in existing buildings, it may be difficult in some cases to separate the affects of vapor intrusion from background sources (e.g., indoor sources of vapors). In other cases, the Volunteer may have to evaluate the potential for vapor intrusion to impact future buildings. In these cases, fate and transport models may be needed to estimate the exposure point concentration at a point of contact and/or to supplement field data. Use of fate and transport modeling is further discussed in section 3.A.c. and in Fact Sheet #25 Using Fate and Transport Models to Evaluate Cleanup Levels. It should be noted that groundwater modeling would be done and the results interpreted within the context of Fact Sheet #13 Groundwater Cleanup Levels. These are Wyoming standards and are not reflected...
in EPA guidance documents. Further guidance on evaluating vapor intrusion to indoor air from groundwater and soils is available in EPA, 2000a and VRP Fact Sheet #25.

The next step in the exposure assessment is to calculate chemical intake for all identified exposure scenario/exposure pathway combinations (for example, residential exposure scenario/soil ingestion; industrial exposure scenario/dermal contact with soil) identified for evaluation in the risk assessment. The exposure point concentrations are the representative concentrations used in these calculations.

These steps in the exposure assessment process are described in the following sections of this document, and in the guidance documents cited.

a. Identifying Exposure Units

An exposure unit represents an area of a site or part of a site that a receptor may contact through the type of current or future site use identified in the conceptual model. Data should be grouped in exposure units for calculating exposure point concentrations based on the type of exposure a current or future receptor may sustain. For example, a site may have both surface and subsurface soil contamination. For evaluation of a residential exposure scenario, exposure to both surface soil (0 to 1 feet bgs, which would occur during day-to-day use of a yard) and surface plus subsurface soil (0 to 12 feet bgs, which could occur in the event of site excavation for a new structure) should be considered, since exposure to both types of soil exposure units could occur under different circumstances. Therefore, for the purpose of developing an exposure point concentration for a COI in soil for evaluating residential risk, surface soil data (0 to 1 foot bgs) would be grouped together as one exposure unit and would not include subsurface soil (soil at 1 feet or greater depth) data for one evaluation, and all soil data for 0-12 feet bgs would be grouped as a second exposure unit for the other evaluation. It should be noted that the 12 foot depth is considered by Wyoming DEQ to be the typical depth of excavation for a home basement/foundation. Meeting soil cleanup levels to a depth of 12 feet is considered by Wyoming DEQ to be protective of human health under conditions of unrestricted land use.

If it is likely that an excavation worker (such as a utility worker) may work in the area in the future and excavate soil for utility access, the worker will contact both surface and subsurface soil to the depth of excavation. The potential depth of excavation that will be used in evaluation of an excavation worker exposure scenario should be identified and supported with site-specific information in the risk assessment work plan. If the exact depth of potential excavation is not known, a default assumption of 12 feet should be used. In this case, surface and subsurface soil would be grouped together as an exposure unit for developing an exposure point concentration.

For large sites, multiple potential exposure units may be present in soil depending on the current and likely future use of the property. Additionally, to support a UCA petition to the local government and any claim of the technical impracticability of conducting cleanup to unrestricted land use conditions, the analysis of the residential exposure scenario will be required for most
sites, regardless of current and likely future land use for the purpose of developing required information. Given the future land use anticipated for the site, it may be inappropriate to group all soils data together, as it may “dilute” the contribution of localized contamination that may result in significant potential exposure. For the residential exposure situation, DEQ has defined a default residential exposure unit as 1/5 acre (the average residential lot size). If the Volunteer maintains that a larger residential default exposure unit should be used (as supported by covenants or zoning laws with minimum/maximum lot sizes), the Volunteer should provide justification for the larger default lot size to DEQ in the risk assessment work plan. It should be noted that the default residential exposure unit of 1/5 acre is a Wyoming guideline not reflected in EPA guidance documents. Additional information about grouping data for developing exposure concentrations is available in reference document (EPA 1989). A discussion of how data will be grouped for the purpose of evaluating exposure should be presented in the risk assessment work plan that will be submitted to DEQ for review and approval.

b. Identifying Exposure Point Concentrations

The exposure point concentration is the concentration of the COI in the environmental media at the point of human exposure. The choice of sampling data used with respect to land use to estimate exposures in each scenario should reflect actual exposure points. DEQ expects that the site-specific human health risk assessment consider conservative distributions of exposure. To that end, the reasonable maximum exposed (RME) individual, as defined by EPA (1989), in each exposure scenario should be quantified.

As described in section 2.E. above, prior to calculating exposure point concentrations, the environmental data should be evaluated for data quality using procedures outlined in the following reference documents: (EPA, 1992a and EPA, 2000). If data are excluded from use in the risk assessment, the basis for exclusion should be included in the risk assessment work plan.

The exposure point concentration for each COI in each environmental media (or in each exposure unit in soil, if exposure units are appropriate for the site) should be estimated using methods appropriate to the amount of data (sample sizes) available, with consideration of whether adequate site characterization has been performed. In cases where 30 samples or more are available for estimating an exposure point concentration, a 95 percent upper confidence limit (UCL) on the arithmetic mean (or geometric mean if the values are log-normally distributed) of the contaminant concentrations should be used. If there is a high degree of variability in contaminant concentrations, the 95 percent UCL on the average concentration may exceed the maximum concentration. In such a situation, the maximum contaminant concentration should be used to represent the exposure point concentration. If fewer than 30 samples are available for use, the Volunteer should discuss procedures for estimating exposure point concentrations with DEQ. In these cases, other statistical methods (e.g. use of maximum detected concentrations, non-parametric analysis) may be expected.

Procedures outlined in the following reference documents: (EPA, 1989; EPA, 1992a; and EPA, 2000) should be followed to decide how “non-detects” will be handled in developing exposure
point concentrations for COIs. Procedures used by the Volunteer to calculate exposure point concentrations should be presented in the risk assessment work plan for DEQ review.

Groundwater samples from a single well should use the 95 percent UCL average concentration that would be contacted by the RME individual, if samples have been collected from a sufficient number (6 or greater) sampling events. If fewer samples are available, the Volunteer should consult with DEQ to determine an alternate approach.

c. **Fate and Transport Modeling**

The two main purposes of fate and transport modeling are:

- Predictive modeling for developing site specific soil cleanup levels where levels specified in Fact Sheet #12 *Soil Cleanup Levels* are not appropriate to site specific circumstances. DEQ guidance on such modeling is found in Fact Sheet #25 *Using Fate and Transport Models to Evaluate Cleanup Levels*.

- Predictive modeling for risk assessment purposes. For example, the Johnson and Ettinger Model may be used in certain circumstances to evaluate the potential for vapor intrusion (see Fact Sheet #25 *Using Fate and Transport Models to Evaluate Cleanup Levels*).

Fate and transport modeling is used to account for site-specific circumstances during risk assessment, for example, to estimate an exposure point concentration for a location where acquiring actual data is infeasible or for a location where there would be considerable variability in the concentration over time.

In situations where actual data from real points of exposure or potential exposure are available, DEQ expects that these data will be used. For example, DEQ expects that potentially affected residential wells will be sampled for groundwater and that indoor air in existing buildings will be sampled for vapors; however, modeling indoor air may be preferred if background contributions or other factors make indoor air concentration data difficult to collect or interpret.

Other examples of situations where it may be necessary to conduct fate and transport modeling for risk assessment purposes include:

- Estimating an exposure point concentration for a location where data are not available for an environmental medium at all potential points of contact with potential receptors, such as a contaminant in groundwater at a location other than a location where data are directly available.

- Predicting the contaminant concentrations at points of contact with receptors due to contaminant migration within an environmental media, such as movement of contamination in soil or groundwater.

- Predicting the contaminant concentrations at points of contact with receptors due to contaminant movement between environmental medium, such as volatilization of contaminants from soil or water into air.
Modeling a predicted concentration of a bioaccumulative contaminant in a food product that may have assimilated site contamination.

Volunteers should use existing DEQ guidance on fate and transport modeling and work with DEQ to develop site-specific fate and transport modeling approaches for risk assessment. Keep in mind that any fate and transport model used to establish site specific cleanup levels must assume that there will be no reduction in soil leachate concentrations from mixing in an aquifer. See Fact Sheet #11 Risk Assessment, Question 3, for additional information on fate and transport considerations during site cleanup.

d. Quantifying Exposure

As previously discussed, site-specific human health risk assessments will require evaluation of the residential exposure scenario to document risk associated with unrestricted land use conditions. Other exposure scenarios may be evaluated to estimate risk associated with current and likely future land use. All exposure scenarios and pathways that will be evaluated in the site-specific risk assessment should be presented in the risk assessment work plan for review by DEQ. The work plan should include equations that will be used to calculate contaminant intake for each exposure scenario/pathway combination, and all input parameters that will be used in the equations. If the exposure scenarios presented in Appendix A are evaluated for a site, deviations from these default equations and exposure parameters may be appropriate for some sites. Such deviations and their justification should be presented in the risk assessment work plan submitted to DEQ for approval.

The exposure scenarios associated with a site are selected based on the location and activities of current and reasonably anticipated future populations associated with probable land use. Chapter 6 of Risk Assessment Guidance for Superfund, Volume I, Human Health Evaluation Manual (Part A) (EPA 1989) provides information to assist the Volunteer in identifying the complete range of potentially exposed populations and methods to be used in quantifying exposure. These methods should be used as a supplement to specific procedures provided in this section that have been identified by DEQ as necessary for use in completing a site-specific human health risk assessment.

An exposure pathway describes a mechanism by which an individual or population is exposed to site chemicals. Exposure pathways that are considered complete should be identified for evaluation in the risk assessment. In order for an exposure pathway to be considered complete, it must contain all of the following elements:

i. A contaminant source
ii. A mechanism for contaminant release
iii. A transport mechanism to the various environmental media
iv. Exposure media
v. Exposure route
vi. Receptors
All probable exposure pathways should be identified in the site conceptual model in the risk assessment work plan, and complete pathways should be identified and evaluated in the risk assessment with respect to the unrestricted use scenario. Exposure pathways that are interrupted with existing engineering controls, such as a parking lot or a street, should also be evaluated with respect to restricted use. The Volunteer should be able to provide adequate site-specific information to support the exclusion of any probable pathways from further analysis in the risk assessment. Examples of exposure pathways that may be evaluated in a site-specific risk assessment include:

- Ingestion of soil and dust
- Dermal intake from contact with soil and dust
- Inhalation of fugitive dust or volatiles from soil
- Ingestion of water
- Inhalation of vapors from water

Other pathways of contact with contaminants in the environment, although less common, may need to be evaluated on individual sites, depending on the type of contaminants present and the land use. These pathways may include ingestion of game, fish, or homegrown vegetables and fruit.

DEQ has defined three default exposure scenarios (residential, industrial, excavation worker), common exposure pathways associated with these exposure scenarios, and associated exposure parameters for use in site-specific human health risk assessments. Equations for estimating chemical intake for these exposure scenarios by their associated exposure pathways and input parameters are provided in Appendix A to this Fact Sheet. Default exposure scenarios and pathways include:

- **Residential exposure**
  - incidental soil ingestion
  - dermal intake from contact with soil
  - inhalation of soil particulate and volatile constituents
  - groundwater ingestion
  - inhalation of volatiles from tap and groundwater

- **Industrial exposure**
  - incidental soil ingestion
  - dermal contact with soil
  - inhalation of soil particulate and volatile constituents
  - groundwater ingestion
  - inhalation of volatiles from tap and groundwater

- **Excavation worker exposure**
  - incidental soil ingestion
- dermal contact with soil
- inhalation of soil particulate and volatile constituents
- inhalation of volatile constituents from groundwater while trenching

Appendix A includes a table (Table I) that provides default parameters to these equations that should be used when calculating chemical intakes to evaluate associated risks, rather than equations and intake parameters provided for these exposure scenarios in EPA guidance documents.

The equations provided in Figures 1-3 and 1-5 of Appendix A should be used to estimate inhalation risk from volatile contaminants present in soil and water, respectively. EPA defines a volatile chemical as those with a Henry’s Law constant (atm-m³/mol) greater than $10^{-5}$ and a molecular weight less than 200 g/mol (EPA 1996a). To develop the airborne concentration term of the volatile contaminant for uses in Figures 1-3 and 1-5, air contaminant data may be used. Airborne contaminant concentrations may be modeled using procedures developed by EPA for the calculation of risks from inhalation exposure (EPA 1989). EPA has updated these procedures for volatilization from tap water (EPA 1996a) and for vapor intrusion (EPA 2002a). According to current EPA policy, the risks from inhalation exposure to volatile contaminants from soil or groundwater (vapor intrusion) should be calculated using the Reference Concentration (RfC) or inhalation unit risk (UR) values provided in the EPA IRIS database (and discussed in the next section of this guidance document), and these procedures are referenced in section 5 of this document (EPA 2002a).

The equation in Figure 1-4 of Appendix A is used to estimate ingestion intake from contaminants in groundwater. If using groundwater at an industrial site, note that DEQ requires the use of residential exposure assumptions, which are reflected in the equation. The equation in Figure 1-5 accounts for the potential for volatile contaminants (as defined by EPA 1996a) in tap water to contribute to risk as a result of their volatilization from the water during its use as a potable water source and subsequent inhalation exposure.

The equations in Appendix A for calculating intake of carcinogens under the residential exposure scenario use age-adjusted intake factors that take into account the difference in intake rates, body weights, and exposure duration for children from 1 to 6 years old and others from 7 to 31 years old. This health protective approach is used to take into account the higher rates of intake in children (especially with respect to soil ingestion), as well as the higher rates of intake in children expected for a long-term resident. Additional information on the assumptions that are used in calculating these age-adjusted intake factors is available in EPA, 1991a and EPA, 1991b. In some cases, it may be appropriate to use more age-specific intake factors for calculating risk. DEQ should be consulted before using alternative values.

B. Toxicity Assessment

The toxicity assessment in the site-specific human health risk assessment is where the relationship between the dose of a contaminant and its toxic effect is established. The
preparation of the toxicity assessment relies primarily on existing toxicity information and does not usually involve development of new toxicity information or dose-response relationships. The existing toxicity criteria developed by EPA are what are typically used in the human health risk assessment. These toxicity criteria include reference dose values for noncarcinogenic compounds and cancer potency values (sometimes referred to as cancer slope factors) for known and potential carcinogens. The toxicity assessment should be conducted according to procedures outlined in Chapter 7 of reference document (EPA 1989).

The hierarchy of toxicological sources of information that should be used for identifying toxicity values is provided in reference document, EPA, 2003a. The hierarchy for obtaining information, in the order that it should be followed, is the following:

Tier 1 – EPA’s online Integrated Risk Information System (IRIS).

Tier 2 – EPA’s Provisional Peer Reviewed Toxicity Values (PPRTVs), which are developed by the EPA Office of Research and Development/National Center for Environmental Assessment/Superfund Health Risk Technical Support Center and are available on their website.

Tier 3 – Other toxicity values, including values developed by the California Environmental Protection Agency (Cal EPA) and the Agency for Toxic Substances and Disease Registry (ATSDR).

As discussed in the previous section, inhalation risk should be calculated using the Reference Concentration (RfC) or inhalation unit risk (UR) values now provided in IRIS.

The risk assessment work plan must identify all compounds that do not have toxicity criteria available. The DEQ believes that in the absence of contrary data, the qualitative default assumption is that, if the compound is absorbed by a route to give an internal dose, it may be absorbed by other routes. Therefore, in the absence of toxicity criteria for any one route of exposure, the work plan may not automatically assume the compound may be eliminated from further consideration. Rather, the risk assessment work plan should evaluate route-to-route exposure extrapolations according to procedures outlined in Chapter 7 of reference document EPA, 1989, and Part E of reference document EPA, 2004b.

Plans for use of toxicity criteria from the three alternate sources cited above and any route-to-route exposure extrapolations should be discussed in the risk assessment work plan and approved by DEQ prior to their use.

The default exposure scenarios provided by DEQ include an excavation worker scenario with an assumed exposure duration of 1 year. Toxicity values based on one year of human exposure are considered “subchronic”. Most of the toxicity values provided in the EPA IRIS database are “chronic” toxicity values based on an assumption of exposure duration longer than 1 year. Toxicity values based on chronic exposure are typically more conservative than values based on subchronic exposure. However, since an excavation worker may work at several
contaminated sites over the course of many years or may work over a longer period than one year at any given site, DEQ maintains that use of a chronic toxicity value is not unreasonable in the absence of specific work history information. If subchronic toxicity values are available on the IRIS database, they may be used in calculating risk under the excavation worker scenario if it has been determined that there is a subchronic exposure duration and it has been approved by DEQ. However, if alternate sources of information will be used in developing subchronic toxicity values because they are not available from EPA, this analysis must be approved by DEQ prior to its use in a risk assessment, and it must be completed by an individual qualified to conduct the analysis.

As mentioned earlier, DEQ acknowledges that information, guidance documents, and references, including toxicity values, are constantly updated. Volunteers are encouraged to bring new or updated information to the attention of DEQ. DEQ policy is to update its material on an as-needed basis, generally when major reference materials are updated or revised.

C. Risk Characterization

Risk characterization involves integrating the information from the exposure assessment and the toxicity assessment to form the basis for the characterization of human health risks. The risk characterization should present the qualitative and quantitative descriptions of risks. Risk characterization should be completed according to the procedures outlined in Chapter 8 of reference document EPA, 1989.

Incremental cancer risks (for known and suspected carcinogens) and hazard indices (for noncarcinogens) should be estimated separately for each exposure scenario/exposure pathway combination. Individual values for chemicals should be summed as described in EPA guidance (EPA, 1989), and total risk summaries for all media and all exposure scenarios should be included in the risk assessment. These risk totals should be compared to the acceptable risk limits established in Article 16 of the Environmental Quality Act (§35-11-1605[a][ii][B]).

The statutory limits for acceptable carcinogenic risk state that the lifetime excess cancer risk to any exposed individual will not exceed one-in-one million (1 x 10^-6) to one-in-ten-thousand (1 x 10^-4). Consistent with the statute and EPA guidance, DEQ will use risk reduction to the one-in-one million level as a point of departure, or target risk level, for remedies when evaluating remedy options (see §35-11-1605[a][ii][B]). Contaminated sites starting with risk that is within the 1 x 10^-4 to 1 x 10^-6 range are not necessarily exempt from remediation. For example, if a site was starting at 1 x 10^-5 risk for unrestricted site use, an evaluation would be needed to determine the potential for risk reduction to 1 x 10^-6. It is DEQ's preference and expectation that cleanups will attain the one-in-one million risk level for all carcinogens.

The statutory risk limit for noncarcinogenic substances is a hazard index of 1.0.

If total carcinogenic or noncarcinogenic risks for any given exposure scenario exceed these statutory limits, consultation with DEQ will be necessary.
D. Uncertainty Analysis

The risks estimated in the site-specific human health risk assessment are conditional estimates based on multiple assumptions about exposures, toxicity, etc. Each assumption is associated with some degree of uncertainty. These uncertainties may contribute to an overestimation or underestimation of the risks at the site. In order to present the risk estimates in the appropriate context for understanding their limitations, a qualitative discussion of uncertainty should be included in all site-specific human health risk assessment reports. Specific uncertainty factors that should be considered include:

- Uncertainty in the adequacy of the site characterization data and historical information about the site
- Uncertainty in selection of contaminants of interest
- Uncertainty in the toxicity criteria used
- Uncertainty in the exposure assessment

If mathematical models are used in the risk assessment to estimate concentrations of contaminants in environmental media where actual measured data are not available, a sensitivity analysis should be completed for the modeled results and presented in the report.

Additional discussion on developing the uncertainty analysis can be found in Chapter 8 of EPA, 1989.

E. Documentation of Results

A risk assessment report should be prepared for all site-specific human health risk assessments and should include a description of all methods used in conducting the site-specific risk assessment and summaries of all risk estimates for all media and exposure scenario/exposure pathway combinations evaluated. A suggested outline for the site-specific human health risk assessment report can be found in Chapter 9 of EPA, 1989. The information in the report should be presented in a transparent manner such that all calculations can be reviewed by DEQ. In all cases, DEQ will request that electronic copies of spreadsheets used in risk calculations be provided for review or sufficient information provided to allow DEQ to perform a QA/QC of all calculations.

4. How can I get more information about the VRP?

To learn about VRP sites that may exist in your community, obtain copies of other VRP Fact Sheets/guidance documents, get answers to your questions, or volunteer for the program, contact DEQ at (307) 777-7752 or visit the website at: http://deq.wyoming.gov/shwd/voluntary-remediation-program/

The VRP website includes all of the Fact Sheets and other guidance documents for the VRP. This website is updated frequently and includes the latest information about DEQ's progress in developing guidance, policy, and other supporting documents for the VRP.
5. References

For additional information regarding human health risk assessment, the Volunteer is referred to the following documents.


Forum (EPA/630/R-03/003, February 2003) Available at:  
http://www.epa.gov/cancerguidelines/draft-guidelines-carcinogen-earlylife.htm


Appendix A

Human Health Chemical Intake Equations and Human Health Exposure Factors

Carcinogens, residential =

\[ ADD = \frac{C_s \cdot IRS_{adj} \cdot CF_{km} \cdot EF_r}{AT_c} \]

Carcinogens, occupational and excavation =

\[ ADD = \frac{C_s \cdot IRS_c \cdot CF_{km} \cdot EF_o \cdot ED_o}{BW_a \cdot AT_c} \]

Noncarcinogens, residential =

\[ ADD = \frac{C_s \cdot IRS_c \cdot CF_{km} \cdot EF_r \cdot ED_r}{BW_c \cdot AT_n} \]

Noncarcinogens, occupational and excavation =

\[ ADD = \frac{C_s \cdot IRS_c \cdot CF_{km} \cdot EF_o \cdot ED_o}{BW_a \cdot AT_n} \]

Where:

- \( ADD \) = Average daily dose from incidental soil ingestion (mg/[kg-d])
- \( AT_n \) = Averaging time, noncarcinogen (d)
- \( AT_c \) = Averaging time, carcinogens (d)
- \( BW_a \) = Body weight, adult (kg)
- \( BW_c \) = Body weight, child (kg)
- \( C_s \) = Contaminant concentration in soil (mg/kg)
- \( CF_{km} \) = Conversion factor (10^{-6} kg/mg)
- \( EF_r \) = Exposure frequency, residential (d/yr)
- \( EF_o \) = Exposure frequency, occupational or excavation (d/yr)
- \( ED_c \) = Exposure duration, child (yr)
- \( ED_r \) = Exposure duration, residential (yr)
- \( ED_o \) = Exposure duration, occupation or excavation (yr)
- \( IRS_{adj} \) = Age-adjusted incidental soil ingestion factor (mg-yr/[kg-d]) (See note (a) below)
- \( IRS_c \) = Soil ingestion rate, child (mg/d)
- \( IRS_o \) = Soil ingestion rate, occupation or excavation (mg/d)

NOTES:

(a) The age-adjusted soil ingestion factor takes into account the difference in daily soil ingestion rates, body weight, and exposure duration for children from 1 to 6 years old, and others from 7 to 31 years old.
Carcinogens, residential = \[ ADD = \frac{C_s \cdot SAS_{adj} \cdot CF_{km} \cdot ABS \cdot EF_r}{AT_r} \]

Carcinogens, occupational and excavation = \[ ADD = \frac{CS_s \cdot SA_s \cdot CF_{km} \cdot AF_o \cdot ABS \cdot EF_o \cdot ED_o}{BW_a \cdot AT_o} \]

Noncarcinogens, residential = \[ ADD = \frac{C_s \cdot SA_s \cdot CF_{km} \cdot AF_c \cdot ABS \cdot EF_c \cdot ED_c}{BW_c \cdot AT_n} \]

Noncarcinogens, occupational and excavation = \[ ADD = \frac{C_s \cdot SA_s \cdot CF_{km} \cdot AF_o \cdot ABS \cdot EF_o \cdot ED_o}{BW_a \cdot AT_n} \]

Where:
- \( ADD \) = Absorbed daily dose from contact with soil (mg/[kg-d])
- \( AF_o \) = Adherence factor, occupational or excavation (mg/cm\(^2\))
- \( AF_c \) = Adherence factor, child (mg/cm\(^2\))
- \( AT_n \) = Averaging time, noncarcinogens (d)
- \( AT_c \) = Averaging time, carcinogens (d)
- \( BW_a \) = Body weight, adult (kg)
- \( BW_c \) = Body weight, child (kg)
- \( C_s \) = Contaminant concentration in soil (mg/kg)
- \( CF_{km} \) = Conversion factor \(10^{-6}\) kg/mg
- \( ABS \) = Dermal absorption factor (unitless)
- \( ED_o \) = Exposure duration, occupation or excavation (yr)
- \( ED_c \) = Exposure duration, child (yr)
- \( ED_r \) = Exposure duration, residential (yr)
- \( EF_r \) = Exposure frequency, residential (d/yr)
- \( EF_o \) = Event frequency, occupation or excavation (d/yr)
- \( SA_a \) = Exposed skin surface area, adult (cm\(^2\))
- \( SA_c \) = Exposed skin surface area, child (cm\(^2\))
- \( SAS_{adj} \) = Age-adjusted soil dermal contact factor ([mg-yr]/[kg-event]) (See note (a)below)

NOTES:
- (a) The age-adjusted soil dermal contact factor takes into account the difference in skin surface area, adherence factor, body weight, and exposure duration for children from 1 to 6 years old, and others from 7 to 31 years old.

| Human Health Chemical Intake Equations: Dermal Contact with Soil | Figure 1-2 |
The lifetime excess cancer risk for the inhalation pathway assumes continuous exposure for 24 hours per day for a lifetime of 70 years and is calculated using EPA’s equation:

\[
Risk = (C_a \cdot 1000) \cdot IUR
\]  \hspace{1cm} \text{[Eq. 1] (a)}

\[
HQ = \left( \frac{C_a}{RfC} \right)
\]  \hspace{1cm} \text{[Eq. 2] (a)}

For less than 70 years of exposure, the cancer risk to a resident from inhalation is shown below.

\[
\text{Carcinogen Risk, residential} = IUR \cdot (C_a \cdot 1000) \left( \frac{ET \cdot EF \cdot ED}{AT} \right)
\]  \hspace{1cm} \text{[Eq. 3]}

For less than 70 years of exposure, the noncancer hazard to a resident from inhalation is shown below.

\[
\text{Noncarcinogen HQ, residential} = \left( \frac{C_a}{RfC} \right) \left( \frac{ET \cdot EF \cdot ED}{AT} \right)
\]  \hspace{1cm} \text{[Eq. 4]}

\[
\text{Carcinogen Risk, occupational, excavation} = IUR \cdot (C_a \cdot 1000) \left( \frac{1/2 \cdot EF \cdot ED}{AT} \right)
\]

\[
\text{Noncarcinogen HQ, occupational, excavation} = \left( \frac{C_a}{RfC} \right) \left( \frac{1/2 \cdot EF \cdot ED}{AT} \right)
\]

Where:

- \(C_a\) = Contaminant Concentration in Air (mg/m\(^3\)) (Measured or modeled\(^{(c)}\))
- \(Risk\) = Lifetime Excess Cancer Risk (unitless)
- \(HQ\) = Hazard Quotient Noncancer Hazard (unitless)
- \(IUR\) = Inhalation Unit Risk (\(\mu g/m^3\))\(^{-1}\)
- \(RfC\) = Reference Concentration (mg/m\(^3\))
- \(ET_r\) = Exposure Time, residential (hours/day)
- \(EF\) = Exposure Frequency, residential or occupational (days/year)
- \(ED\) = Exposure duration, residential or occupational (years)
- \(AT_{n}\) = Averaging time, noncarcinogen (d)
- \(AT_{c}\) = Averaging time, carcinogen (d)

NOTES:


b) In this equation, exposure time is replaced by \(1/2\) and 24 hours per day is eliminated from the Averaging Time. These adjustments are made because it is likely that a higher exposure will occur during a normal 8 hour shift due to increased physical activity and rate of inhalation. Using an 8 hour per 24 hour for adjustment would likely underestimate exposure to workers from a chemical.

c) \(C_a\) may be measured. Or, particulate, indoor and outdoor \(C_a\) may be modeled via Particulate Emissions Factors, the Johnson-Ettinger model, and soil Volatilization Factors, respectively (See EPA, 1991a).
Carcinogens, residential = \[
ADD = \frac{C_w \cdot IRW_{adj} \cdot EF_r}{AT_c}
\]

Carcinogens, occupational\(^{(a)}\) = \[
ADD_a = \frac{C_w \cdot IRW_a \cdot EF_o \cdot ED_o}{AT_c \cdot BW_a}
\]

Noncarcinogens, residential = \[
ADD = \frac{C_w \cdot IRW_{adj} \cdot EF_r}{AT_n}
\]

Noncarcinogens, occupational\(^{(a)}\) = \[
ADD_a = \frac{C_w \cdot IRW_a \cdot EF_o \cdot ED_o}{AT_n \cdot BW_a}
\]

Where:

- **ADD** = Average daily dose from water ingestion (mg/kg-d)
- **AT\(_c\)** = Averaging time, carcinogen (days)
- **AT\(_n\)** = Averaging time, noncarcinogen (days)
- **BW\(_a\)** = Body weight, adult (kg)
- **C\(_w\)** = Constituent concentration in water (mg/L)
- **ED\(_o\)** = Exposure duration, occupational (yr)
- **ED\(_r\)** = Exposure duration, resident (yr)
- **EF\(_o\)** = Exposure frequency, occupational (d/yr)
- **IRW\(_{adj}\)** = Age-adjusted water ingestion rate ([L-yr]/[kg-d]) (See note (b) below)
- **IRW\(_a\)** = Ingestion rate, occupational ([L/d]) (See note (c) below)

**NOTES:**

- **(a)** Occupational groundwater ingestion exposure is assumed only if groundwater is being used to provide drinking water to workers. Incidental ingestion while trenching is not assumed.
- **(b)** The age-adjusted ingestion rate takes into account the difference in the daily water ingestion rate, body weight, and exposure duration for children from 1-6 years and from 7 to 31 years old. Consistent with RAGS, Part B (EPA, 1991a).
- **(c)** Assumes the adult water consumption rate of 2.5 liters per day. This assumes a worker engages in a higher work activity and drinks 2.5 liters of water while at work (see Table 1).
See Figure 1-3 for the citations associated with this pathway.

Carcinogen Risk, residential = \[ IUR \cdot (C_w \cdot 1000 \cdot VF_w) \left( \frac{ET_r \cdot EF_r \cdot ED_r}{AT_r} \right) \]

Noncarcinogen HQ, residential = \[ \left( \frac{(C_w \cdot VF_w)}{RfC} \right) \left( \frac{ET_r \cdot EF_r \cdot ED_r}{AT_r} \right) \]

Carcinogen Risk, occupational = \[ IUR \cdot (C_w \cdot 1000 \cdot VF_w) \left( \frac{1/2 \cdot EF_o \cdot ED_o}{AT_o} \right) \]

Noncarcinogen HQ, occupational = \[ \left( \frac{(C_w \cdot VF_w)}{RfC} \right) \left( \frac{1/2 \cdot EF_o \cdot ED_o}{AT_o} \right) \]

Where:
- \( C_w \) = Contaminant concentration in water (mg/L)
- \( Risk \) = Lifetime Excess Cancer Risk (unitless)
- \( HQ \) = Hazard Quotient Noncancer Hazard (unitless)
- \( IUR \) = Inhalation Unit Risk (\( \mu g/m^3 \))^{-1}
- \( RfC \) = Reference Concentration (mg/m^3)
- \( VF_w \) = Chemical-specific volatilization factor for tap water (L/m^3) (See note (a) below)
- \( ET_r \) = Exposure Time, residential (hours/day)
- \( EF_r \) = Exposure Frequency, residential (days/year)
- \( EF_o \) = Exposure Frequency, occupational (days/year)
- \( ED_r \) = Exposure duration, residential (years)
- \( ED_o \) = Exposure duration, occupational (years)
- \( AT_c \) = Averaging time, cancer (d)
- \( AT_n \) = Averaging time, noncancer (d)

NOTES:
(a) \( VF_w \) for tap water is typically based on volatilization from tap water into a residence. This assumption may potentially overestimate the risk to an occupational receptor where building volumes may be greater.
### Table 1: Human Health Exposure Factors

<table>
<thead>
<tr>
<th>Exposure Factor (Symbol)</th>
<th>Units</th>
<th>Residential</th>
<th>Occupational Worker</th>
<th>Excavation Worker</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Child</td>
<td>Adult</td>
<td>Adult</td>
</tr>
<tr>
<td>Body Weight (BW)</td>
<td>kg</td>
<td>BW&lt;sub&gt;c&lt;/sub&gt; = 15&lt;sup&gt;b&lt;/sup&gt;</td>
<td>BW&lt;sub&gt;a&lt;/sub&gt; = 80&lt;sup&gt;a&lt;/sup&gt;</td>
<td>BW&lt;sub&gt;a&lt;/sub&gt; = 80&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Incidental soil ingestion rate (IRS)</td>
<td>mg/d</td>
<td>200&lt;sup&gt;b&lt;/sup&gt;</td>
<td>100&lt;sup&gt;b&lt;/sup&gt;</td>
<td>100&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>Age-adjusted incidental soil ingestion (IRS&lt;sub&gt;adj&lt;/sub&gt;)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>([mg·yr]/[kg·d])</td>
<td>114&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Groundwater ingestion rate (IRW)</td>
<td>L/d</td>
<td>IRW&lt;sub&gt;c&lt;/sub&gt; = .78&lt;sup&gt;f&lt;/sup&gt;</td>
<td>IRW&lt;sub&gt;a&lt;/sub&gt; = 2.5&lt;sup&gt;a&lt;/sup&gt;</td>
<td>IRW&lt;sub&gt;a&lt;/sub&gt; = 2.5&lt;sup&gt;a&lt;/sup&gt;</td>
</tr>
<tr>
<td>Age-adjusted groundwater ingestion rate (IRW&lt;sub&gt;adj&lt;/sub&gt;)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>([L·yr]/[kg·d])</td>
<td>1.1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Chemical-Specific Volatilization Factor for water (VF&lt;sub&gt;w&lt;/sub&gt;)</td>
<td>See RAGS Part B (EPA, 1991b) and EPA 2004b.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposed surface area (SA) soil contact</td>
<td>cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>SA&lt;sub&gt;c&lt;/sub&gt; = 2690&lt;sup&gt;h&lt;/sup&gt;</td>
<td>SA&lt;sub&gt;a&lt;/sub&gt; = 6032&lt;sup&gt;h&lt;/sup&gt;</td>
<td>SA&lt;sub&gt;a&lt;/sub&gt; = 3470&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
<tr>
<td>Age-adjusted exposed surface area (SAS&lt;sub&gt;adj&lt;/sub&gt;)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>([mg·yr]/[kg·d])</td>
<td>361&lt;sup&gt;g&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inhalation rate (IRA)</td>
<td>m&lt;sup&gt;3&lt;/sup&gt;/d</td>
<td>IR&lt;sub&gt;c&lt;/sub&gt; = 10&lt;sup&gt;i&lt;/sup&gt;</td>
<td>IR&lt;sub&gt;a&lt;/sub&gt; = 20&lt;sup&gt;b&lt;/sup&gt;</td>
<td>IR&lt;sub&gt;a&lt;/sub&gt; = 20&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Age-adjusted inhalation factor (INF&lt;sub&gt;adj&lt;/sub&gt;)&lt;sup&gt;j&lt;/sup&gt;</td>
<td>([m&lt;sup&gt;3&lt;/sup&gt;·yr]/[kg·d])</td>
<td>11&lt;sup&gt;g&lt;/sup&gt;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatilization Factor for soil (VF&lt;sub&gt;s&lt;/sub&gt;)</td>
<td>See Soil Screening Guidance (EPA 1996 a,b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Particulate Emission Factor (PEF)</td>
<td>See Soil Screening Guidance (EPA 1996 a,b)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exposure frequency (EF)</td>
<td>d/yr</td>
<td>EF&lt;sub&gt;c&lt;/sub&gt; = 350&lt;sup&gt;b&lt;/sup&gt;</td>
<td>EF&lt;sub&gt;c&lt;/sub&gt; = 350&lt;sup&gt;b&lt;/sup&gt;</td>
<td>EF&lt;sub&gt;a&lt;/sub&gt; = 250&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Exposure duration (ED)</td>
<td>yr</td>
<td>ED&lt;sub&gt;c&lt;/sub&gt; = 6&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ED&lt;sub&gt;a&lt;/sub&gt; = 26&lt;sup&gt;b&lt;/sup&gt;</td>
<td>ED&lt;sub&gt;a&lt;/sub&gt; = 25&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Soil adherence factor (AF)</td>
<td>mg/cm&lt;sup&gt;2&lt;/sup&gt;</td>
<td>AF&lt;sub&gt;c&lt;/sub&gt; = 0.2&lt;sup&gt;b&lt;/sup&gt;</td>
<td>AF&lt;sub&gt;a&lt;/sub&gt; = 0.07&lt;sup&gt;b&lt;/sup&gt;</td>
<td>AF&lt;sub&gt;a&lt;/sub&gt; = 0.12&lt;sup&gt;h&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

(a) RAGS, Part A (EPA, 1989), and applicable updates
(b) Exposure Factors Handbook (EPA, 1997, 2011)
(c) Soil Screening Guidance (EPA, 2001 a, b)
(d) EPA 1997. This value represents an upper bound or “worst-case” scenario for certain outdoor activities with high soil contact (e.g., construction or landscaping).
(e) RAGS, Part B (EPA, 1991b)
(f) PEA, Cal-EPA (DTSC, 1994)
(g) By analogy to RAGS, Part B (EPA, 1991b)
(j) See note on age adjusted factors on Figures 1-1, 1-2, 1-3, and 1-4