Title 10—DEPARTMENT OF NATURAL RESOURCES
Division 25—Hazardous Waste Management Commission
Chapter 17—Risk-Based Corrective Action

New Rule

PURPOSE: The Department of Natural Resources (department) oversees response, characterization, risk assessment, and risk management under a variety of authorities at over two thousand contaminated sites in Missouri. Many more sites are in an early stage of investigation or as yet unknown to the department. The impetus and philosophy behind Missouri Risk-Based Corrective Action (MRBCA) is to provide a framework for cleanup decisions that facilitates the constructive use of contaminated sites by protecting human health and the environment in the context of current and reasonably anticipated future site use. This framework can streamline the process of site cleanup and closure and focus finite resources on appropriate cleanups for sites which address their current or potential risks to human health and the environment.

Risk management and associated activities at contaminated sites cross departmental programs and divisions. Within the Hazardous Waste Program, a number of state and federal cleanup authorities work together, such as the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), federal and state-equivalent Resource Conservation and Recovery Act (RCRA), Brownfields/Voluntary Cleanup Program (B/VCP), and Petroleum Storage Tanks (PST). The Water Protection, Land Reclamation, Air Pollution, Solid Waste Management and Environmental Services Programs and the Geologic Survey and Resource Assessment Division are often involved in risk management decisions. The rule provides a cleanup model based on risk, and recognizes that other cleanup authorities that may be involved in a particular site may have additional or different requirements that must be observed at that site.

In addition, the Missouri Department of Health and Senior Services (DHSS) is responsible for protecting and promoting public health. In this capacity, it may conduct or review risk assessments, provide review and comment on site characterization and remediation plans, and advise the department on risk management decisions.

While the primary objective of each authority is to protect human health and the environment, the specific decision-making framework to achieve this objective can vary among the authorities and programs. This guidance is written to provide a consistent and predictable process for responsible parties, development interests, landowners and other entities that are involved in the evaluation and management of contaminated sites, regardless of regulatory context. (In this document, these entities and their designees are referred to collectively and generically as the "remediating party").

This department-wide program should provide (i) a scientifically defensible and consistent framework to make decisions related to site characterization, risk assessment and risk management and (ii) a predictable process for property owners and developers. An additional benefit may be a reduction in the overall costs of these activities. Although applicable laws do not allow cost considerations to compromise human health, public welfare or the environment, the department recognizes the need to promote cost-effective site characterization and risk

management.

This rule includes the key elements and methodologies of the MRBCA process. It is consistent with the risk-based corrective action standard developed by the American Society for Testing and Materials (ASTM E1739-95). However, it has been modified to account for the large variety of sites and contaminants for which it is applicable and in response to input from the stakeholders involved with contaminated sites.

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[add] (1) Definitions

(2) Applicability

This rule applies to contaminated or potentially contaminated sites. The risk-based corrective action process does not in any way supercede or change applicable federal statutes and regulations. This rule does not supercede the requirement that state programs authorized by the United States Environmental Protection Agency that are operating in lieu of the federal program, including but not limited to the federal Resource Conservation and Recovery Act, be at least as protective as the federal program. This rule does not change the federally mandated, program-specific administrative, technical and notification requirements on either a

remediating party or regulators. Neither the remediating party nor the department can pick or choose portions of the media or sites to which this process will apply. This rule will be applicable only to new releases discovered at previously closed sites, newly discovered sites, on-going cleanups, and site reviews where a different use is being contemplated than planned for at the time of closure.

(3) Rationale and characteristics of tiered approach
Each tier will result in cleanup target levels that provide an acceptable level of protection to human health, public welfare and the environment. This rule is based on *Missouri Risk-Based Corrective Action (MRBCA) Technical Guidance* (MRBCA) published by the department. Table 1 shows a comparison of risk-based assessment options.

(4) Risk-based corrective action process

(A) Determination and Abatement of Imminent Threat(s)
When imminent threats are discovered, the remediating party must inform the department immediately. Upon completion of abatement actions, the remediating party shall submit a report to the department that documents the activities and confirms that all imminent threats have been abated.
(B) Initial Characterization and Comparison with Default Target Levels
The remediating party must perform an Initial Characterization. The Initial Characterization shall be conducted to identify with certainty the maximum concentrations of the contaminants of concern in each impacted environmental media and compare the sample concentrations with default target levels (DTLs) and, to the extent needed, water quality criteria (10 CSR 7.031). Impacts are to be delineated to the higher of DTLs or other levels necessary to protect the receptors from complete routes of exposure.
(C) Development and Validation of Conceptual Site Model
If the maximum concentrations of COCs exceed the DTLs or the DTLs are not selected as the cleanup levels, the remediating party shall develop and validate a conceptual site model. A conceptual site model shall qualitatively and/or quantitatively describe the relevant site-specific factors that determine the risk to human health and the environment. The extent of contamination and complete routes of exposure, not the property boundaries, determine the extent of site-specific data collection and analysis.
(D) Tier 1 Risk Assessment
For the MRBCA process, the acceptable risk levels are:

1. Carcinogenic Risk
   The total risk for each chemical, which is the sum of risk for all complete exposure pathways for each chemical, must not exceed 1×10^{-5}. The cumulative site-wide risk (sum of risk for all chemicals and all complete exposure pathways) must not exceed 1×10^{-4}.
2. Non-carcinogenic Risk
   The hazard index for each chemical, which is the sum of hazard quotients for all complete exposure pathways for each chemical (the total risk) must not exceed 1.0. The site-wide hazard index, which is the sum of hazard quotients for all chemicals and all complete exposure pathways, must not exceed 1.0.

Table 1

Comparison of Risk Assessment Options

Factors	DTL	Tier 1	Tier 2	Tier 3
Exposure Factors	Default	Default	Default	Site-specific
Toxicity Factors	Default	Default	Default	Most current
Physical and Chemical Properties	Default	Default	Default	Most current
Fate and Transport Parameters	Default	Default	Site-specific	Site-specific
Unsaturated Zone Attenuation	Depth to water table dependent	Depth to water table dependent	Depth to water table dependent	Site-specific model
Fate and Transport Models	Default	Default	Default	Alternative
Comparative Concentrations	Maximum	Representative Concentrations	Representative Concentrations	Representative Concentrations
IELCR for Each Chemical & ROE	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
Hazard Quotient for Each Chemical & ROE	1	1	1	1
Site-wide IELCR	1×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4}
Site-wide Hazard Index	1	1	1	1
Domestic Use of Groundwater Pathway if Complete	MCL or equivalent	MCL or equivalent	MCL or equivalent	MCL or equivalent
Ecological Risk	Compare with WQC	Evaluate	Evaluate	Evaluate
Outcome of Evaluation	LOC, Tier 1, RMP	LOC, Tier 2, RMP	LOC, Tier 3, RMP	LOC, RMP
Land Use	No	Yes	Yes	Yes
Activity and Use Limitations	None	Depend on land use, groundwater use, and other assumptions in risk assessment		

DTL: Default Target Level
LOC: Letter of Completion
ROE: Route of Exposure
IELCR: Individual Excess Lifetime Cancer Risk
MCL: Maximum Contaminant Level
RMP: Risk Management Plan
WQC: Water Quality Criteria, 10 CSR 20-7.031

If the hazard index exceeds 1.0, a qualified toxicologist may calculate the hazard index corresponding to a specific toxicological end point. Based on the comparison of representative concentrations and Tier 1 risk-based target levels, the remediating party may:

1. Request a determination from the department that the residual concentrations are protective of human health, public welfare and the environment;
2. Adopt Tier 1 risk-based target levels and submit a Risk Management Plan to manage the risk associated with these levels; or

3. Perform a Tier 2 risk assessment.

(E) Tier 2 Risk Assessment

Tier 2 risk assessments allow for the use of site-specific fate and transport parameters to calculate site-specific risk-based target levels. Tier 2 site-specific target levels are calculated values based on site-specific data, including but not limited to, the nature and extent of contamination and physical characteristics of the site. After the Tier 2 site-specific target levels have been calculated, the results shall be compared with representative COC concentrations at the site. Based on the comparison results, the remediating party may:

1. Request a determination from the department that the residual concentrations are protective of human health, public welfare and the environment;
2. Adopt calculated Tier 2 site specific target levels as cleanup levels and develop a risk management plan to manage the risk associated with these levels; or
3. Develop a work plan for a Tier 3 risk assessment.

Upon completion of the Tier 2 risk assessment, the remediating party must provide a Tier 2 Risk Assessment Report to the department.

(F) Tier 3 Risk Assessment

The remediating party must submit a work plan to the department and receive approval prior to the performance of a Tier 3 risk assessment. Upon completion of the Tier 3 risk assessment, the remediating party must provide a Tier 3 Risk Assessment Report to the department.

(G) Development, Approval, and Implementation of Risk Management Plan (RMP)

The risk management plan shall protect human health, public welfare and the environment under current and reasonably anticipated future use conditions. A RMP shall be developed after the department approves media-specific cleanup levels under any of the tiers. The Risk Management Plan shall be implemented as written and approved.

Data must be collected and analyzed to evaluate the performance of the plan and, if needed, to implement modifications. If additional information becomes available that shows the site poses an unacceptable risk to human health, public welfare or the environment or that the land use has changed and is no longer compatible with the risk management plan, the department may rescind its decision and require further action at the site.

(H) Long Term Stewardship

Long term stewardship (LTS) is the system of controls, institutions and information required to ensure protection of human health, public welfare and the environment at sites where residual contamination has been left in place above unrestricted use levels. Activity and Use Limitations (AUL's) may be an integral part of long term stewardship. AULs must be designed to ensure that pathways of exposure to COCs, through current or reasonably anticipated future uses, are not completed for as long as the COCs pose an unacceptable risk to human health, public welfare or the environment. Without compromising their protective function, AULs are also intended to facilitate the property transaction, redevelopment and beneficial reuse of brownfields and other contaminated properties.

(5) Risk-based target levels within the MRBCA process

If an analysis moves from DTLs through the tiers, the risk-based target levels become lower, and the remediating party does not have the option of using higher levels from the previous tier. Large sites may be divided into smaller areas and these areas may be managed using different risk-based target levels and different AULs.

(6) Documentation of the MRBCA process

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. This is accomplished by the development of several documents including the initial site characterization, the conceptual site model, the risk assessment and the risk management plan.

(7) Initial Site Characterization

(A) Objective of initial site characterization

The objective of an initial site characterization is to collect data to determine whether:

1. The site qualifies for a Letter of Completion;
2. An ecological risk exists;
3. The preferred remediation cleanup standards will be the default target levels (DTLs) and/or applicable water quality criteria; or
4. The analysis of the site will continue to a Tier 1, Tier 2, or Tier 3 assessment.

(B) Site description

The remediating party shall conduct a thorough site reconnaissance and a historic review of site use and site operations to identify existing and potential sources of contamination. The remediating party shall prepare a site description based on available information, including but not limited to:

1. Knowledge of known or documented releases;
2. Current and past location of certain structures that represent potential sources (for example, pipelines, process areas, pumps, or transformers);
3. Historic documentation of site layout such as aerial photographs, fire insurance maps, etc.;
4. Interviews with current and past owners and operators;
5. Permits issued for various activities; and
6. One or more site visits.

The remediating party shall prepare a list of potential chemicals of concern (COCs) and the probable on-site location(s) of COCs.

(C)(15) Collection of data

Prior to the collection of any environmental data, the remediating party must submit the Initial Characterization and Data Collection Work Plan to the department for review and approval. The work plan must meet the minimum Data Quality Assurance/Quality Control requirements of the department's Quality Management Plan (See Appendix K for more information). After approval, the remediating party shall implement the work plan and collect samples of environmental media in areas that are representative of the maximum concentrations. At sites with multiple discrete sources of contamination, data shall 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. The objective is to identify with certainty the maximum concentrations of the COCs in each impacted environmental media.

(D) Comparison with default target levels and relevant water quality criteria

To determine if an ecological risk exists at the site at the default target level, it is necessary to use aquatic life protection criteria of the Missouri's Water Quality Standards, 10 CSR 20-

7.031, summarized in Table 5.1 of the guidance, to answer the following questions:

1. Are any of the COCs detected in groundwater listed for aquatic life protection in the water quality standards? If not, no further ecological evaluation is necessary because, for any other chemicals with Tier 1 risk-based target levels, the water quality criteria for an ecological receptor is higher than the human health value listed in the DTL table in Appendix B. However, a yes response for any one of the chemicals listed for aquatic life protection implies the possibility of ecological impacts; therefore, the second question must be answered;
2. Does the maximum concentration of any of the COCs found exceed its water quality criteria? If not, then no further ecological evaluation is necessary. However, if the maximum concentration for any one of these chemicals exceeds its water quality criteria, then it is necessary to determine if there are any complete pathways for ecological receptors; therefore, the next question must be answered; and
3. Do any ecological receptors that would result in a complete exposure pathway exist at or near the site? This can be determined by completing the Level 1 Ecological Risk Assessment discussed in subsection 8 and, if necessary, proceeding to Level 2 and 3.

After completing the Ecological Risk Assessment and any further ecological evaluation required by the department, if ecological issues exist, the maximum groundwater concentrations must be compared with the lower of the DTLs or the applicable water quality criteria (only for the chemicals listed for aquatic life protection). For both ecological and human health risk assessments, the maximum soil and groundwater concentrations must be compared with the default target levels (DTLs) presented in Appendix B. If the maximum soil and groundwater concentrations do not exceed the DTLs and no ecological risk is identified, the remediating party may petition the department for a Letter of Completion. If either the soil or groundwater maximum concentrations exceed its comparative value, the remediating party has two alternatives:

1. Conduct a Tier 1, Tier 2, or Tier 3 evaluation; or
2. Select the DTLs (or lower of DTLs and water quality criteria if ecological issues are of concern) as the cleanup levels. Further, the remediating party must develop a Risk Management Plan as discussed in Section 8.

(E) Initial Characterization Report

The remediating party shall document the results of the initial characterization and comparison with target levels in a report to the department.

(8) Conceptual Site Model

(A) Components of Conceptual Site Model

1. A conceptual site model provides a convenient format to present an overall understanding of the site. A conceptual site model may be developed at the start of a project and refined and up-dated throughout the life of the site activities. A complete and detailed conceptual model is essential to making sound professional judgements about sampling design and for optimizing that design. It can help identify the pros and cons of various remediation activities or activity and use limitations. Key elements of the conceptual site model include:
    a. The chemical release scenario, source(s), and chemicals of concern (COCs);
    b. Spatial and temporal distribution of COCs in the various affected media;
    c. Current and reasonably anticipated future land and groundwater use;

d. Description of any known existing or proposed land or water use restrictions;
e. Description of site stratigraphy, determination of the predominant vadose zone soil type, hydrogeology, meteorology, and surface water bodies that may potentially be affected by site COCs;
f. Remedial activities conducted to date; and
g. An exposure model that identifies the receptors, exposure pathways and routes of exposure under current and reasonably anticipated future land use conditions.

2. To adequately characterize a site to determine risks, the following categories of data are required. If any categories of data are not included, the site characterization report shall document the reason(s) for the omission.
   a. Site information (See Section (8)(B));
   b. Description and magnitude of the spill or release;
   c. Adjacent land use, activity and use limitations, and receptor information;
   d. Analysis of current and reasonably anticipated future groundwater use;
   e. Vadose zone soil characteristics;
   f. Characteristics of saturated zones;
   g. Surface water body characteristics;
   h. Ecological risk assessment;
   i. Meteorology (such as rainfall, infiltration rate, evapotranspiration, wind speed and direction);
   j. Distribution of chemicals of concern in soil;
   k. Distribution of chemicals of concern in groundwater;
   l. Distribution of chemicals of concern in soil vapor; and
   m. Distribution of chemicals of concern in sediments and surface water bodies.
3. The remediating party must carefully review all the available data and identify any data inadequacies. A systematic planning process is used to develop a work plan to be approved by the department. To fill in data inadequacies, the work plan must include:
   a. A sampling and analysis plan; and
   b. A Quality Assurance Project Plan (QAPP). The objectives of the QAPP and the Sampling and Analysis Plan components of the work plan are to ensure that:
      (A) The intended use of the data is clearly defined and understood to ensure that the collected data will be of adequate quality and quantity;
      (B) All environmental data used to make risk assessment and risk management decisions is scientifically valid, defensible and of known quality;
      (C) The specific location where samples will be collected, the handling requirements for the samples, and methods of analysis are clearly specified to avoid any confusion or ambiguity once the field work begins; and
      (D) All data collected is consistent with the Quality Management Plan for the Missouri Department of Natural Resources.

(B) Site Information

1. The following information is necessary to complete an MRBCA conceptual site model:
   a. A site location map;
   b. A site map;
   c. Ground surface conditions;
   d. Location of utilities on and adjacent to the site;
   e. Surface waters;

   f. On-site and adjacent off-site groundwater use; and
   g. Local hydrogeology and aquifer characteristics.
2. Site maps must be drawn to scale and include a bar scale and a north arrow. In addition to the site map(s), a land use map is also required. The site map must show features relevant to the remediation, including as appropriate:
   a. Property boundaries;
   b. 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;
   c. Locations of area(s) of release;
   d. 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);
   e. Locations of water wells (public and private);
   f. Location of surface water features;
   g. Ecological or terrestrial sensitive features; and
   h. Locations of soil borings, soil vapor extraction wells, and soil excavation areas.
3. For ground surface conditions:
   a. Identify the portion of the site that is paved, unpaved or landscaped;
   b. Note the type, extent, date of installation, and general condition of the pavement;
   c. Describe the unpaved areas (for example, vegetated, gravel, or bare soil); and
   d. Determine the direction in which the surface is sloping and note relevant topographic features (for example, swales, drainage, or detention ponds).
4. For the location of utilities on and adjacent to the site, the following must be performed at a minimum:
   a. If explosive conditions are encountered, immediately inform the local fire department and the department Emergency Response Spill Line at (573) 634-2436; and
   b. 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.
5. The following information must be collected if available:
   a. Direction of water flow in utility lines (potable water, storm water, and sewage);
   b. Location of the utility lines and conduits on a base map that shows the extent and thickness of non-aqueous phase liquid (NAPL), free product, if any, and soil and groundwater contamination;
   c. 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 and the locations and depths of the utility lines and conduits is recommended;
   d. Types of materials used for utility lines and conduits and the type of backfill around the utilities; and
   e. Any historical work completed on any of the utilities and if any contamination-related issues were identified at the time the work was performed.
6. For on-site groundwater use, all wells will be identified based on a search of local, state and federal records and databases and/or windshield or door-to-door surveys, as appropriate. To the extent that such information is available, the remediating party 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 identified well is not currently in use or not likely to be used, it may be closed in accordance with sections 256.603(1) and 256.637.4 RSMo.

7. For local hydrogeology and aquifer characteristics, local conditions will be evaluated to determine the type and depth of aquifers in the area and whether they are confined, semi-confined or unconfined. This review will also identify surface water bodies (lakes, rivers and 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. In karst areas, the department may require a larger search area.
8. For description and magnitude of spill or release, it is necessary to identify:
   a. Soil and groundwater source(s) at the site;
   b. Chemicals of concern;
   c. Methods that will be used to analyze the samples; and
   d. Horizontal and vertical extent of soil and groundwater contamination.
9. The remediating party must collect as much of the following information as is available for each release that has occurred at the site:
   a. History of site activities related to the release;
   b. Location(s) and date(s) of spill(s) or release(s);
   c. Quantity of the release(s);
   d. Product(s) or chemical(s) released; and
   e. Interim response or corrective action measure(s) taken with respect to each release.
10. For history of activities at the site, develop a comprehensive chronology of historical events related to any chemical impacts. The chronology must describe the site activities, identify COCs and data collection work. The chronology shall include information such as the dates, descriptions and results of:
    a. Installation, removal or upgrade of containment, process, delivery or waste systems;
    b. Remedial activities such as excavation and disposal of contaminated soil;
    c. Drilling, sampling and gauging of monitoring wells; and
    d. Collection of environmental media samples.
11. In cases where interim response actions 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 remediating party must collect additional soil and groundwater concentration data representative of current conditions.
12. For adjacent land use, activity and use limitations, and receptor information, identify:
    a. Current land use and zoning;
    b. Potential future land use and zoning;
    c. Local ordinances, easements and restrictions that affect land or groundwater use;
    d. Quality and availability of potable water supplies;
    e. Off-site groundwater use;
    f. Location and type of potential receptors;
    g. Ecological receptors;
    h. Routes of exposure by which the potential receptors may be exposed to the COCs; and

i. Presence of any site activity and use limitations (AULs) that may affect the completion of exposure pathways.

13. For current land use, 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 schools, hospitals, residences (apartments, condominiums, townhouses, and single-family homes), buildings with basements, day care centers, churches, nursing homes, and types of businesses. The survey must also identify surface water bodies, parks, recreational areas, wildlife sanctuaries, wetlands and agricultural areas. The results of the survey must be accurately documented on a land use map. A north arrow on the map is required.
14. For reasonably anticipated future land use, future land use and receptors must be established and the proximity to wetlands, critical habitat and other environmentally sensitive areas must be considered in predicting future land uses.
15. For off-site groundwater use, obtain the following information:
    a. A water well survey to locate all public water supply wells within a one-mile radius of the site and all private water wells within a quarter-mile radius of the site. Other distances may be used if prescribed by law, or necessary and appropriate based on COC mobility and hydrogeology. The rationale for using alternative distances shall be documented;
    b. To the extent that such information is available, the remediating party shall 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; and
    c. If available, average well pumping rates and drawdown information also shall be provided.
16. For the ecological receptor survey, use the Ecological Risk Assessment, Level 1, Checklist A of the MRBCA guidance document, as a screening tool that must be completed for a Tier 1, Tier 2, or Tier 3 risk assessment. An Ecological Risk Assessment may also be required at the Default Target Level if certain COCs are present at a site.

17. The analysis of current and future groundwater use shall include all groundwater zones beneath or in the vicinity of the site that could potentially be:
    a. Impacted by site-specific COCs; or
    b. Targeted in the future for the installation of water use wells.

17. For the purposes of this analysis, groundwater-bearing zones must be evaluated in a three dimensional context. As a part of this analysis, other groundwater uses including but not limited to, cooling water, irrigation, livestock watering, and industrial process water, must also be identified and documented. The current groundwater domestic consumption pathway is considered complete if water use wells are located on or near the site and the wells may be impacted by site-specific chemical releases. Whether a well may be impacted depends on the hydrogeological conditions, well construction and use of the well, including the following factors:
    a. Characteristics of soil and rock formations;
    b. Groundwater flow direction;
    c. Hydraulic conductivity;
    d. Distance to the well;
    e. The zone where the well is screened;

f. Casing of the well;
g. Zone(s) of influence and capture generated by well pumpage; and
h. Biodegradability and other physical and chemical properties of the COCs.

18. For each zone, determining if the future groundwater use pathway is complete or likely to be complete shall be based on the following factors. All of these factors shall be evaluated on a "weight of evidence" basis; the weight that a single factor will be given in determining the probability of future groundwater use will vary based on site-specific considerations, including the durability of any AULs.
    a. Evaluation of Activity and Use Limitations (AULs**):** If an AUL is in place that minimizes or eliminates the potential that a specified groundwater zone will serve as a future source of domestic water, the presence of the AUL will be considered along with other relevant site-specific domestic consumption factors. For early relief from consideration of this pathway, an ordinance that prohibits well drilling along with a Memorandum of Agreement with a governing body can be used to justify an incomplete pathway;
    b. Suitability for Use Determination: For groundwater to be considered a viable domestic water supply source, it must meet appropriate total dissolved solids (TDS) and yield criteria;
    c. Total Dissolved Solids Criteria – Groundwater containing less than 10,000 mg/L total dissolved solids is considered a potential source of domestic consumption;
    d. Yield Criteria – Groundwater zones capable of producing a minimum of 1/4 gallon per minute or 360 gallons per day on a sustained basis have sufficient yield to serve as a potential source of domestic consumption. The yield of a bedrock aquifer should be based on the measured or calculated production of a 6-inch drilled well that penetrates the lesser of either the full saturated thickness of the aquifer or the uppermost 200 feet of the saturated zone. The yield of a low-yield, unconsolidated (glacial drift or alluvial) aquifer should be based on the measured or calculated production of a 3-foot-diameter, augured or bored well that penetrates the lesser of either the entire saturated thickness of the aquifer or the uppermost 50 feet of the saturated zone. Refer to Appendix G, "A Method for Determining If a Water Bearing Unit Should Be Considered an Aquifer," for further guidance on determining whether a particular zone should be considered as a potential domestic water source;
    e. Determination of Sole Source/Availability of Alternative Water Supplies**:** If the groundwater zone being considered is the only viable source of water at or in the vicinity of the site, then the remediating party must assume that future domestic use is reasonable. This conclusion is irrespective of TDS or yield considerations, and this zone must be evaluated if it is likely to be impacted by COCs from the site. Determining the availability of alternative water supplies should include consideration of other groundwater zones, municipal water supply systems, and surface water sources;
    f. Reasonable Probability of Future Use Determination**:** The probability that a groundwater zone could be used as a future source of water for domestic consumption must be evaluated based on consideration of the following factors:
        (A) Current groundwater use patterns in the vicinity of the site under evaluation;
        (B) Suitability of use (TDS and yield criteria);
        (C) Availability of alternative water supplies;

(D) AULs;
(E) Urban development considerations for sites in areas of intensive historic industrial or commercial activity, having groundwater zones in hydraulic communication with industrial or commercial surface activity, and located within metropolitan areas with a population of at least 70,000 as established by the 1970 census; and
(F) Aquifer capacity limitations (ability to support a given density of production wells);

g. Probability of Impact Determination: If a groundwater zone has a reasonable probability of future use as a domestic water supply, the zone must be evaluated for the probability that the zone could be impacted by site COCs. The evaluation must consider the nature and extent of contamination at the site, site hydrogeology including the potential presence of karst features, contaminant fate and transport factors and mechanisms, and other pertinent variables. To evaluate potential site impacts to groundwater zones that could serve as future water supply sources, the potential impact must be evaluated at the nearest down-gradient location that could reasonably be considered for installation of a groundwater supply well. In the absence of durable AULs, the nearest location might be on the site itself.

19. The occurrence and rate of monitored natural attenuation may be evaluated at a site. Measuring appropriate indicators (such as chemical concentrations, geo-chemical indicators, electron acceptors, microorganisms, or carbon dioxide) will be required only when monitored natural attenuation is proposed as the principal element of the risk management plan.
20. Surface water characteristics are described by the following data that must be collected for a surface water body that may be impacted by site-related COCs:
    a. Distance to the surface water body;
    b. Likely location where COCs from the site would discharge into a surface water body;
    c. Flow direction and depth of any groundwater contamination plume(s) in relation to the water body;
    d. Lake or stream classification as found in 10 CSR 20-7.031, Table G and Table H respectively;
    e. Lake or pond acreage or stream 7Q10 flow rate;
    f. Determination of the beneficial uses of the lake or stream as found in 10 CSR 20-7.031, Table G and Table H respectively; and
    g. Water quality criteria based upon the beneficial uses of the lake or stream as found in 10 CSR 20-7.031, Table A. If a water quality criterion for a COC is not available, contact the department project manager. If necessary, the project manager can then coordinate with the Water Protection Program (WPP) for further guidance.
21. To delineate impacts in soil and groundwater prior to the performance of a risk assessment, the remediating party 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. Lateral and vertical impacts in soil and groundwater must be delineated to the extent required to determine:
    a. Potential routes of exposure by human and ecological receptors under current and reasonably anticipated future conditions; and
    b. The extent of impacts above risk-based levels for corresponding potential routes of exposure.

22. The exposure model must consider receptors on site and on adjacent properties that may be exposed to contamination. In developing any risk-based target levels, cumulative site-wide risk must be addressed. After the delineation levels for each COC have been established, the following field activities shall be conducted:
    a. Direct push investigations should be conducted downgradient of the site source/release area until data indicates levels at or below the delineation level;
    b. For sites where the available data indicates that the extent of contamination may be migrating, the remediating party must conduct sufficient investigations to determine the extent and rate of migration. Wells must be monitored at a frequency and for a period of time sufficient to clearly demonstrate that the extent of contamination is decreasing and that COC concentrations in the downgradient wells are below the delineation levels;
    c. Upon preliminary completion of the site characterization, a check should be made to confirm that the assumptions used in the initial conceptual site model were accurate and that the delineation levels are appropriate; and
    d. For delineation of soil impacts, borings should be installed at increasing distances from the source area until the delineation levels are reached.
23. To delineate impacts in other media (for example, surface water, sediments, and air), the number of samples, sample locations, delineation levels, and sampling methodologies will be based on site-specific considerations; hence the remediating party must receive the department'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 the extent of the impacts. If air concentrations are to be measured, the work plan must contain a strategy to determine ambient background levels.
24. The ecological risk assessment has three levels:
    a. Level 1 is a qualitative screening evaluation comprised of Checklists A and B of the MRBCA guidance document;
    b. Level 2 requires comparison of site-specific levels with applicable ecological criteria, readily available in literature; and
    c. Level 3 allows for a site-specific evaluation.
25. A Level 2 and /or Level 3 evaluation is necessary only if ecological concerns continue to persist beyond the Level 1 evaluation.
26. A Level 1 ecological assessment must be performed at every Tier 1, 2, and 3 site to identify whether any ecological receptors or habitat exist at, adjacent to, or near the site. The following decision criteria shall be used:
    a. If the answers to all of the Checklist A questions are negative, no further ecological evaluation is necessary;
    b. 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, and this evaluation is Ecological Risk Assessment Checklist B;
    c. If the answer to all of the Checklist B questions are 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
    d. If the answer to one or more of the seven questions is positive, a Level 2 ecological risk assessment is necessary to determine whether contamination at the site poses an

unacceptable risk to ecological receptors.

27. In a Level 2 ecological risk assessment, site-specific COC concentrations that may reach an ecological receptor are compared to Missouri's Water Quality Standards or literature values when standards are not available. If the comparison of representative, site-specific soil, groundwater, surface water or sediment values indicates that applicable values are exceeded, the remediating party may perform a Level 3 ecological risk assessment or use the applicable water quality criteria or literature values as cleanup goals. If water quality criteria or literature values are used, then at least one element of the Risk Management Plan must address remediation goals to protect ecological receptors.
28. A Level 3 ecological risk assessment will include a detailed site-specific evaluation as per current EPA guidance on performing risk assessment. A Level 3 ecological risk assessment will require the development of a site-specific, detailed work plan and approval by the department prior to its implementation. If a site-specific analysis determines that the risk to ecological receptors remains unacceptable, then at least one element of the risk management plan must address managing the risk to ecological receptors.
29. The characterization of the distribution of chemicals of concern in soil must be sufficient to (i) delineate the extent of site-related COCs to identify the exposure domains for each combination of receptor-pathway-complete route of exposure, and (ii) estimate maximum and representative concentrations for each area of impact/exposure domain. For the subsurface soil, this pathway is considered incomplete except for the construction worker who may be involved in excavation activities below the surficial zone and hence may come in direct contact with subsurface soil.
30. To determine the distribution of COCs in soil and groundwater monitoring well boreholes, a professional under the supervisions of a Registered Geologist (R.G.) or Professional Engineer (P.E.) registered in Missouri must log each soil boring to indicate depths correlating with changes in lithology with lithologic descriptions, occurrence of groundwater, total depth, visual and olfactory observations, and other pertinent data such as a soil vapor screening reading. 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 lithologic 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 lithologic zones, obvious areas of soil discoloration, organic content, fractures, and other lithologic characteristics.
31. To determine the distribution of COCs in groundwater, an adequate number of groundwater samples must be collected to:
    a. Delineate the horizontal and vertical extent of dissolved groundwater COC plumes and non-aqueous phase liquids (NAPLs), and to identify the exposure domain for each receptor, pathway and route of exposure combination;
    b. Allow calculation of representative COC concentrations for each exposure domain; and
    c. Determine the status of the extent of contamination (increasing, stable or decreasing).
32. For delineating groundwater impacts where the domestic use of groundwater pathway is complete, delineation criteria will be the lower of the following four criteria:
    a. MCLs (in the absence of MCLs, risk-based concentrations that assume ingestion of

groundwater, dermal contact and inhalation of vapors due to indoor water use);

b. Land use-dependent concentrations protective of indoor inhalation;
c. Concentrations for the protection of ecological receptors (when present); or
d. Non-domestic uses of groundwater when present.

33. Where the domestic use of groundwater pathway is incomplete, the delineation criteria will be based on other potentially complete pathways, including the 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.
34. To assess plume stability, groundwater monitoring must be conducted for a period of time sufficient to show a reliably consistent trend in contaminant concentrations. Sampling and analysis of groundwater must be performed at a frequency and for parameters that are appropriate for site-specific conditions and are sufficient to enable assessment of contaminant trends, natural attenuation rates and seasonal or temporal variations in groundwater quality. Once cleanup levels are achieved, groundwater monitoring shall continue for a period of time sufficient to ensure that residual subsurface contamination does not result in recontamination of groundwater above applicable MCLs or levels protective of other pathways, such as migration to surface water or indoor inhalation. Groundwater monitoring for the purpose of evaluating plume stability must be conducted under a work plan approved by the department. Depending on site-specific data, statistical, graphical or other techniques may be used to demonstrate plume stability.
35. For groundwater sampling, an adequate number of monitoring wells must be installed to sufficiently delineate the horizontal and vertical extent of the dissolved and non-aqueous phase groundwater plume and the direction of groundwater flow. A sufficient number of monitoring wells must be installed to fully define the groundwater extent of contamination to levels protective of applicable exposure pathways. Well placement and design must consider the concentration of chemicals in the source area, the possible occurrence of both dense and light NAPLs at the site, presence of multiple water bearing zones, and groundwater flow direction. Well casing and screen materials must be compatible with the COCs to be monitored. Wells must be properly developed and the water level must be measured after installation. A professional land surveyor shall conduct a site survey to establish well elevations and, by that, groundwater elevations. Accuracy shall be to within plus or minus 0.01 foot relative to an established national geodetic vertical datum (NGVD) or some other appropriate datum. Based on the groundwater elevations, groundwater flow direction and gradient must be determined and plotted on a site map. Appropriate geographic coordinates must be identified and documented.
36. For sites where soil or groundwater concentrations result in the exceedance of Tier 1 risk levels for the vapor migration to indoor air pathway, soil vapor monitoring may be conducted. When site investigation data or modeling shows or suggests that COCs have migrated to a surface water body, surface water samples shall be collected. Sampling must consider the representativeness of the samples with regard to the flow conditions. Water samples must be collected both upstream and downstream of each area where a discharge of contaminated groundwater is suspected. If site investigation suggests that contaminated groundwater is discharging to surface water, sediment samples must be collected. The remediating party must compare the sediment sample data with sediment criteria that are protective of human health and ecological receptors that can be obtained from literature or

develop site-specific levels.

(9) Representative Concentrations

(A) Estimating representative soil and groundwater concentrations

A representative chemical concentration is the average concentration to which a receptor is exposed over the specified exposure duration, within a specified geographical area, and for a specific route of exposure. The calculation of a representative concentration requires the following steps for each receptor:

1. Identification of all of the media of concern. Typically these include surficial soil, subsurface soil, soil up to the depth of construction, and groundwater;
2. Identification of all the complete routes of exposure under current and reasonably anticipated future conditions;
3. Identification of the exposure domain for each media identified in Step1, and each complete route of exposure identified in Step 2;
4. Identification of the chemical concentration data available within the exposure domain for each media; and
5. Calculation of the representative concentration, which is the average of the data from Step 4 above.

To ensure the average value is representative:

1. Do not use data beyond the exposure domain. If there is not enough data within the domain and data is available immediately outside the domain, that data may be used and its use documented in the report. If there is not enough data within the domain and additional data is not available outside the domain, additional data may be collected within the exposure domain;
2. Replace the non-detect values with half the detection limit. Concentrations with a J laboratory qualifier, which is a judgement made at the laboratory, should use the laboratory-estimated value;
3. Determine if the maximum concentration of any chemical exceeds ten times the representative concentration of that chemical for any exposure pathway and document the reason for the high value in the report;
4. Document in the report the site-specific data used to establish the representative concentration if it is based on an extrapolation using a model;
5. For representative groundwater concentration, first estimate the average concentration in each well based on recent data, assuming data from multiple events is available, and then use the average of each well to estimate the representative concentration;
6. If free product is present at a monitoring point, use the effective solubility or effective vapor pressure to estimate the concentration at that point;
7. If wells have multiple years of groundwater data, use the two most recent years to estimate the representative concentration. Use of any data more than two years old must be justified in the report;
8. If the area of impact is smaller than the exposure domain, the exposure factors may be modified in a Tier 3 evaluation and representative concentrations calculated over the area of impact; and
9. Do not use soil data collected below the water table for the subsurface-soil-to-indoor-inhalation pathway. Groundwater data from the first encountered saturated zone must be used for the groundwater-to-indoor-inhalation pathway.

(B) Calculating representative concentrations

1. For surficial soil concentration for leaching to groundwater, the exposure domain is the area of release through which leachate generation may occur and chemicals can migrate to the water table. The representative surficial soil concentration is calculated using the surficial soil data collected within this exposure domain.

2. For the direct contact pathway (surficial soil concentrations 0 to 3 feet deep), the concentration is based on the receptor's exposure domain, which is the area of the site over which the receptor might be exposed to the surficial soil. In the absence of specific information about the receptor's activities, the unpaved portion of a site is the receptor's exposure domain. For potential future exposures in the absence of any engineered controls, assume that the pavement will be removed and the receptor will be exposed to surficial soil. To calculate the representative concentration estimate the receptor's exposure domain(s), and determine the number of soil samples available within this domain or the number of samples necessary to represent the domain. For a non-resident worker, the average concentration over the domain may be used. For a child receptor (actual or potential), the maximum concentration must be used and the representative concentration need not be calculated.

3. For subsurface soil greater than 3 feet below ground surface, consider two routes of exposure: leaching of residual chemical concentrations from subsurface soil to groundwater, and indoor inhalation of vapor emissions. Calculate a representative concentration for each complete pathway. Calculate additional representative concentrations if the receptor's domain differs under current and reasonably anticipated future conditions.

4. For subsurface soil concentration for protection of groundwater, the representative concentration is the average concentration in subsurface soil measured within the area of impact.

5. For representative subsurface soil concentration for protection of indoor inhalation, use an emission model approved by the department. Ensure consistency with the model by using data that meets the requirements of the model. Estimate the size (footprint) and location of the planned structure. In the absence of site-specific information regarding planned structures, the future size of the structure must be approximated and the future location established over the area of release. To estimate the representative concentration, the evaluator must:

1. Identify the footprint of the structure within which the receptor is located;
2. Identify the footprint of the potential future enclosed structure;
3. Identify the soil concentration data available within each of these two footprints; and
4. Calculate the average of these concentrations.

If sufficient data is not available within the footprint, data collected within 20 feet of the footprint may be used if it is documented in the report. Data beyond 20 feet may be considered if preferential pathways such as macropores, utility conduits, or fractures may cause vapor migration towards the buildings and the use of this data is documented in the report. If several samples within and adjacent to the building footprint are available, more weight is given to the samples closer to the footprint.

6. For representative concentrations for the construction worker, consider accidental ingestion, dermal contact and outdoor inhalation of vapors and particulates from soil, outdoor inhalation of vapors from groundwater, and dermal contact with groundwater. For representative soil concentration for the construction worker, no distinction is made between surficial and subsurface soil. Estimate the representative concentration from the depth of construction, the areal extent of construction, and samples within the zone of construction. The potential future

depth of construction is estimate from the likely type of structure that might be built and the typical depth of utilities on and adjacent to the site. If the areal extent of the construction area is not known, assume that the zone will be within the area of release unless there are site limitations that would prevent construction in that zone. The representative concentration is the average concentration within this zone of construction. For representative groundwater concentrations for construction worker, estimate the areal extent of the construction zone and identify the groundwater data available for this zone. The representative concentration is calculated as the average concentration within this zone.

7. Groundwater

a. For groundwater, consider three routes of exposure: ingestion, dermal contact, and indoor inhalation of vapor emissions from shallow groundwater. The analysis must consider the specific aquifers that are or might be used for domestic use or in any other manner in which dermal contact could occur. Representative concentrations must be calculated for each aquifer that is or is reasonably likely to be used for domestic purposes. The shallowest aquifer must be considered for the volatilization pathway.

b. For the ingestion of groundwater pathway, maximum contaminant levels (MCLs) or, where MCLs are not established, calculated risk-based concentrations must be met at the point of exposure well. The point of exposure well may be hypothetical and one or more point of demonstration wells must be established and the target concentrations calculated. The representative concentration at the points of exposure and/or demonstration are calculated as follows. If chemical concentrations in groundwater are stable, the representative concentration is the arithmetic average of the most recent data collected over a period of at least two years on at least a quarterly basis. If chemical concentrations are decreasing, the representative concentration is the arithmetic average of the most recent data collected over a period of at least one and one-half years on at least a quarterly basis.

c. For representative groundwater concentration for the protection of indoor inhalation, use a model approved by the department. The representative concentration for this pathway is based on groundwater concentrations measured within the footprint of the building or up to 20 feet from the building.

d. For the groundwater to indoor air pathway, multiple representative concentrations may be calculated if the plume has migrated below several current or potential future buildings. Where groundwater data is not available for each footprint, the following methods may be used to establish the representative concentration:

1. Install additional monitoring wells within the footprint lacking data;
2. Interpolate or extrapolation of existing data. Where the plume originates under a building, extrapolated data gathered from areas adjacent to the footprint may not be adequate); or,
3. Use data from wells upgradient of the building.

e. For representative groundwater concentration for dermal contact, use the average concentration of chemicals in the groundwater that a receptor might contact. More than one representative concentration may be needed if a receptor might contact groundwater from more than one aquifer or saturated zone.

(10) Selection of COCs for MRBCA Evaluation

(A) The remediating party may eliminate data for some chemicals and focus the risk assessment on the data for chemicals of concern (COCs) that contribute to the total risk at a site. Examples of data that may be eliminated include:

1. Data analyzed using an outdated analytical method or a wrong and unproven method;
2. Data that is not adequately supported by corresponding QA/QC data/measures;
3. Old data that is not considered representative of current conditions; or
4. Data collected prior to any remediation at the site.

Data may not be eliminated unless better information is available or the data is clearly unusable for risk assessment purposes. Elimination of data for COCs from further consideration due to laboratory artifacts or common laboratory contaminants must be supported by site-specific QA/QC information.

(B) If the above screening process results in more than 30 chemicals, additional chemicals may be eliminated by the use of the toxicity screen (EPA, 1989). The screening procedure shall identify and possibly eliminate chemicals that are likely to contribute less than 1 to 5 percent of the total risk. Use the following steps to complete this procedure:

1. Identify the maximum concentration of the chemical in each media.
2. Select the toxicity value(s). For chemicals that have different toxicity values for various routes of exposure, use the most "toxic" value;
3. Estimate the carcinogenic and non-carcinogenic toxicity score by multiplying the concentration with the slope factor, and by dividing the concentration with the reference dose, respectively;
4. Estimate the site score by adding the toxicity score for each chemical and each media. A separate site score will be calculated for carcinogenic and non-carcinogenic effects; and
5. Estimate the percent contribution of each chemical to the site score and eliminate chemicals that have a very low score relative to the other chemicals.

(C) The elimination of any chemicals as well as the rationale used must be clearly documented. Upon completion of the Tier 1, Tier 2, or Tier 3 evaluation, chemicals that were eliminated must be reviewed and a determination made of whether their inclusion would have resulted in an unacceptable risk.

(11) Risk-Based Target Levels

Following are the inputs required to calculate default target levels (DTLs) and Tier 1 risk-based target levels. Several of these parameters may also be used in Tier 2 evaluation. The calculation of the Tier 1 risk-based target levels and the Tier 2 and 3 site-specific target levels requires the following:

1. Acceptable risk level;
2. Chemical-specific toxicological factors;
3. Physical and chemical properties of the chemicals of concern (COCs);
4. Receptor-specific exposure factors;
5. Fate and transport parameters; and
6. Mathematical models.

A. Tier 1 Target Levels

Tier 1 risk-based target levels are calculated by the department for each of the COCs, the receptors (child, adult resident, age-adjusted resident, non-residential worker, and construction worker), and the following exposure pathways using conservative assumptions applicable to most Missouri sites. The department shall update and publish these levels as new information becomes available. These Tier 1 risk-based target levels are not adjusted for the presence of other routes of exposure and COCs, and any additional routes of exposure must be considered in using these levels. The following pathways shall be considered in Tier 1:

1. Pathways for Surficial Soils, defined as 0 to 3 feet below ground surface (bgs):
    a. Leaching to groundwater and potential use of groundwater;
    b. Leaching to groundwater and subsequent migration to a surface water body; and
    c. Ingestion of soil, dermal contact with soil, and outdoor inhalation of vapors and particulates emitted by surficial soils.
2. Pathways for Subsurface Soils, defined as greater than 3 feet bgs to the water table:
    a. Volatilization and upward migration of vapors from subsurface soil and potential indoor inhalation of these vapor emissions;
    b. Leaching to groundwater and potential use of groundwater; and
    c. Leaching to groundwater and subsequent migration to a surface water body.
3. Pathways for Groundwater
    a. Volatilization and upward migration of vapors from groundwater and potential indoor inhalation of these vapor emissions;
    b. Volatilization and upward migration of vapors from groundwater and potential outdoor inhalation of these vapor emissions;
    c. Ingestion of water if the domestic use of groundwater pathway is complete;
    d. Dermal contact with groundwater; and
    e. 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:

1. Ingestion of surface water;
2. Contact with surface water during recreational activities (ingestion, inhalation of vapors, and dermal contact);
3. Ingestion of fish; and
4. Contact with (accidental ingestion and dermal contact with) sediments.

B. Tier 2 Target Levels

In a Tier 2 assessment, leaching to groundwater, horizontal migration of the plume under a building, and volatilization from the plume into the building are other surface and subsurface pathways that may be complete at some sites. These must be evaluated where present. For Tier 2 risk assessments, the remediating part must calculate the site-specific target levels using technically justifiable, site-specific data. The default fate and transport models used for developing the Tier 1 risk-based target levels must be used.

C. Tier 3 Target Levels

A Tier 3 risk assessment must evaluate other routes of exposure where present. These include exposure through (i) ingestion of produce grown in impacted soils, (ii) use of groundwater for irrigation purposes, (iii) use of groundwater for industrial purposes, or (iv) ingestion of fish or other aquatic organisms that have bioaccumulated COCs through the food chain as a result of surface water or sediment contamination.

For Tier 3 assessments, site-specific target levels are calculated using site-specific data and may use alternative fate and transport models, and different exposure scenarios, if approved by the department.

D. Risk Levels

For carcinogenic effects, risk is quantified using individual excess lifetime cancer risk (IELCR) and for non-carcinogenic effects, the risk is quantified using a hazard quotient (HQ) or hazard index (HI) which is the sum of hazard quotients when multiple chemicals and multiple exposure pathways are evaluated.

For evaluating the domestic use of water, maximum contaminant levels (MCLs) are used as the target concentrations at the point of exposure. For COCs that do not have MCLs, the target concentration at the point of exposure (POE) is estimated assuming ingestion of groundwater, dermal contact and indoor inhalation of vapors due to water use under residential conditions. Potential impacts to streams and other surface water bodies from a release must be evaluated and water quality standards (10 CSR 20-7.031) must be achieved. Tier 1 risk-based target levels are based on a risk levels of 1×10^{-5} for the carcinogenic chemicals and a hazard quotient of 1.0 for non-carcinogenic chemicals. The calculation of risk-based target levels does not account for cumulative site-wide risk; these target levels must be adjusted to address cumulative site-wide risk, where appropriate. The acceptable risk levels are as follows:

1. Carcinogenic Risk
    a. The total risk for each COC, which is the sum of risk for all complete exposure pathways for each COC, must not exceed 1×10^{-5}; and
    b. The cumulative site-wide risk (sum of risk for all COCs and all complete exposure pathways) must not exceed 1×10^{-4}.
2. Non-carcinogenic Risk
    a. The hazard index for each COC, which is the sum of hazard quotients for all complete exposure pathways for each COC must not exceed 1.0; and
    b. The site-wide hazard index, which is the sum of hazard quotients for all COCs and all complete exposure pathways, must not exceed 1.0.

If the hazard index exceeds 1.0, the hazard index corresponding to a specific toxicological end point may be calculated by a qualified toxicologist. In this case, the specific hazard indices for each toxicological end point must be less than 1.0.

E. Factors used in Calculations

1. Toxicity Factors

Data sources for toxicity factors are described below. The department may approve the use of other sources if it believes the resulting analyses are more accurate. Toxicity data is extracted from a hierarchy of sources according to *"Human Health Toxicity Values in Superfund Risk Assessments," OSWER directive 9285.7-53, December 5, 2003,and s*pecifically includes:

a. Tier 1: Integrated Risk Information System (IRIS);
b. Tier 2: Provisional Peer Reviewed Toxicity Values (PPRTVs); and
c. Tier 3: Miscellaneous Sources:
    1. National Center for Environmental Assessment (NCEA);
    2. California Office of Environmental Health Hazard Assessments (OEHHAs) chemical database; and
    3. Health Effects Assessment Summary Tables (HEAST) as listed in EPA's

Region IX Preliminary Remediation Goal (PRG) tables.

Dermal toxicity values are calculated to be the same as the oral toxicity values, except that the skin affects absorption. The differing absorption efficiencies are factored into the formula for dermal toxicity as the term "oral absorption factors (RAF_o)." The formulae for calculation of slope factor (SF_d) and reference dose (RfD_d) for dermal exposure are:

$$SF_d = \frac{SF_o}{RAF_o}$$

$$RfD_d = RfD_o \times RAF_o$$

where,

SF_o	=	Slope factor for oral exposure (mg/kg-day)$^{-1}$,
RfD_o	=	Reference dose for oral exposure (mg/kg-day)$^{-1}$, and
RAF_o	=	Oral adsorption factor (dimensionless)

The dermal absorption factors are obtained from EPA's *Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual, Part E Supplemental Guidance for Dermal Risk Assessment* (July 2004). For volatile organic compounds (VOCs), or inorganic compounds. For these compounds, the absorption factors are obtained from EPA Region III and RAGS, Volume 1, Part A.

The chemical specific dermal permeability coefficient in water for the chemicals considered in the MRBCA are obtained from Exhibit B-2 of the *Risk Assessment Guidance for Superfund (RAGS) Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment), July 2004.* This document provides calculated and experimentally measured values of dermal permeability coefficients for a large number of chemicals. When both values are available for a chemical the document suggests the use of calculated values. For chemicals for which these values are not tabulated, the following equation may be used:

$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW$$

where,

K_{ow}	=	Octanol/water partition coefficient (dimensionless)
MW	=	Molecular Weight (g/mole)
K_p	=	Dermal permeability coefficient (cm/hr)

For metals and inorganics, if no value is available, the permeability coefficient of 1×10^{-3} cm/hr is recommended as default value (*EPA, 2004*).

2. Physical and Chemical Properties

Physical and chemical properties of the COCs are listed in department guidance and must be used for all MRBCA evaluations unless the department approves alternative values. The use of different values is allowed only under a Tier 3 risk assessment. The following hierarchy is used to obtain the physical and chemical properties:

a. Missouri Department of Natural Resources, RBCA for Petroleum Storage Tanks;
b. Missouri Department of Natural Resources, Cleanup Levels for Missouri (CALM);
c. EPA Region IX, PRG's Inter Calc Tables;
d. Texas Commission on Environmental Quality (TCEQ), Texas Risk Reduction Program (TRRP); and

e. Idaho Department of Environmental Quality (IDEQ), RBCA Tables.

3. Exposure Factors

Exposure factors and the values that were used to develop Tier 1 risk-based target level values are presented in department guidance. Exposure factors are estimated based on literature rather than site-specific measurements. For a Tier 3 risk assessment, site-specific exposure factors may be used with clear justification and the department's approval. For the evaluation of inhalation exposures, the values of both the exposure time (hours/day) and inhalation rate (cubic meters/day) are significant and interrelated. The primary source of exposure factor information is EPA's *Exposure Factors Handbook Volume 1 – General Factors* (August 1997). Other sources of exposure factor data may be used for Tier 3 risk assessment with approval of the department.

4. Fate and Transport Parameters

Fate and transport parameters are used to estimate the target levels for indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate at a site. A Tier 1 risk assessment uses default values contained in department guidance. These include parameters for:

a. soil type 1, representative of a sandy soil;
b. soil type 2, representative of a silty soil; and
c. soil type 3, representative of clayey soil.

For a Tier 2 risk assessment, a combination of site-specific and default fate and transport values may be used, and the value of each parameter used, whether site-specific or default, must be justified based on site-specific conditions.

For a Tier 3 risk assessment, the specific fate and transport parameters required to calculate the target levels are selected appropriate for the model used.

F. Target Levels for Groundwater

If the groundwater use pathway is deemed to be complete under current or future conditions, it must be quantitatively evaluated by this procedure.

1. Identify the critical point of exposure (POE). The POE is the nearest down-gradient, three-dimensional location that could reasonably be considered for installation of a groundwater supply well. The POE need not be an actual existing well; the POE could be a hypothetical well. Further the POE may be screened in a deeper zone, and not necessarily the shallowest water-bearing zone.

2. Determine the target levels at the POE. For COCs that have MCLs, the target level at the POE is the MCL. For COCs that do not have MCLs, 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. The indoor inhalation of vapors based on water use pathway is considered only for volatile COCs.

3. Identify point of demonstration (POD) wells and calculate target levels at the POD. POD wells are located between the source and the POE to monitor the COC concentrations in groundwater to prevent exceedances at the POE. Risk-based target concentrations are developed for the POD using appropriate fate and transport models and site-specific parameters.

4. Calculate representative soil COC concentrations in the area of release. Risk-based target levels for soil should be calculated for the area of release using the equations and models. This step requires an evaluation of the dilution and attenuation of the COC in the unsaturated zone. For Tier 1 and Tier 2 evaluation, the following depth-dependent

unsaturated zone dilution attenuation factor (DAF) values are used:

a. Depth to groundwater less than 20 feet, DAF = 1;
b. Depth to groundwater 20-50 feet, DAF = 2; and
c. Depth to groundwater >50 feet, DAF = 4.

F. Target Levels for Groundwater

If the groundwater use pathway is deemed to be complete under current or reasonably anticipated future conditions, it must be quantitatively evaluated by this procedure.

A. Identify the critical point of exposure (POE). The POE is the nearest down-gradient, three-dimensional location that could reasonably be considered for installation of a groundwater supply well. The POE need not be an actual existing well; the POE could be a hypothetical well. Further the POE may be screened in a deeper zone, and not necessarily the shallowest water-bearing zone.

B. Determine the target levels at the POE. For COCs that have MCLs, the target level at the POE is the MCL. For COCs that do not have MCLs, 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. The indoor inhalation of vapors based on water use pathway is considered only for volatile COCs.

C. Identify point of demonstration (POD) wells and calculate target levels at the POD. POD wells are located between the source and the POE to monitor the COC concentrations in groundwater to prevent exceedances at the POE. Risk-based target concentrations are developed for the POD using appropriate fate and transport models and site-specific parameters.

D. Calculate representative soil COC concentrations in the area of release. Risk-based target levels for soil should be calculated for the area of release using the equations and models. This step requires an evaluation of the dilution and attenuation of the COC in the unsaturated zone. For Tier 1 and Tier 2 evaluation, the following depth-dependent unsaturated zone dilution attenuation factor (DAF) values are used:

a. Depth to groundwater less than 20 feet, DAF = 1;
b. Depth to groundwater 20-50 feet, DAF = 2; and
c. Depth to groundwater >50 feet, DAF = 4.

G. Target Levels for Surface Waters

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected. Sampling for COCs in surface water bodies is necessary when COC migration is known or suspected to adversely affect a surface water body. The procedure for protection of streams and surface waters is shown in Figure E-4 and discussed below:

1. Determine water classification as specified in 10 CSR 20-7.031, Table H. Flowing waters are classified as Class C, P, or P1. Lakes are classified as Class L1, L2 and L3. Classifications apply to specific reaches of a water. Flowing waters not included in Table H are unclassified (Class U) and have no assigned designated uses.

2. Determine the beneficial use designation(s) of the water specified in 10 CSR 20-7.031. These may include:

a. Irrigation (IRR);
b. Livestock & wildlife watering (LWW);
c. Protection of warm water aquatic life and human health – fish consumption (AQL);
d. Cool water fishery (CLF);

e. Cold water fishery (CDF);
f. Whole body contact recreation (WBC);
g. Boating and canoeing (BTG);
h. Drinking water supply (DWS); and
i. Industrial (IND).

3. Determine applicable water quality criteria corresponding to the beneficial use designation(s) of the water. For waters with multiple beneficial uses, select the most protective applicable criteria. For metals, the criteria for the protection of aquatic life depend on the hardness of water. Site-specific water quality criteria may be needed for COCs present at a site and not listed in 10 CSR 20-7.031. For Class C and Class P or P1 streams and lakes, water quality criteria must be met at the downstream edge of the mixing zone (defined as an area of dilution of effluent in the receiving water beyond which chronic toxicity criteria must be met). For unclassified waters, applicable water quality criteria must be met at the point of groundwater discharge to the stream.

4. For flowing waters, determine 7Q10 and groundwater discharge. The 7Q10 low-flow of a stream is the average minimum flow for seven consecutive days that has a probable recurrence interval of once-in-ten years. Estimation of 7Q10 must follow current practices of USGS and EPA. The lowest value of 7Q10 that can be used as a default value for a Tier 1 risk assessment that includes Class C and Class P or P1 streams is 0.1 cubic feet per second (cfs). Unclassified streams have a default 7Q10 value of 0 cfs. The volume of impacted groundwater discharging into the stream must be determined. This determination is based on the dimensions of the plume at the point of discharge and an average Darcy velocity at the point of discharge.

5. Estimate concentrations at the point of discharge. The concentrations at the point of discharge are estimated using mass balance considerations. For streams with a 7Q10 of 0.1 cfs or greater, the flow to be used in the calculation is 0.25 of the 7Q10 flow calculated in Step D.

6. Estimate groundwater and soil concentrations. Applicable COC concentrations for soil and groundwater can be back-calculated using the concept of DAFs.

The soil and groundwater COC concentrations estimated 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.

7. In addition to specific water quality criteria, general water quality criteria must be met in waters of the state at all times, including mixing zones. General water quality criteria are promulgated in 10 CSR 20-7.031(3), and include, among other criteria, the following:

a. Chronic water quality criteria must be achieved at the downstream edge of the mixing zone;
b. For Class C and unclassified streams, the acute criteria must be met at the point of discharge;
c. For Class P and P1 streams, the acute criteria must be met at the edge of the zone of initial dilution and throughout the mixing zone; and
d. For an unclassified stream that flows into a classified stream or becomes a classified stream downstream of the point of discharge, the acute criteria must be met at the point of groundwater discharge to the unclassified stream.

8. For lakes, the mixing zone cannot exceed one-quarter (¼) of the lake width at the discharge point or one hundred feet (100 feet) from the point of discharge, whichever is less. A zone of initial dilution is not allowed in lakes.

H. Models and Equations for Estimating DTLs, Tier 1 and Tier 2 Target Levels

The above parameters are used in two types of models to calculate the risk-based target levels. These models are uptake equations and fate and transport models. Tier 1 and Tier 2 risk assessments use the models and equations listed here. A different set of models may be used for Tier 3 risk assessments with the prior approval of the department through the submittal of a Tier 3 work plan.

1. Indoor Inhalation of Vapors (Child and Adult Resident, Non-residential Worker, and Construction Workers)

Carcinogenic effects

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

Non-carcinogenic effects

$$RBTL_{ai} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ai} \times ET_{in} \times ED \times EF}$$

where:

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

2. Outdoor Inhalation of Vapors (Child and Adult Resident, Non-residential Worker, and Construction Worker)

Carcinogenic effects

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

Non-carcinogenic effects

$$RBTL_{ao} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{IR_{ao} \times ET_{out} \times ED \times EF}$$

where:

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

3. Domestic Water Use (Child And Resident Only For Chemicals Without Missouri Water Quality Standards)

<u>Carcinogenic effects</u>

$$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times \left[\left(SF_o \times IR_w\right) + \left(SF_i \times ET \times K_f \times IR_a\right)\right]}$$

<u>Non-carcinogenic effects</u>

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w\right) + \left(\frac{1}{RfD_i} \times K_f \times ET \times IR_a\right)\right]}$$

where:

$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens[year]
AT_{nc}	=	Averaging time for non-carcinogens[year]

IR_w = Water ingestion rate [L/day]
IR_a = Indoor inhalation rate [m^3/hr]
ED = Exposure duration [year]
EF = Exposure frequency [day/year]
K_f = Volatilization factor [L/m^3]
ET = Exposure time [hr/day]
RfD_o = Chemical-specific oral reference dose [mg/kg-day]
RfD_i = Chemical-specific inhalation reference dose [mg/kg-day]
SF_o = Chemical-specific oral cancer slope or potency factor [mg/(kg-day)]$^{-1}$
SF_i = Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]
365 = Converts AT_c, AT_{nc} in years to days [day/year]

4. Dermal Contact with Chemicals in Groundwater (Child and Adult Resident)

<u>Carcinogenic effects</u>

$$RBTL_{dw} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_d \times SA \times PC \times ET \times EF \times ED}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_d}{SA \times PC \times ET \times EF \times ED}$$

where:

$RBTL_{dw}$ = Risk-based target level for dermal contact with groundwater [mg/L-H_2O]
TR = Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ = Target hazard quotient for individual constituents [-]
BW = Body weight [kg]
AT_c = Averaging time for carcinogens[year]
AT_{nc} = Averaging time for non-carcinogens[year]
SA = Skin surface area available for contact [cm^2]
PC = Chemical-specific dermal permeability constant [cm/hr]
ET = Exposure time [hour/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]
1000 = Conversion factor from cm^3 to L [cm^3/L]

5. Dermal Contact with Chemicals in Surficial Soil (Child and Adult Resident, Non-residential Worker, and Construction Worker)

Carcinogenic effects

$$RBTL_{dcss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_d \times 10^{-6} \times SA \times M \times RAF_d}$$

Non-carcinogenic effects

$$RBTL_{dcss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_d}{EF \times ED \times 10^{-6} \times SA \times M \times RAF_d}$$

where:

$RBTL_{dcss}$	=	Risk-based target level for dermal contact of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
SA	=	Skin surface area [cm^2/day]
M	=	Soil to skin adherence factor [mg/cm^2]
RAF_d	=	Chemical-specific dermal relative 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]

6. Ingestion of Chemicals in Surficial Soil (Child and Adult Resident, Non-residential Worker, and Construction Worker)

Carcinogenic effects

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

Non-carcinogenic effects

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

where:

$RBTL_{ingss}$	=	Risk-based target level for ingestion of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [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]
RAF_o	=	Oral relative absorption factor [-]
SF_o	=	Oral cancer slope factor [(mg/kg-day)$^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

7. Inhalation of Vapors and Particulates of Chemicals in Surficial Soil (Child and Adult Resident, Non-residential Worker, and Construction Worker)

<u>Carcinogenic effects</u>

$$RBTL_{inhss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_i \times IR_{ao} \times ET_{out} \times (VF_{SS} + VF_p)}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{inhss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_i}{EF \times ED \times ET_{out} \times IR_{ao} \times (VF_{ss} + VF_p)}$$

where:

$RBTL_{inhss}$	=	Risk-based target level of inhalation of chemicals in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED	=	Exposure duration [year]
EF	=	Exposure frequency [day/year]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
SF_i	=	Inhalation cancer slope factor [(mg/kg-day)$^{-1}$]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-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)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

Note: The depth to surficial soil for a construction worker is up to the typical construction depth.

8. Inhalation of Vapors and Particulates, Dermal Contact with and Ingestion of Chemicals in Surficial Soil (Child and Adult Resident, Non-residential Worker, and Construction Worker)

<u>Carcinogenic effects</u>

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

<u>Non-carcinogenic effects</u>

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

Where:

$RBTL_{ss}$	=	Risk-based target level of surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_c	=	Averaging time for carcinogens [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]
RAF_o	=	Oral relative absorption factor [-]
SA	=	Skin surface area [cm^2/day]
M	=	Soil to skin adherence factor [mg/cm^2]
RAF_d	=	Dermal relative adsorption factor [-]
IR_{ao}	=	Outdoor inhalation rate [m^3/hr]
ET_{out}	=	Outdoor Exposure time [hr/day]
SF_o	=	Oral cancer slope factor [(mg/kg-day)$^{-1}$]
SF_i	=	Inhalation cancer slope factor [(mg/kg-day)$^{-1}$]
RfD_o	=	The chemical-specific oral reference dose [mg/kg-day]
RfD_i	=	The chemical-specific inhalation reference dose [mg/kg-day]

VF_p	=	Volatilization factor 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)]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

9. Indoor Inhalation of Vapors (Age-Adjusted Resident)

<u>Carcinogenic effects</u>

$$RBTL_{ai\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ai-aa} \times SF_i}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{ai\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ai-aa}}$$

where

$$IR_{ai-aa} = \frac{IR_{ai-c} \times ED_c \times EF_c \times ET_{i-c}}{BW_c} + \frac{IR_{ai-a} \times ED_a \times EF_a \times ET_{i-a}}{BW_a}$$

Where:

$RBTL_{ai\text{-}adj}$	=	Age-adjusted risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
$IR_{ai\text{-}aa}$	=	Age-adjusted indoor inhalation rate [m^3/ kg]
$IR_{ai\text{-}c}$	=	Resident Child indoor inhalation rate [m^3/hr]
$IR_{ai\text{-}a}$	=	Resident Adult indoor inhalation rate [m^3/hr]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
$ET_{i\text{-}c}$	=	Indoor exposure time for a child [hour/day]
$ET_{i\text{-}a}$	=	Indoor exposure time for an adult [hour/day]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [mg/kg-day]$^{-1}$
365	=	Conversion factor [day/year]

10. Outdoor Inhalation of Vapors (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{ao\text{-}adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i}$$

Non-carcinogenic effects

$$RBTL_{ao\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao\text{-}aa}}$$

where

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

Where:

$RBTL_{ao\text{-}adj}$	=	Age-adjusted risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
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]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [(mg/kg-day)$^{-1}$]
365	=	Conversion factor [day/year]
$IR_{ao\text{-}aa}$	=	Age-adjusted outdoor inhalation rate [m^3/kg]
$IR_{ao\text{-}c}$	=	Resident Child outdoor inhalation rate [m^3/hr]
$IR_{ao\text{-}a}$	=	Resident Adult outdoor inhalation rate [m^3/hr]
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]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o\text{-}a}$	=	Outdoor exposure time for an adult [hour/day]

11. Domestic Water Use (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{TR \times AT_c \times 365}{\left[\left(SF_o \times IR_{w\text{-}aa}\right) + \left(SF_i \times K_f \times IR_{a\text{-}aa}\right)\right]}$$

Non-carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{THQ \times AT_{nc} \times 365}{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa}\right) + \left(\frac{1}{RfD_i} \times K_f \times IR_{a-aa}\right)\right]}$$

where:

$$IR_{w\text{-}aa} = \frac{ED_c \times EF_c \times IR_{w-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{w-a}}{BW_a}$$

$$IR_{a\text{-}aa} = \frac{ED_c \times EF_c \times ET_c \times IR_{a-c}}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times IR_{a-a}}{BW_a}$$

Where:

$RBTL_{w\text{-}adj}$	=	Age-adjusted risk-based target level for ingestion of groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
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)$^{-1}$]
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident Child groundwater ingestion rate [L/day]
$IR_{a\text{-}c}$	=	Resident Child inhalation rate [m^3/hr]
$IR_{w\text{-}a}$	=	Resident Adult groundwater ingestion rate [L/day]
$IR_{a\text{-}a}$	=	Resident Adult inhalation rate [m^3/hr]
BW_c	=	Resident Child body weight [kg]
BW_a	=	Resident Adult body weight [kg]
ED_c	=	Resident Child exposure duration [year]
ET_c	=	Resident Child exposure time [hr/day]
ET_a	=	Resident Adult exposure time [hr/day]
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]
K_f	=	Volatilization factor [L/m^3]
365	=	Conversion factor [day/year]
SF_i	=	Chemical-specific inhalation cancer slope or potency factor [(mg/kg-day)$^{-1}$]

12. Dermal Contact with Chemicals in Groundwater (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{TR \times AT_c \times 365 \times 1000}{SF_d \times PC \times DC_{w-aa}}$$

Non-carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times 1000 \times RfD_d}{PC \times DC_{w-aa}}$$

where

$$DC_{w\text{-}aa} = \frac{ED_c \times EF_c \times ET_c \times SA_c}{BW_c} + \frac{ED_a \times EF_a \times ET_a \times SA_a}{BW_a}$$

Where:

$RBTL_{dcw\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with chemicals in groundwater [mg/L-H_2O]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
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-day)$^{-1}$]
PC	=	Chemical-specific dermal permeability constant [cm/hr]
$DC_{w\text{-}aa}$	=	Age-adjusted dermal contact rate with groundwater [hr-cm^2/kg]
SA_c	=	Resident child skin surface area available for contact [cm^2]
SA_a	=	Resident adult skin surface area available for contact [cm^2]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
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]
ET_c	=	Exposure time for a child [hr/day]
ET_a	=	Exposure time for an adult [hr/day]

13. Dermal Contact with Chemicals in Surficial Soil (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{dcss\text{-}adj} = \frac{TR \times AT_c \times 365}{SF_d \times SA_{aa} \times RAF_d \times 10^{-6}}$$

<u>Non-carcinogenic effects</u>

$$RBTL_{dcss\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_d}{SA_{aa} \times RAF_d \times 10^{-6}}$$

where

$$SA_{aa} = \frac{ED_c \times EF_c \times M_c \times SA_c}{BW_c} + \frac{ED_a \times EF_a \times M_a \times SA_a}{BW_a}$$

Where:

$RBTL_{dcss\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
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]
RAF_d	=	Dermal relative absorption factor [-]
M_c	=	Resident Child soil to skin adherence factor [mg/cm^2]
M_a	=	Resident Adult soil to skin adherence factor [mg/cm^2]
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_c	=	Resident Child skin surface area [cm^2/day]
SA_a	=	Resident Adult skin surface area [cm^2/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

14. Direct Ingestion of Chemicals in Surficial Soil (Age-Adjusted Resident)

<u>Carcinogenic effects</u>

$$RBTL_{ingss-adj} = \frac{TR \times AT_c \times 365}{SF_O \times IR_{s-aa} \times RAF_O \times 10^{-6}}$$

Non-carcinogenic effects

$$RBTL_{ingss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_o}{IR_{s-aa} \times RAF_o \times 10^{-6}}$$

where

$$IR_{s-aa} = \frac{ED_c \times EF_c \times IR_{s-c}}{BW_c} + \frac{ED_a \times EF_a \times IR_{s-a}}{BW_a}$$

Where:

$RBTL_{ingss-adj}$	=	Risk-based target level for ingestion of soil [mg/kg-wet soil]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
RAF_o	=	Oral relative absorption factor [-]
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]

15. Inhalation of Vapors and Particulates of Chemicals in Surficial Soil (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{ss-adj} = \frac{TR \times AT_c \times 365}{IR_{ao-aa} \times SF_i \times \left(VF_{ss} + VF_p\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-adj} = \frac{THQ \times AT_{nc} \times 365 \times RfD_i}{IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

where

$$IR_{ao-aa} = \frac{IR_{ao-c} \times ED_c \times EF_c \times ET_{o-c}}{BW_c} + \frac{IR_{ao-a} \times ED_a \times EF_a \times ET_{o-a}}{BW_a}$$

where:

$RBTL_{ss-adj}$	=	Age-adjusted risk-based target level in surficial soil [mg/kg]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
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]
IR_{ao-aa}	=	Age-adjusted outdoor inhalation rate [m^3/kg]
IR_{ao-c}	=	Resident Child outdoor inhalation rate [m^3/hr]
IR_{ao-a}	=	Resident Adult outdoor inhalation rate [m^3/hr]
AT_c	=	Averaging time for carcinogens [year]
AT_{nc}	=	Averaging time for non-carcinogens [year]
ED_c	=	Exposure duration for child [year]
ED_a	=	Exposure duration for an adult [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
ET_{o-c}	=	Outdoor exposure time for a child [hour/day]
ET_{o-a}	=	Outdoor exposure time for an adult [hour/day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
SF_i	=	Chemical-specific inhalation cancer slope factor [(mg/kg-day)$^{-1}$]
365	=	Conversion factor [day/year]

16. Inhalation of Vapors and Particulates, Dermal Contact and Ingestion of Chemicals in Surficial Soil (Age-Adjusted Resident)

Carcinogenic effects

$$RBTL_{ss-combined} = \frac{TR \times AT_c \times 365}{\left(SF_o \times 10^{-6} \times IR_{s-aa} \times RAF_o\right) + \left(SF_d \times 10^{-6} \times SA_{aa} \times RAF_d\right) + SF_i \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Non-carcinogenic effects

$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times IR_{s-aa} \times RAF_o + \frac{1}{RfD_d} \times 10^{-6} \times SA_{aa} \times RAF_d + \frac{1}{RfD_i} \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Note: All parameters are defined under the individual pathway equations

17. Subsurface Soil Vapor Concentrations Protective of Indoor Vapor Inhalation

$$RBTL_{svi} = \frac{RBTL_{ai}}{VF_{sv}}$$

where:

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

18. Subsurface Soil Concentrations Protective of Indoor Vapor Inhalation

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

where:

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

19. Groundwater Concentrations Protective of Indoor Vapor Inhalation

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

where:

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

[(mg/m^3-air)/(mg/l-H_2O)]

20. Groundwater Concentrations Protective of Outdoor Vapor Inhalation

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

where:

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

21. Volatilization Factors

A.

$$VF_{ss} = \left[Q/C \times \frac{\left(3.14 \times D_A \times \tau\right)^{1/2}}{\left(2 \times \rho_s \times D_A\right)} \times 10^{-4} \right]^{-1}$$

where:

$$D_A = \frac{\left(\theta_{as}^{10/3} \times D^a \times H + \theta_{ws}^{10/3} \times D^w\right) / \theta_T^2}{\rho_s \times K_{sv} + \theta_{ws} + \theta_{as} \times H}$$

or

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

Use smaller of the two VF_{ss}

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-H_2O/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-H_2O/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [(L-H_2O)/(L-air)]

10^{-4} = Conversion factor [m^2/cm^2]
W_a = Dimension of soil source area parallel to wind direction [cm]
d_s = Depth to base of surficial soil zone [cm]
U_m = Mean annual wind speed [m/s]
δ_a = Breathing zone height [cm]
10^3 = Conversion factor [(cm^3-kg)/(m^3-g)]

Note: Surficial soil properties are assumed same as the vadose zone properties.

B.

$$VF_p = \left[Q/C \times \frac{3600}{0.036 \times (1 - V) \times \left(U_m / U_t\right)^3 \times F(x)} \right]^{-1}$$

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]

C.

$$VF_{sv} = \frac{\left[\dfrac{D_s^{eff} / d_{sv}}{ER \times L_B} \right]}{1 + \left[\dfrac{D_s^{eff} / d_{sv}}{ER \times L_B} \right] + \left[\dfrac{D_s^{eff} / d_{sv}}{\left(D_{crack}^{eff} / L_{crack}\right) \times \eta} \right]}$$

where:

VF_{sv} = Volatilization factor from subsurface soil vapor to indoor (enclosed space) air [-]
θ_{ws} = Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil]
θ_{as} = Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil
d_{sv} = Depth to subsurface soil vapor samples taken [cm]
L_B = Enclosed space volume/infiltration area ratio [cm]
L_{crack} = Enclosed space foundation or wall thickness [cm]
ER = Enclosed space air exchange rate [1/s]
D_s^{eff} = Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
D_{crack}^{eff} = Effective diffusion coefficient through foundation cracks [cm^2/s]
η = Area fraction of cracks in foundation and/or walls

[cm^2-cracks/ cm^2-total area]

D.

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

where:

VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [m^3-air/(mg/kg-soil)]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]
ρ_s	=	Dry soil bulk density [g-soil/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3-soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$
	=	Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
θ_{as}	=	Volumetric air content in vadose zone soils [cm^3-air/cm^3-soil
d_{ts}	=	Depth to subsurface soil sources [cm]
L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
D_s^{eff}	=	Effective diffusion coefficient in soil based on vapor-phase concentration [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [(cm^3-kg)/(m^3-g)]

E.

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

where:

VF_{wesp}	=	Volatilization factor from groundwater to indoor (enclosed space) air [(mg/m^3-air)/(mg/L-H_2O)]
H	=	Vadose zone chemical specific Henry's Law constant [(L-H_2O)/(L-air)]
L_{GW}	=	Depth to groundwater [cm]

L_B	=	Enclosed space volume/infiltration area ratio [cm]
L_{crack}	=	Enclosed space foundation or wall thickness [cm]
ER	=	Enclosed space air exchange rate [1/s]
D_{ws}^{eff}	=	Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
D_{crack}^{eff}	=	Effective diffusion coefficient through foundation cracks [cm^2/s]
η	=	Area fraction of cracks in foundation and/or walls [cm^2-cracks/ cm^2-total area]
10^3	=	Conversion factor [L/m^3]

F.

$$VF_{wamb} = \frac{H}{1+\left(\frac{100 \times U_m \times \delta_a \times L_{GW}}{W_{ga} \times D_{ws}^{eff}}\right)} \times 10^3$$

where:

VF_{wamb}	=	Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-H_2O)]
H	=	Vadose zone chemical specific Henry's Law constant [(L-H_2O)/(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]

22. Effective Diffusion Coefficients

A.

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

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

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in capillary fringe soils [cm^3-H2O/cm^3-soil]
θ_T	=	Total soil porosity in the impacted zone [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]

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

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

where:

h_c	=	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 ($h_c + h_v$) [cm]

B.

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

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

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{acap}	=	Volumetric air content in capillary fringe soils [cm^3-air/cm^3-soil]
θ_{wcap}	=	Volumetric water content in capillary fringe soils [cm^3-H2O/cm^3-soil]
θ_T	=	Total soil porosity [cm^3/cm^3-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air

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

where:

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

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

23. Subsurface Soil Concentrations Protective of Leaching to Groundwater

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

where:

$RBTL_{SL}$	=	Risk-based target level for leaching to groundwater from subsurface soil [mg/kg-soil]
$RBTL_w$	=	Risk-based target level for ingestion of groundwater [mg/L-H_2O]
LF_{SW}	=	Leaching Factor (from subsurface soil to groundwater) [(mg/L-H2O)/(mg/kg-soil)]

24. Leaching Factor from Subsurface Soil to Groundwater

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

where:

LF_{SW}	=	Leaching factor from subsurface soil to groundwater [(mg/L-H_2O)/(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-H_2O/cm^3- soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
H	=	Chemical-specific Henry's Law constant [L-H_2O/L-air]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
U_{gw}	=	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.

25. Soil Concentration at Which Dissolved Pore Water and Vapor Phases Become Saturated

<u>Single Component</u>

$$C_s^{SAT} = \frac{S}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv}\rho_s]$$

<u>Multiple Components</u>

$$C_s^{SAT} = \frac{S_{ei}}{\rho_s} \times [H \times \theta_{as} + \theta_{ws} + K_{sv}\rho_s]$$

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-H_2O]
S_{ei}	=	Effective solubility of component i in water = $x_i \times S$ [mg/L-H_2O]
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-H_2O/L-air]
θ_{as}	=	Volumetric air content in the vadose zone soils [cm^3-air/cm^3-soil]
θ_{ws}	=	Volumetric water content in vadose zone soils [cm^3-H_2O/cm^3- soil]
K_{sv}	=	$f_{ocv} \times K_{oc}$ = Chemical-specific soil-water sorption coefficient in vadose zone [cm^3-H_2O/g-soil]
f_{ocv}	=	Fraction organic carbon in vadose zone [g-C/g-soil]

26. Soil Vapor Concentration at Which Vapor Phase Becomes Saturated

<u>Single Component</u>

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

<u>Multiple Components</u>

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

where:

C_v^{SAT}	=	Soil vapor concentration at which vapor phase become saturated [mg/m^3-air]
P^s	=	Saturate 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-H_2O]
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]

10^6 = Conversion factor [(g/L)/(mg/m^3)]

27. Domenico Model: Dilution Attenuation Factor (DAF) in the Saturated Zone

A.
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	=	$C_o/C(x)$

B.
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 λ = 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 $C_o = C_{source}$

28. Allowable Soil and Groundwater Concentration for Groundwater Resource Protection

Allowable soil concentration at the source [mg/kg] = *Target groundwater concentration at the POE* $\times \frac{DAF_{POE}}{LF_{SW}}$

Allowable groundwater concentration at the POD [mg/L] = *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
LF_{SW}	=	Dry soil leaching factor [(mg/L-H_2O)/(mg/kg-soil)]

Concentration at POE is expressed in mg/L-H_2O

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

First order decay rate [1/day] = $\frac{0.693}{Half\ \ Life}$; $v = \frac{Ki}{\theta_{TS} R_s}$

Retardation factor for organics in the saturated zone (R_s) = $1 + \left(\frac{\rho_{ss} \times K_{ss}}{\theta_{TS}}\right)$,

$K_{ss} = f_{ocs} \times K_{oc}$ (for organics only)

where:

v	=	Regarded seepage velocity [cm/year]
K	=	Hydraulic conductivity in saturated zone [cm/year]
i	=	Hydraulic gradient in saturated zone [-]
ρ_{ss}	=	Saturated zone dry soil bulk density [g-soil/cm^3-soil]
K_{ss}	=	Chemical-specific soil-water sorption coefficient in the saturated zone [cm^3-H_2O/g-soil]
K_{oc}	=	Chemical-specific normalized partition coefficient [cm^3/g-C]
θ_{TS}	=	Total porosity in the saturated zone [cm^3/g-C]
f_{ocs}	=	Fractional organic carbon content in the saturated zone [g-C/g-soil]

29. 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}= Impacted groundwater discharge into the stream [ft^3/day]
Y= Allowable concentration in groundwater at the point of discharge into the stream [mg/L]
Z= Stream flow upstream of the point of groundwater discharge (stream flow rate) [ft^3/day]
α_y= Allowable concentration at the downstream edge of the stream's mixing zone, i.e., the applicable stream water quality criteria [mg/L]
α_z= The COCs' concentration upstream of the groundwater plume discharge [mg/L]
GW source dimension perpendicular to GW flow direction [ft]
GW source (mixing zone) thickness [ft]
X_s= Lateral dispersivity [ft]
U_{gw}= Vertical dispersivity [ft]

30. Stream Protection: Allowable Soil and Groundwater Concentration at the Source & POD

Allowable soil concentration at the source [mg/kg] = *Target concentration* [mg/L] *at the POE* $\times \frac{DAF_{POE}}{LF_{SW}}$

Allowable groundwater concentration at the POD [mg/L] = *Target concentration* [mg/L] *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 the source estimated using Domenico's equation
LF_{SW}	Dry soil leaching factor [(mg/L-H_2O)/(mg/kg-soil)]

For calculation of DAF_{POE} and DAF_{POD}, please refer to Domenico's model.

I. Target Levels for Lead

The Integrated Exposure Uptake Biokinetic (IEUBK) Model predicts the risk of elevated blood lead (PbB) in children under the age of seven that are exposed to environmental lead from various sources. The model predicts the probability that a child exposed to lead concentrations in a specified media will have a PbB level greater than 10 micrograms per deciliter (μg/dL), the level associated with adverse health effects. Risk to children is the primary concern in a residential setting. In a non-residential scenario, children are not directly exposed, but fetuses carried by female workers can be exposed. The adult lead methodology (ALM) is used to assess risk in this scenario. The groundwater target level where domestic use of groundwater is a complete pathway is the water quality standard for the protection of drinking water. The department may require a site-specific analysis where leaching to groundwater is a relevant consideration.

J. Target Levels for LNAPL/DNAPL

For sites where light, nonaqueous phase liquids (LNAPL) or dense, nonaqueous phase liquids (DNAPL) are present, the primary routes of exposure to include are the indoor inhalation for a residential or a non-residential receptor, and, if the domestic use of groundwater pathway is complete or potentially complete, the protection of a current or potential future point of exposure groundwater well. Calculate the vapor concentration and the dissolved concentration emanating from the LNAPL/DNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in subsection H above.

The soil vapor concentration in equilibrium with LNAPL/DNAPL is the effective soil vapor concentration. This concentration depends on the chemical-specific saturated soil vapor concentration, and the mole fraction of the chemical in the LNAPL/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/DNAPL, may be used if the NAPL can be analyzed and its components determined. Alternatively, the LNAPL/DNAPL may be sampled 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 subsection H. The effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration in the point of demonstration. If DNAPL is located below the water table, pathways related to inhalation of vapors will be considered incomplete as vapors will not penetrate the overlying column of saturated soil.

(12) Conducting a Tier One Risk Assessment

If the maximum soil or groundwater concentrations exceed the default target levels (DTLs), the remediating party may choose to either complete a Tier 1 Risk Assessment or conduct the cleanup using DTLs levels.

(A) When conducting a Tier One risk assessment, the following steps must be completed:

1. Compile data and identify data gaps;
2. Develop exposure model;
3. If necessary, collect data to fill data gaps;
4. Calculate media and pathway-specific representative concentrations for chemicals of concern (COCs);
5. Select relevant Tier 1 risk-based target levels from lookup tables and compare with site concentrations;
6. If necessary, calculate cumulative site-wide risk and compare with acceptable risk,
7. Evaluate the next course of action; and
8. Document Tier 1 risk assessment and recommendations.

(B) An exposure model is developed to identify:

1. All complete routes of exposure for current and reasonably anticipated future land use;
2. The exposure domain for each complete route of exposure; and
3. The point of exposure for each route of exposure.

(C) The exposure model is developed as follows: Prior to determining exposure pathways, sufficient site characterization must be conducted such that the horizontal and vertical extent of COCs in soil and groundwater has been determined to appropriate risk-based levels. The analysis then identifies exposure pathways at a site that are currently complete or that are reasonably likely to become complete in the future. Pathways are determined by considering the locations of the point and size of release, the extent of contamination, the location of receptors, and the media through which chemicals migrate from the location of the release to the receptors.

(D) Using the information from Steps 1 through 3 in Subsection (10)(A), the remediating party must calculate representative chemical concentrations for each exposure domain.

(E) The need to calculate representative concentrations may be avoided by initially using the maximum media-specific concentrations for each pathway as the representative concentration. If the risk calculated with the use of the maximum concentrations (which is the most protective assumption) meet the Tier 1 risk-based target levels, calculation of representative concentrations is not necessary.

(F) In accordance with Paragraph (10)(A)5., Tier 1 risk-based target levels for each chemical, each receptor, and each route of exposure must be selected. For residential land use, Tier 1 values must be selected for three receptors: child, adult, and age-adjusted individual. The Tier 1 risk-based target levels for each complete route of exposure and each COC must be compared with the appropriate representative concentration.

(G) The requirement in Paragraph (10)(A)6 to calculate cumulative site-wide risk applies only in cases where the number of COCs and routes of exposure may warrant the calculation of cumulative site-wide risk. When required, the cumulative site-wide risk is calculated for each receptor using the following two-step process.

1. First, the total risk of each chemical for each complete or potentially complete route of exposure must be calculated.
2. Second, the total risk for each chemical (sum of the risk for all the routes of exposure

calculated in 1, above) and the site-wide risk (sum of the risk of all chemicals for all routes) for each receptor must be calculated.

The cumulative site-wide risks calculated in this step are compared with acceptable cumulative site-wide risk levels.

(H) The remediating party may request that the department issue a letter of completion for the site if:

1. The analysis in Paragraph (10)(A)5. or (10)(A)6. indicates that both the cumulative site-wide risk (all chemicals and all complete pathways, $IELCR_T$ and HI_T) and the risk for each chemical (all pathways, $IELCR_{Ci}$ and HI_{Ci}) for all receptors is acceptable; or
2. The representative concentration for all COCs and all the routes of exposure are below the Tier 1 risk-based target levels.

In either case above, the following four conditions must be met.

1. The plume, if one exists, is stable or decreasing (refer to Section 6.13.2 for discussion of plume stability). If this condition is not satisfied, the remediating party must continue groundwater monitoring until the plume is demonstrably stable. Actions may be taken to hasten plume stability. This recommendation must include a sampling plan with specifics such as:
   A. Wells to be sampled;
   B. Frequency of sampling;
   C. Laboratory analysis method;
   D. Method to be used to demonstrate that the plume is stable or shrinking; and
   E. The format and frequency of reporting requirements.
2. The maximum concentration of any COC is less than ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration of a chemical in the exposure domain, not the site-wide maximum concentration. This condition can be met if an exceedance can be justified because the maximum concentration is an outlier or there is another explanation satisfactory to the department. Additional work may be needed if the average concentration was inaccurately calculated, the site is not adequately characterized or a hot spot may not have been adequately characterized. Any exceedance of this condition must be documented and the possible rationale, if any, submitted to the department.
3. Prior to issuance of a letter of completion, adequate assurance is provided that the land use assumptions used in the MRBCA evaluation are not violated for current or reasonably anticipated future conditions. This condition may require that one or more activity and use limitations (AULs) are placed on the site and plans are in place to maintain long-term stewardship (LTS) for as long as needed to protect human health, public welfare and the environment.
4. There are no ecological concerns at the site, as determined by confirmation that the maximum representative concentrations are below levels protective of ecological receptors or completion of the Ecological Risk Assessment. If this condition is not met, the remediating party must provide recommendations to the department to manage the ecological risk. If the department approves the recommendations and they are implemented, this condition would be met.

(I) If the remediating party decides to remediate the site to Tier 1 risk-based target levels, the cleanup levels will be the lower of the concentrations protective of human health, both

carcinogenic and non-carcinogenic, and ecological receptors.

(J) The Tier 1 risk assessment must be clearly documented, both to facilitate the department's review and to provide information to interested third parties. If a Tier 2 assessment is also conducted, both Tier 1 and Tier 2 assessments may be submitted as one report. At a minimum, the Tier 1 Risk Assessment Report must include the following:

1. Site background and chronology of events;
2. Data used to perform the evaluation;
3. Documentation of the exposure model and its underlying assumptions;
4. If cumulative risk calculation is required, the estimated risk for each chemical, each route of exposure, each receptor, each media, and the cumulative site-wide risk for each receptor;
5. Recommendations based on the Tier 1 risk assessment (either Tier 2 assessment or preparation of a risk management plan); and
6. If a letter of completion is requested, documentation that all four of the conditions (carcinogenic and noncarcinogenic chemicals, individual and site-wide risk criteria) have been met.

(13) Conducting a Tier Two risk assessment

If any of the representative concentrations at the site are above the Tier 1 risk-based target levels or if the cumulative site-wide risk exceeds acceptable target risk levels, the remediating party may choose to complete a Tier 2 risk assessment in lieu of cleanup to the Tier 1 risk-based target levels. A Tier 2 risk assessment may also be required by the department if the site-specific fate and transport parameters or other site conditions are clearly different from the default assumptions used to develop Tier 1 risk-based target levels.

(A) A Tier 2 risk assessment must include the following steps:

1. Compile site-specific fate and transport parameters;
2. Calculate Tier 2 risk levels;
3. Compare Tier 2 risk levels with acceptable risk;
4. Recommend the next course of action; and
5. Document Tier 2 risk assessment.

(B) Fate and transport parameters are considered site-specific if they are:

1. Correctly measured on site at the appropriate location using approved methods;
2. Literature values that can be justified as being representative of site conditions;
3. Default values that can be justified as representative of current conditions at the site or shown to be conservative based on site conditions; or
4. Documented values, such as may be obtained from Hazardous Waste Program site files, from a nearby site in a similar hydrogeologic setting.

(C) The remediating party must review the site information and select values for each of these parameters and provide justification for the selection of each specific value. Literature values consistent with the site stratigraphy may be used in lieu of field measurements. In cases that show considerable variability, the department may require a sensitivity analysis.

(D) Soil Parameters

1. Dimension of Exposure Domain for Surficial Soil Parallel to Wind (W_a)

If wind direction is variable and or unknown at the site, the longest dimension of the exposure domain is used.

2. Depth to Subsurface Soil Sources (d_{ts})

Tier 2 requires the use of the actual measured depth of COCs in soil for which risk is calculated.

3. Thickness of Capillary Fringe (h_c)

The thickness of the capillary fringe must be representative of the site soils/sediments and is primarily dependent on soil grain size.

4. Thickness of Vadose Zone (h_v)

At Tier 2, the thickness of the vadose zone is calculated by subtracting the capillary fringe thickness from the depth to groundwater ($L_{gw} – h_c = h_v$), where L_{gw} is depth to groundwater.

5. Vadose Zone Dry Soil Bulk Density (ρ_s)

If multiple measurements from the vadose zone are available or when multiple values are necessary to represent different soil types, use the average value.

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

If measurements of fractional organic matter (not the same as fractional organic carbon) are available, the value must be converted to fractional organic carbon. 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.

7. Porosity in the Vadose Zone (θ_T)

If multiple porosity values are available, an average value should be used. Where total and effective porosity differ or are expected to differ, the effective porosity value must be used. Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and may be composited into one sample for porosity analysis. If multiple values are available (as is recommended), and if technically appropriate, the average value should be used.

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

An average value based on multiple representative samples must be used. The laboratory must report soil COCs concentration on a dry weight basis and the moisture content of each sample. Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and may be composited into one sample for volumetric water content analysis. If multiple values are available (as is recommended), and if technically appropriate, the average value should be used.

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

Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and may be composited into one sample for volumetric air content analysis. If multiple values are available (as is recommended), and if technically appropriate, the average value should be used.

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

Volumetric water content in the capillary fringe may be 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 may be assumed to be equal to the total vadose zone porosity.

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

Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and may be composited into one sample for volumetric air content analysis. If multiple values are available (as is recommended), and if technically appropriate,

the average value should be used.

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

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

(E) Groundwater Parameters

1. Depth to Groundwater (L_{gw})

The average depth to groundwater should be based on several years of data. 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 all of the wells 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." If data collected over an extended period of time is not available, the site-specific average depth to groundwater should be calculated by determining the depth to groundwater in each well and then averaging the single well water depths. However, where significant differences in static water levels occur across the site, conservatively the shallowest average depth to groundwater should be used (that is, a single well average using data from the well showing the shallowest depth to groundwater).

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

The dimension Y may be estimated by projecting the area of release to the water table.

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

W_{ga} may be estimated by projecting the area of release to the water table.

4. Porosity in Saturated Zone (θ_{TS})

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.

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

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.

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

If a site-specific value for saturated zone fractional organic carbon content is to be used at Tier 2, the value must be determined based on field samples collected below the water table or by choosing a justifiable literature value.

7. Groundwater Mixing Zone Thickness (δ_{gw})

The mixing zone thickness may be approximated based either on photoionization detector (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. EPA's Soil Screening Guidance (1996, page 45, equation 45) contains an equation to calculate the groundwater mixing zone thickness that may be used at Tier 2. Other procedures for determining the mixing zone thickness may be used with the prior approval of the department. The mixing zone thickness should not exceed the thickness

of the aquifer.

8. Groundwater Darcy Velocity (U_{gw})

At Tier 2, the groundwater Darcy velocity must be a site-specific value. The value is the product of the saturated zone hydraulic conductivity and the hydraulic gradient. Site-specific hydraulic conductivity can be estimated based on the results of site-specific pump tests, if available, or using literature values based on site-specific lithology. The hydraulic gradient should be estimated (as the average gradient) using groundwater elevation data 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 need to be estimated for more than one direction and/or a range of velocities presented.

9. Infiltration Rate (I)

Unless site-specific information is available, the infiltration rate may be estimated as 10 percent of the average annual rainfall at the site. Average annual rainfall values are based on a 30-year average and may be obtained from literature.

(F) Calculating Tier 2 Risk

At Tier 2, risk values must be individually calculated for each COC and each complete route of exposure in the exposure model. Then the total risk for each COC and the cumulative site-wide risk must be calculated. In calculating the Tier 2 risk, the models, physical-chemical properties, toxicological properties, and exposure factors will be the same as used in the Tier 1 risk calculations.

(G) Comparing Tier 2 Risk With Acceptable Risk Levels

Tier 2 risks for each COC as well as the total site-wide risk will be compared with their respective acceptable risk level. The total acceptable individual excess lifetime cancer risk (IELCR) for each COC is 1×10^{-5}. The acceptable risk level for site-wide cumulative IECLR is 1×10^{-4}. The acceptable hazard quotient (H) for each COC and each route of exposure as well as the Hazard Index of 1.0. There are four possible outcomes from this analysis:

1. The calculated IELCR for each COC and the cumulative site-wide IELCR are below the acceptable risk levels. In this case, it is not necessary to develop Tier 2 site-specific target levels for carcinogenic effects;
2. Either the individual COC or the cumulative site-wide IELCR exceeds the acceptable risk level. In this case, Tier 2 site-specific target levels must be developed. The remediating party must carefully explain the method and the assumptions used to calculate the target levels;
3. The calculated cumulative site-wide hazard index (sum of the hazard quotients for all chemicals for all routes of exposure) is acceptable (less than 1.0). In this case, the non-carcinogenic risk is deemed acceptable and it is not necessary to develop Tier 2 site-specific target levels for non-carcinogenic adverse health effects; and
4. The hazard quotient for each COC is acceptable (less than unity), but the site-wide hazard index is unacceptable (greater than 1.0). In this case, it may be appropriate to segregate the COCs by target organ, system or mode of action and derive hazard indices for each. If each of these cumulative hazard indices is acceptable (less than 1.0), it is not necessary to develop Tier 2 site-specific target levels for these COCs for non-carcinogenic health effects. If not acceptable, it is necessary to develop the target levels for the COCs in the group that exceed the hazard index of unity.

A toxicologist must perform the analysis that is conceptually described above. In calculating the Hazard Index, COCs with multiple effects must be included in each category of organ that

the COC affects.

(H) The remediating party may request that the department issue a letter of completion for the site if:

1. The analysis in Step 4 indicates that both the cumulative site-wide risk (all chemicals and all complete pathways, $IELCR_T$ and HI_T) and the risk for each chemical (all pathways, $IELCR_{Ci}$ and HI_{Ci}) for all receptors is acceptable; or
2. The representative concentration for all COCs and all the routes of exposure are below the Tier 2 site-specific target levels.

In each case above, the following four conditions must be met.

1. The plume, if one exists, is stable or decreasing (refer to Section 6.13.2 for discussion of plume stability). If this condition is not satisfied, the remediating party must continue groundwater monitoring until the plume is demonstrably stable. Actions may be taken to hasten plume stability. This recommendation must include a sampling plan with specifics such as:
   A. Wells to be sampled;
   B. Frequency of sampling;
   C. Laboratory analysis method;
   D. Method to be used to demonstrate that the plume is stable or shrinking; and
   E. The format and frequency of reporting requirements.
2. The maximum concentration of any COC is less than ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration of a chemical in the exposure domain, not the site-wide maximum concentration. This condition can be met if an exceedance can be justified because the maximum concentration is an outlier or there is another explanation satisfactory to the department. Additional work may be needed if the average concentration was inaccurately calculated, the site is not adequately characterized or a hot spot may not have been adequately characterized. Any exceedance of this condition must be documented and the possible rationale, if any, submitted to the department. The department will determine what actions, if any, will be necessary to address the situation.
3. Prior to issuance of a Letter of Completion, adequate assurance must be provided that the land use assumptions used in the MRBCA evaluation are not violated for current or reasonably anticipated future conditions. This condition may require that one or more activity and use limitations (AULs) are placed on the site and plans are in place to maintain long-term stewardship (LTS) for as long as needed to protect human health, public welfare and the environment.
4. 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 Ecological Risk Assessment. If this condition is not met, the remediating party must provide ecological risk management recommendations to the department as part of the risk management plan. If the department approves the plan, then this condition would is met.

(I) The remediating party must decide either to use the calculated Tier 2 site specific target levels as the cleanup levels and conduct corrective action to meet these levels or to perform a Tier 3 risk assessment if the analysis finds that:

1. The risk for any chemical (all pathways, $IELCR_{Ci}$ and HI_{Ci}) for any human or

ecological receptors exceeds acceptable levels; or

2. The cumulative site-wide risk (all chemicals and all complete pathways, $IELCR_T$ and HI_T) exceeds acceptable levels; or
3. The representative concentrations exceed the calculated Tier 2 site specific target levels.

Based on the decision above, the remediating party must recommend one of the following:

1. Remediation to Tier 2 site-specific target levels (if the remediating party decides to remediate the site to Tier 2 site-specific target levels, the cleanup levels will be the lower of concentrations protective of human health, both carcinogenic and non-carcinogenic, and ecological receptors); or
2. Performance of a Tier 3 risk assessment.

(O) Documentation of the Tier 2 Risk Assessment

The risk assessment must be clearly documented. If a Tier 1 risk assessment is also conducted, both Tier 1 and Tier 2 risk assessments may be submitted as one report. At a minimum, the Tier 2 risk assessment report must include the following:

1. Site background and chronology of events;
2. Data used to perform the evaluation;
3. Documentation of the exposure model and its assumptions;
4. Documentation and justification of all fate and transport parameters;
5. Estimated risk for each COC, each route of exposure, each receptor, and the cumulative site-wide risk for each receptor and media;
6. Recommendations based on the Tier 2 risk assessment; and

A. If a Letter of Completion is requested, documentation that all four of the conditions (carcinogenic and non carcinogenic chemicals, individual and site-wide risk criteria) have been met.

(14) Conducting a Tier Three (3) Risk Assessment

(A) A Tier 3 risk assessment is a detailed, site-specific evaluation. A Tier 3 assessment may use the most recent toxicity factors, physical and chemical properties, site-specific exposure factors, and alternative models.

(B) The Tier 3 risk assessment requires the following steps:

1. Develop a Tier 3 work plan;
2. Collect additional data, if necessary;
3. Calculate Tier 3 risk;
4. Compare Tier 3 risk with acceptable risk levels and if necessary, develop clean-up levels;
5. Recommend the next course of action; and
6. Complete a Tier 3 Risk Assessment Report.

(C) Preparation of a Tier 3 Work Plan

1. The department must approve a Tier 3 work plan prior to its implementation.
2. In Tier 3, the only receptors that need to be considered are those for which the risk in Tier 2 exceeds acceptable levels and any additional receptors that are identified in Tier 3. Receptors for whom the Tier 2 risk is not exceeded need not be evaluated. However, none of the chemicals of concern (COCs) considered in the Tier 2 risk assessment can be eliminated at Tier 3. Thus the COCs considered in Tier 2 and Tier 3 assessments

would be identical.

3. The technical portion of the work plan must, at a minimum, include the following:
   A. Identification of the receptors that will be evaluated in Tier 3;
   B. Identification of the COCs and the complete and potentially complete routes of exposure for which Tier 3 risk will be calculated;
   C. An explanation of the fate and transport models to be used for the calculation of risk for the complete and potentially complete routes of exposure. The remediating party may propose the use of a model(s) different than that used in Tier 1 or Tier 2 assessment. At a minimum, the proposed model must:
      (I) Be peer reviewed;
      (II) Be publicly available or a copy provided to the department at no cost to the department;
      (III) Have a history of use on similar projects; and
      (IV) Be technically defensible;
   D. A tabulation of the input parameters required to compute the Tier 3 risk. For each of these parameters, the remediating party must justify the use of the selected value. Examples of input parameters that may be specific to Tier 3 are:
      (I) Chemical-specific physical properties;
      (II) Chemical-specific toxicological properties;
      (III) Site-specific or other alternate exposure factors. If alternative exposure factors are used for the inhalation pathway, the remediating party must review and adjust as appropriate both the inhalation exposure time (hours/day) and inhalation rate (m^3/hour);
      (IV) Media and site-specific parameters required by the selected fate and transport models;
   E. A discussion of the data and the methodology that will be used to calculate the representative concentrations;
   F. An explanation of data gaps, if any, that require additional fieldwork. A scope of work for the collection of this data must be included in the Tier 3 risk assessment work plan;
   G. 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;
   H. An evaluation of ecological risk. Ecological Risk Assessments previously completed at any tier are also acceptable in Tier 3 and do not need to be re-done; and
   I. Any changes to the methodology or input parameters made subsequent to the department's approval must also be approved by the department and documented by the remediating party.

(D) Collection of additional data

Upon approval of the work plan, the remediating party must perform the necessary fieldwork to collect the data. Any changes in the data collection due to field conditions or logistics of fieldwork must be approved by the department prior to completion of the field effort. Documentation of the data collection efforts may be included as an appendix to the Tier 3 report.

(E) Calculating Tier 3 Risk

Estimate the carcinogenic and non-carcinogenic risk for all COCs, receptors and routes of exposure, using the models and data in accordance with the approved work plan. At Tier 3, the risk values must be calculated for each COC and each route of exposure. Then the total risk for each COC (sum of risk for all the complete routes of exposure for a chemical) and the cumulative site-wide risk (sum of risk for all COCs and all complete routes of exposure) must be calculated. If needed, ecological risk should also be considered according to the work plan.

(G) Comparing Tier 3 Risks with acceptable risk levels and if necessary, developing risk-based target levels

Total risks for each COC as well as cumulative site-wide risk for each receptor are compared with their respective acceptable risk levels. The remediating party may request a Letter of Completion from the department if the calculated risks for each COC and the cumulative site-wide risk do not exceed the target risk levels and the following four conditions are met:

1. The plume, if one exists, is stable or decreasing (refer to Section 6.13.2 for discussion of plume stability). If this condition is not satisfied, the remediating party must continue groundwater monitoring until the plume is demonstrably stable. Actions may be taken to hasten plume stability. This recommendation must include a sampling plan with specifics such as:
   A. Wells to be sampled;
   B. Frequency of sampling;
   C. Laboratory analysis method;
   D. Method to be used to demonstrate that the plume is stable or shrinking; and
   E. The format and frequency of reporting requirements.
2. The maximum concentration of any COC is less than ten times the representative concentration of that COC for any exposure pathway. Note the maximum concentration here refers to the maximum concentration of a chemical in the exposure domain, not the site-wide maximum concentration. This condition can be met if an exceedance can be justified because the maximum concentration is an outlier or there is another explanation satisfactory to the department. Additional work may be needed if the average concentration was inaccurately calculated, the site is not adequately characterized or a hot spot may not have been adequately characterized. Any exceedance of this condition must be documented and the possible rationale, if any, submitted to the department. The department will determine what actions, if any, will be necessary to address the situation.
3. Prior to issuance of a letter of completion, adequate assurance is provided that the land use assumptions used in the MRBCA evaluation are not violated for current or reasonably anticipated future conditions. This condition may require that one or more activity and use limitations (AULs) are placed on the site and plans are in place to maintain long-term stewardship (LTS) for as long as needed to protect human health, public welfare and the environment.
4. 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 the completion of the Ecological Risk Assessment. If this condition is not met, the remediating party must provide recommendations to the department to manage the ecological risk. If the department approves the recommendations, their implementation and effectiveness, then this condition would be met.

(H) The remediating party must develop site-specific target levels and propose remedial

actions to achieve these levels if the analysis finds that either:

1. The total risk for each COC (all pathways, $IELCR_{Ci}$ and HI_{Ci}) is unacceptable for any of the human or ecological receptors; or
2. The cumulative site-wide risk (all COCs and all complete pathways, $IELCR_T$ and HI_T) is unacceptable for any of the human or ecological receptors.

The site-specific target levels and the methodologies used to achieve these levels must be included in the Risk Management Plan.

(I) Documentation of Tier 3 Risk Assessment

The remediating party 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 department must be clearly documented in the report. At a minimum the report must include:

1. Site background and chronology of events;
2. Data used to perform the evaluation;
3. Documentation of the exposure model and its assumptions;
4. Documentation and justification of all input parameters used;
5. Estimated risk for each COC, each route of exposure, each receptor, and the site-wide risk for each receptor and media;
6. Recommendations based on the Tier 3 risk assessment; and
7. If a Letter of Completion is requested, documentation that all the conditions (carcinogenic and noncarcinogenic chemicals, individual and site-wide risk criteria) have been met.

(15) Data Quality

Following are the areas that must be addressed to meet quality assurance/quality control requirements for environmental measurement data collected as part of the MRBCA process. These minimum requirements include the necessary components for Work Plans submitted for department approval to conduct environment data collection and the necessary QA/QC documentation to be submitted after data collection.

A. Work Plans for Site Characterization:

1. Sampling and Analysis Plan;
2. Field Sampling Plan;
3. Quality Assurance Project Plan; and
4. Health and Safety Plan.

B. Characterization Reports including Tier 1, Tier 2 and Tier 3 Risk Assessment Reports:

1. Field QA/QC documentation requirements; and
2. Laboratory QA/QC documentation requirements.

For B.1, the following practices must be observed in field QA/QC planning and documentation, if applicable:

a. Calibration and maintenance records for field instrumentation;
b. Documentation of sample collection procedures;
c. Reporting of any variances made in the field to sampling plans, SOPs or other applicable guidance documents;
d. Reporting of all field analysis results;
e. Documentation of sample custody (provide copies of Chain-of-Custody

documents);

f. Documentation of sample preservation, handling and transportation procedures;
g. Documentation of field decontamination procedures (and if applicable, collection and analysis of equipment rinsate blanks);
h. Collection and analysis of all required duplicate, replicate, background and trip blank samples; and
i. Documentation of disposal of investigation-derived wastes.

For B.2, laboratory analytical data must be accompanied by QA/QC sample results. The following must be considered in laboratory QA/QC planning and documentation, if applicable:

a. If the published analytical method used specifies QA/QC requirements within the method, those requirements must be met and the QA/QC data reported with the sample results; and
b. At a minimum, QA/QC samples must consist of the following items (where applicable):
    1. Method/instrument blank;
    2. Extraction/digestion blank;
    3. Initial calibration information;
    4. Initial calibration verification;
    5. Continuing calibration verification;
    6. Laboratory fortified blanks/laboratory control samples;
    7. Duplicates;
    8. Matrix spikes/matrix spike duplicates; and
    9. Documentation of appropriate instrument performance data such as internal standard and surrogate recovery.

C. Risk Management Plan

If the Risk Management Plan involves environmental data collection such as further site characterization, confirmatory samples following remedial activities or monitoring then:

1. Sampling and Analysis Plan;
2. Field Sampling Plan;
3. Quality Assurance Project Plan; and
4. Documentation of the Health and Safety Plan.

If the Risk Management Plan does not involve sampling but only LTS and AUL etc. then data QA/QC would not be a component.

D. Completion of Risk Management Plan

If the Risk Management Plan involves sampling then:

2. Field QA/QC documentation requirements; and
3. Laboratory QA/QC documentation requirements.

(16) Long-term stewardship (LTS) for risk-based corrective action sites

Institutional controls and engineered controls, where used, are a component of the cleanup decisions under MRBCA, and they must be effective for the program to be successful. In performing risk-based corrective action, preventing unacceptable exposures or releases of hazardous substances may be achieved by removing the contamination entirely, or by

managing exposure pathways from contamination to a "receptor" (such as a person or the natural environment). This rule provides the minimum controls needed to accomplish LTS under MRBCA. Any other specific controls that are required by the authority governing a particular cleanup must be met. Activity and use limitations (AULs) apply whenever contaminants of concern exceed unrestricted use levels. The department will approve a Risk Management Plan where the proposed controls and limitations are consistent with this rule and any other controls or limitations that are required by the specific legal authority governing the cleanup.

(A) Activity and Use Limitations

If needed, AULs must be fully developed and proposed as part of the Risk Management Plan. AULs must be designed to ensure that site restrictions that make the site safe for reuse remain effective. AULs must guarantee that pathways of exposure to chemicals of concern (COCs) remain incomplete for as long as there are chemicals remaining that could pose an unacceptable risk to human health, public welfare or the environment. AULs must be readily accessible, durable, reliable, enforceable, and consistent with the risk posed by the COCs. Environmental Covenants, Letters of Completion, and the recording requirements of the authority under which remediation is being performed apply to the property and must be transferred with the property.

(B) Environmental Covenants

For MRBCA purposes, environmental covenants must be enforceable by the state and must contain the following elements:

1. Name of the property owners and declaration of property ownership;
2. Identification of the property to which the environmental covenant applies by common address, and legal description;
3. A reference to the Department of Natural Resources contact information for the program and authority under which the remediation was conducted;
4. A statement of the cleanup standards that were achieved in the site's cleanup;
5. A statement of the reason for the application of land use limitations and requirements relative to protecting human health, public welfare and the environment from soil, groundwater, and/or other environmental contamination;
6. The language instituting such land use limitations or requirements, and granting access to the department or its designee to inspect the condition of the property, the integrity of controls, or other matters related to the contamination remaining onsite;
7. A statement that the conditions, limitations, restrictions or requirements apply to the current owners, occupants, and all heirs, successors, assigns, and lessees;
8. A statement that the limitations or requirements apply in perpetuity or until the department issues a new Letter of Completion approving modification or removal of the limitations or requirements, and a release or modification of the land use limitation is filed in the chain of title for the property that is the subject of the covenant;
9. Scaled site maps showing:
   A. The legal boundary of the property to which the covenant applies,
   B. The horizontal and vertical extent of chemicals of concern above applicable remediation objectives for soil and groundwater to which the covenant applies,
   C. Global position system (GPS) data describing parts A and B,
   D. Any physical features to which a covenant applies (e.g., engineered barriers, monitoring wells, caps),

E. The location of the source (if different from part A); and

F. The direction(s) of groundwater movement in subsurface zone(s) impacted by site-specific chemicals of concern;

10. A statement that any information regarding the remediation performed on the property for which the covenant is necessary may be viewed or obtained from the department. This information is maintained and available under the Missouri Sunshine Law (Chapter 610 RSMo.); and
11. The dated, notarized signatures of the property owners or authorized agent.

An approved environmental covenant must be recorded in the Office of the Recorder for the county in which the property that is the subject of the covenant is located. A copy of the recorded covenant that references the book and page of recording must be submitted to the department as part of the Risk Management Plan completion report, before the department will issue a Letter of Completion. The covenant does not become effective until it is officially recorded in the chain of title for the property. A covenant remains in effect unless terminated in accordance with this guidance and applicable laws and regulations. The use of a site must be consistent with the terms of the environmental covenant imposed on the property unless the department approves a change in the terms of the covenant. In such case, documentation of the change shall be recorded in the chain of title and a copy of the materials recorded provided to the program under which the covenant was first imposed.

(C) Ordinances and Supporting Memoranda of Agreement

An ordinance may be used as an AUL if it prohibits the installation of water supply wells and requires the closure of any existing private wells, but does not expressly prohibit the installation of public potable water supply wells and require the closure of such wells owned and operated by units of local government. In a request for approval of a local ordinance as an AUL, the remediating party must submit the following to the department:

1. A copy of the ordinance restricting groundwater use, including prohibitions on new wells, certified by an official of the unit of local government in which the site is located that it is a true and accurate copy of the ordinance;
2. A scaled map(s) delineating the area and extent of groundwater contamination above the applicable remediation objectives including a summary of any measured data showing concentrations of chemicals of concern for which the applicable remediation objectives are exceeded;
3. Scaled map delineating the boundaries of all properties under which groundwater is located that exceeds the applicable groundwater remediation objectives, information identifying the current owner(s) of each property identified in the boundary map above;
4. Documentation that the current owners identified in 3. above have been notified that groundwater that extends beneath their property is the subject of a risk-based cleanup and that each has been sent a copy of this request as submitted to the department; and
5. Documentation that adjacent property owners have been notified of the intent to use the local ordinance as an AUL.

After approval by the department and issuance of the Letter of Completion, the remediating party must also notify, in writing, the unit of local government that an ordinance has been approved and used as an AUL. Written proof of this notification must be submitted to the department within 45 days from the date that the department's Letter of Completion is recorded. The department may void a Letter of Completion that is based on an ordinance if the

local government revokes or repeals the ordinance or modifies the ordinance so that it no longer provides the protection that the Letter of Completion relied upon. Where an ordinance passed by a local unit of government is used as an AUL, the department cannot issue a Letter of Completion unless a Memorandum of Agreement (MOA) is in place. The MOA must include the following:

1. Identification of the authority of the unit of local government to enter into the MOA;
2. Identification of the legal boundaries, or equivalent, to which the ordinance is applicable;
3. A certified copy of the ordinance expressly prohibiting the installation of public and private potable water supply wells, the use of such wells, and the closure of existing wells;
4. A commitment by the unit of local government to notify the department of any variance requests or proposed ordinance changes at least 30 days prior to the date the local government is scheduled to take action on the request or proposed change;
5. A commitment by the unit of local government to maintain a list of all sites within the geographical unit of local government that have received Letters of Completion under the MRBCA process;
6. A provision that allows departmental access to information necessary to monitor adherence to requirements 4 and 5 above;
7. If applicable, the terms of any commitment by the local government to reimburse the department for periodic review of the local ordinance and actions relating to it, and for any actions taken by the department to address increased risks that arise from actions taken by the local government on the ordinance or related to it; and
8. The commitment of the local government to enforce the ordinance.

(D) Engineered Controls

Engineered barriers may be used as AULs to prevent direct human or environmental exposure to contaminants, but controls to ensure long-term monitoring and maintenance must accompany their use. The use of engineered controls can be recognized in determining remediation objectives only if the engineered controls are intended for use as part of the final remediation. Any Letter of Completion determination that is based, in whole or in part, upon the use of engineered controls requires effective inspection and maintenance of the engineered control. The inspection, maintenance and integrity certification requirements will be included in the Risk Management Plan.

(E) Well Location and Construction Restrictions

These can be used as AULs to the extent that they restrict access to certain groundwaters and thus limit the pathway for contaminants.

(F) Department of Defense Properties

An environmental covenant may be required for property owned by the Department of Defense (DOD) at the time that such property is transferred to a nonfederal entity or person. For property owned by the DOD, other land use and/or institutional control mechanisms may be used as part of the federal Risk Management Plan or other appropriate remedial documentation, such as: corrective action decisions, statements of basis or similar decisions, whether formalized in a permit, consent decree, order, or similar enforceable mechanism that may be issued pursuant to the Solid Waste Disposal Act (42 USC §§ 6901 et. seq.) or any Missouri solid and hazardous waste laws. Other acceptable land use and/or institutional control mechanisms may include specific use and activity restrictions or

conditions incorporated into base master plans, real property master plans, federal facility master land use plans, federal facility construction review and approval procedures, federal facility dig and ground disturbing activity review and approval procedures, federal facility environmental impact analysis procedures, or physical controls such as fences and signs.

(F) Letters of completion issuance and voidance

A Letter of Completion is issued by the department after the satisfactory completion of the Risk Management Plan and after all applicable AULs are in place and their existence has been documented. The department will issue a Letter of Completion within 30 days of the department's approval of a Risk Management Plan completion report, which would include documentation of all filings of any covenants. This time frame may vary based on the implementing authority. The department will mail the Letter of Completion to the remediating party and all property owners by certified mail, postmarked with a date stamp and with return receipt requested. The department will include all of the following in a Letter of Completion:

1. An acknowledgement that the requirements of the Risk Management Plan 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 unit of local government has adopted an appropriate ordinance and entered into a MOA with the department;
3. A statement that the department's issuance of the Letter of Completion signifies a release from further responsibilities under applicable laws and regulations in implementing the approved Risk Management Plan and that the site does not present unacceptable risks to human health, public welfare 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 contaminants of concern, or both, the Letter of Completion 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 Risk Management Plan or a reference that specifies where in the Risk Management Plan this information can be found;
6. The obligation to record the Letter of Completion in the chain of title for the site;
7. Notification that further information regarding the remediation site can be obtained from the department through a request under the Missouri Sunshine Law (Chapter 610, RSMo.);
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 Letter of Completion may be voided for reasons listed below; and
10. A description of the remediation site by legal description, by reference to a plat showing the boundaries, or by other means sufficient to identify site location, any of which may be an attachment to the letter.

If only a portion of the site or only selected contaminants at a site were remediated, the Letter

of Completion may contain any other provisions agreed to by the department and the remediating party, such as the limitation of the letter to the specific area or contaminants. The remediating party receiving a Letter of Completion from the department must submit the letter, and, where the remediating party is not the sole owner of the remediation site, an owner certification described below, to the Office of the Recorder of the county in which the remediation site is located within 45 days after receipt of the letter. The Office of the Recorder will record the letter and, where applicable, the owner certification so that it forms a permanent part of the chain of title for the property. The remediating party is responsible for any cost of recording required by the county. Where the remediating party is not the sole owner of the remediation site, the remediating party must obtain a certification by original signature of each owner, or the authorized agent of the owner(s), of the remediation site or any portion of the remediation site. The certification must be recorded in the chain of title along with the Letter of Completion. The certification must read as follows: "I hereby certify that I have reviewed the attached Letter of Completion, and that I accept the terms and conditions and will abide by any AULs set forth in the letter." The issuance of the letter is contingent on obtaining this certification from all owners. A Letter of Completion is effective upon the date of the official recording of the letter and any associated owner certifications(s). Until it is in the chain of title, the Letter of Completion is effective only between the department and the remediating party. The remediating party must obtain and submit to the department an acknowledgement from the county recorder office that a copy of the letter and any owner certifications has been recorded. This acknowledgement must be provided to the department within 30 days after recording to demonstrate that the recording requirements have been satisfied.

(G) No remediation site with AULs may be used in a manner inconsistent with any limitations unless further evaluation and/or remediation documents the attainment of objectives appropriate for the new land use. If the department approves modified AULs, then an updated Letter of Completion reflecting the new site conditions and requirements may be obtained and recorded as described above. The department may void the Letter of Completion if the remediation site activities are not managed in full compliance with the approved Risk Management Plan upon which the issuance of the Letter of Completion was based. The Risk Management Plan must also contain the specific details of any Long-Term Stewardship requirements that are relied upon to reach the conclusion. Specific acts or omissions that may result in voiding of the Letter of Completion include:

1. Failure to adhere to the terms of an environmental covenant;
2. Failure to adhere to any other applicable institutional controls, land use restrictions, or other AUL(s);
3. 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;
4. Disturbance or removal of contamination that has been left in place that is not in accordance with the Risk Management Plan. Disturbance of soil contamination may be allowed if, during and after any activity, human health, public welfare, and the environment are protected consistent with the Risk Management Plan or other health and safety requirements;
5. Failure to comply with the recording requirements or to complete them in a timely manner;
6. Obtaining the Letter of Completion by fraud or misrepresentation; and

7. 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.

If the department intends to void a Letter of Completion, it must provide notice to the current title holder of the remediation site and to the remediating party at his or her last known address, specifying the cause for the voiding and the facts in support of that cause. The remediating party or current title holder may appeal or seek dispute resolution on the department's final decision within 30 days after the receipt of the notice of voiding.

(17) Information and tracking

This information will be maintained in an available and retrievable form. The department will maintain separate lists for:

1. Sites safe for reuse after cleanup; and
2. Sites where contaminants were found but not fully assessed or remediated.

The department must maintain records on all sites remediated under the MRBCA process, including those cleaned up to unrestricted use levels and those with COCs above background levels.

(18) Risk Management Plan

1. A Risk Management Plan encompasses all activities necessary to manage a site's risk to human health, public welfare and the environment so that acceptable risk levels are not exceeded under current or reasonably anticipated future land use conditions. A site-specific Risk Management Plan, approved by the department, is required at a site under any one of the following conditions:
   a. The total (sum of all pathways) carcinogenic risk for any COC exceeds 1×10^{-5},
   b. The Hazard Index (sum of all pathways) for any COC exceeds 1.0 (or, if appropriate, the Hazard Index for individual organ, system or mode of action),
   c. The cumulative site-wide carcinogenic risk (sum of COCs and all routes of exposure) exceeds 1×10^{-4},
   d. The site-wide Hazard Index (sum of COCs and all routes of exposure) for individual adverse health effect exceeds 1.0 (or, if appropriate, the Hazard Index for individual organ, system or mode of action),
   e. Although neither the carcinogenic or non-carcinogenic risk for any COC nor the site-wide risk exceeds acceptable levels, the risk assessment was based on site-specific assumptions that require a Risk Management Plan,
   f. Although neither the carcinogenic nor non-carcinogenic risk for any COC or site-wide risk exceeds acceptable levels, the groundwater plume is expanding, or
   g. Ecological risk does not meet the acceptable criteria.

3. The Risk Management Plan must ensure that:
   a. Site conditions are protective of human health, public welfare and the environment based on achieving acceptable risk levels at any one of the three tiers.
   b. Acceptable ecological protection is based on meeting any one of the three levels of ecological risk assessment.
   c. Assumptions made in the estimation of risk and development of risk-based target levels are not violated in the future, and

d. The groundwater extent of contamination is stable or decreasing.

4. Successful implementation of the Risk Management Plan will result in a letter of completion from the department. The plan must include:
   a. Reasons why a Risk Management Plan is being prepared and the specific objectives of the plan. An example of a specific objective would be "remediation of soil to achieve specific risk-based concentrations for specific COCs.";
   b. Dated reference to the approved Risk Assessment Report, particularly its discussion of pathways and receptors;
   c. Application of technologies to reduce mass, concentration, and/or mobility of COCs to meet the risk-based target levels determined for the site or specific engineering activities. Examples of technologies or remediation activities include soil excavation and off-site disposal, pump and treat, vapor extraction, enhanced in-situ attenuation, and monitored natural attenuation;
   d. Data that will be collected and quality control/quality assurance procedures for collection, documentation, analysis and reporting during the implementation of the Risk Management Plan. Examples of data that may be collected include confirmatory soil or groundwater sampling data to demonstrate the effectiveness of the remedial measures;
   e. Details of how and when data will be evaluated and presented to the department. Examples include trend maps, concentration contours, concentration vs. distance plots, calculations related to mass removal rates, or application of specific statistical techniques;
   f. Application of activity and use limitations (AULs) to eliminate certain pathways of exposure and ensure that the pathways remain incomplete under current and reasonably anticipated future uses. Examples include conditions imposed on the property that prevent the installation of wells, thus eliminating the groundwater future use pathway, or prohibition of future residential land use;
   g. If needed, monitoring to demonstrate plume stability or the effectiveness of natural attenuation;
   h. A long-term stewardship plan that ensures that the AULs are effective and maintained, that site conditions do not change to result in unacceptable risk, and that site information remains available to interested parties;
   i. 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 department;
   j. Criteria that will be used to demonstrate that the Risk Management Plan has been successfully completed; and
   k. As appropriate, contingency plans if the final fails to meet the objectives of the Risk Management Plan in a timely manner.

5. The department will approve the Risk Management Plan as submitted or provide comments. Upon receipt of approval, the remediating party should begin implementing the plan.

(19) Completion of Risk Management Activities

Upon successful implementation of the approved Risk Management Plan, the remediating party must submit a Completion of the Risk Management Plan Report to the department for

approval that includes:

1. Documentation of completion of all risk management activities, and
2. If applicable, a request to plug and abandon all nonessential monitoring wells related to the environmental activities at the site.

(20) Procedure for Letter of Completion

After the Risk Management Plan has been successfully implemented, the remediating party may request a Letter of Completion from the department**.** The department will issue a letter if the site satisfies all requirements of the approved Risk Management Plan. The letter would state that, based on the information submitted, the concentrations of COCs on or adjacent to the site do not pose an unacceptable level of risk to human health, public welfare and the environment for the current and reasonably anticipated future land use and provided that all AULs remain in place.

(21) Administrative review of RBCA decisions

Any person affected by a RBCA decision may request an administrative review. Any written decision of the Project Manager, including those transmitted via e-mail, regarding the applicability of the Missouri RBCA guidance or rules to a specific site being addressed under those rules or guidance may be reviewed. Where the decision in question is made by a Project Manager, the affected person (Requestor) shall contact the Project Manager's immediate supervisor and request an evaluation of the matter, before initiating a written request for a RBCA Review. The supervisor will convey the decision in written form. If the Requester finds that the response from this review is not satisfactory or timely, Requester may initiate further review by submitting the relevant information on the Request for RBCA Review form provided by the department. The request shall include a written summary of the matter and include supporting documentation as needed, or refer to such documentation that may be in the department's files. The request shall go first to the Section Chief of the Project Manager who rendered the decision in question. The Section Chief may either attempt to resolve the matter through the RBCA Review Process or may refer the matter immediately to the Program Director. The Section Chief may solicit the review and input of other section chiefs. If referring immediately to the Program Director, the Section Chief shall do so within three working days of receipt. If the Requester does not agree with the decision of the Section Chief, the Requester may submit a request to the Program Director to review the matter. The Reviewer (Section Chief or Program Director) shall review the file and impartially consider the relevant facts. The Reviewer may discuss the substance of the Request for Review with the Requester and other relevant individuals at a mutually acceptable time and manner. The Reviewer shall provide a written decision summarizing the issue under review, the relevant facts of the decision, the rationale behind the decision and any information or considerations outside of the specific situation that were used in making the decision. The decision of the Program Director shall be a final decision and may be appealed. Decisions made within the Hazardous Waste Program would be appealed as prescribed by law. This appeal is a contested case. Any written decision shall be retained in the Hazardous Waste Program and maintained as a compendium of review decisions made under this process. A Requester must file a Request for RBCA Review within ninety (90) days of the original decision except in the case of a "clean letter" or "no further remedial action letter," in which case the Requester must file

the request within thirty (30) days. The Section Chief shall respond with a final decision within forty-five (45) days of receipt of the request, and the Program Director within sixty (60) days of the Section Chief's decision. These timeframes may be extended by mutual agreement of all parties.

[add] (22) References