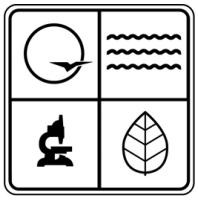

MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

MISSOURI RISK-BASED CORRECTIVE ACTION PROCESS FOR PETROLEUM STORAGE TANKS

October 17, 2013

ACKNOWLEDGEMENTS

The Missouri Department of Natural Resources acknowledges the help provided by stakeholders in the development and revision of this document. These stakeholders, too many to individually list here, participated in numerous meetings, small subgroups, and conference calls. Their untiring efforts and support of the process are highly appreciated.

This guidance document describes a risk-based process that persons responsible for addressing petroleum releases at petroleum storage tank sites may use to satisfy the regulations administered by the Tanks Section of the Missouri Department of Natural Resources (MDNR). This process is consistent with the policies and procedures discussed by the Groundwater Remediation Rule stakeholders group and documented in their June 2003 *Process Document*.

This final document is a result of:

- Policies agreed upon, and input received from, the stakeholders group,
- MDNR's experience in the management of petroleum impacted sites in Missouri,
- Assistance provided by outside consultants, and
- Review of comments received on the draft document.

IMPLEMENTATION OF MISSOURI'S RISK-BASED CORRECTIVE ACTION (MRBCA) PROCESS

The MRBCA Process for Petroleum Storage Tanks may be used at any petroleum storage tank site. Persons conducting investigations of newly-discovered releases are encouraged to use this guidance.

REVISION OF FEBRUARY 2004 AND MARCH 2005 MRBCA TANKS GUIDANCE

This October 17, 2013, version of the MRBCA Process for Petroleum Storage Tanks guidance document replaces the following guidance of the Department of Natural Resources:

- February 2004, *Missouri Risk-Based Corrective Action Process for Petroleum Storage Tanks* guidance document, as amended March 8, 2005 by *Notice of Modifications to the Process and Interim Guidance Pertaining to Application of the New Soil Type Dependent Tier 1 Risk-Based Target Levels*; March 18, 2005, *Soil Type Determination Guidelines*; March 3, 2005, Table 3-1 *Default Target Levels*; April 2005, Table 4-1 *Soil Concentration Levels to Determine the Need for Groundwater Evaluation During Tank Closure*; February 2005, Tables 7-1(a) through 7-12(c) Tier 1 Risk-Based Target Levels; and the April 21, 2005, *Soil Gas Sampling Protocol*.

DEPARTMENT WEBSITE FOR IMPLEMENTATION OF MRBCA

This document is available on the web at:
http://dnr.mo.gov/env/hwp/tanks/mrbca-pet/mrbca-pet-tanks.htm.

API	American Petroleum Institute
AST	Aboveground Storage Tank
ASTM	American Society for Testing and Materials
AUL	Activity Use and Limitations
BTEX	Benzene, Toluene, Ethylbenzene, and Xylenes (total)
bgs	Below Ground Surface
cfs	Cubic Feet per Second
CAP	Corrective Action Plan
COC	Chemicals of Concern
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CSR	Code of State Regulations
DAF	Dilution Attenuation Factor
DOT	Department of Transportation
DTL	Default Target Level
EDB	Ethylene Dibromide
EDC	Ethylene Dichloride
EER	Environmental Emergency Response
EM	Exposure Model
EPA	Environmental Protection Agency
ft	Feet
GSRAD	Geological Survey and Resource Assessment Division
HWP	Hazardous Waste Program
IELCR	Individual Excess Lifetime Cancer Risk
IRIS	Integrated Risk Information System
LNAPL	Light Non-Aqueous Phase Liquid
LEL	Lower Explosive Limit
MCL	Maximum Contaminant Level
MDNR	Missouri Department of Natural Resources
MEGA	Missouri Environmental Geology Atlas
MLWL	Mean Low Water Level
MNA	Monitored Natural Attenuation
MRBCA	Missouri's Risk-Based Corrective Action
MSDS	Material Safety Data Sheet
MTBE	Methyl tert-Butyl Ether
NAPL	Non-Aqueous Phase Liquid
NELAP	National Environmental Laboratory Accreditation Program
NFA	No Further Action
OAC	Outreach and Assistance Center
OVM	Organic Vapor Monitor
PAH	Polynuclear Aromatic Hydrocarbons
PID	Photoionization Detector

PNA	Poly Nuclear Aromatics
POD	Point of Demonstration
POE	Point of Exposure
POTW	Publicly Owned Treatment Works
PSTIF	Petroleum Storage Tank Insurance Fund
QA/QC	Quality Assurance/Quality Control
RBCA	Risk-Based Corrective Action
RBTL	Risk-Based Target Level
RCRA	Resource Conservation and Recovery Act
RM	Risk Management
RMP	Risk Management Plan
RRL	Required Reporting Limit
RSMo	Revised Statues of the State of Missouri
SCM	Site Conceptual Model
SSTLs	Site-Specific Target Levels
SWMP	Solid Waste Management Program
TC	Toxicity Characteristic
TDS	Total Dissolved Solid
TPH-DRO	Total Petroleum Hydrocarbon-Diesel Range Organic
TPH-GRO	Total Petroleum Hydrocarbon-Gasoline Range Organic
TPH-ORO	Total Petroleum Hydrocarbon-Oil Range Organic
TSP	Trisodium Phosphate Dodecahydrate
UEL	Upper Explosive Limit
USDA	United States Department of Agriculture
USGS	United States Geological Survey
UST	Underground Storage Tank
VOA	Volatile Organic Analysis
VOC	Volatile Organic Compounds
WPP	Water Protection Program

1.1 INTRODUCTION

In early 2004, the Missouri Department of Natural Resources issued a draft guidance document, titled "Missouri Risk-Based Corrective Action (MRBCA) Process for Petroleum Storage Tanks." That document, published after extensive discussions with and work by a variety of stakeholders, built on the generic framework developed by the American Society for Testing and Materials (ASTM) in their standard E1739-95, and implemented a more technically sound approach to the risk-based cleanup of tank sites that had been used in Missouri since 1992.

In 2005, the process provided for by the draft guidance was modified by the addition of six supplemental guidance documents. These seven guidance documents were formally incorporated into regulations issued by the Missouri Hazardous Waste Management Commission in 2011.

This 2013 version of the 2004 Guidance Document incorporates most of the 2005 supplemental documents; those not incorporated are no longer applicable. In addition, this version of the guidance streamlines, clarifies and adds some requirements.

1.2 APPLICABILITY AND PURPOSE

This document will go into effect when it is incorporated into rules issued by the Hazardous Waste Management Commission, and will apply to any petroleum tank release that occurs or is discovered on or after the effective date of those rules.

Because some persons will be in the midst of cleaning up a petroleum tank site when that occurs, the following "transition procedures" will apply:

> Any petroleum tank release that occurred or was discovered after January 2004 and prior to the effective date of the rules that incorporate this revised guidance document may be addressed under either this guidance or the 2004/2005 MRBCA tanks guidance documents, provided that –
>
> > a) prior to the effective date of the rules, the Department approved a work plan for site characterization, risk assessment, or corrective action pertaining to the release, and
> >
> > b) that work plan is or was implemented within one year of the Department's approval of the plan.

If both of these criteria are not met, the release must be addressed under this guidance, unless another method is approved by the Department.

MDNR will not require that sites previously granted a NFA letter be reevaluated under this revised guidance unless new information related to previously addressed releases becomes available, or a new hydrocarbon release occurs at the site.

This document does not in any way replace or supercede MDNR's enforcement or permitting authority, notification requirements, or other applicable requirements, nor does it reduce any of the responsible party's obligations under state or federal laws or regulations.

The intent of the MRBCA process for tank sites is to ensure sites are adequately characterized and to provide a means by which site-specific target levels can be developed. These levels are protective of human health and the environment under current and reasonably anticipated future conditions. This document provides a technically defensible procedure for developing site-specific risk-based target levels and investigating releases at petroleum storage tank sites.

This document has been developed for environmental professionals having experience in, and a working knowledge of, site assessment and investigation, risk assessment, and remedial actions. Technical information is included that describes the MRBCA process and its elements, including site assessment, risk assessment, risk management, and the tank closure process. The calculation of risk-based target levels is described at length in this document. However, this document is not intended to be a guide to every aspect of the practice of risk assessment. Prior experience or training is necessary for an individual to correctly implement the MRBCA process and, by that, ensure efficient site management.

2.0
OVERVIEW OF MRBCA PROCESS

2.1 INTRODUCTION

This section presents an overview of the MRBCA process as it applies to petroleum underground and above ground storage tanks (UST/ASTs). The MRBCA process begins when a petroleum release is suspected or discovered and includes all subsequent activities (except those conducted under 260.500 through 260.550 RSMo and the regulations promulgated thereunder) until MDNR issues a "No Further Action" (NFA) letter for the release. Subsequent to site discovery and the control of any imminent hazards, the MRBCA process requires the following types of activities:

- Site Characterization and delineation of impacts in soil, groundwater, surface water, sediments and soil vapor, as applicable. The activities culminate in the development of a site conceptual model, which includes an exposure model;

- Risk assessment activities at the Tier 1, Tier 2, and Tier 3 level, as applicable. At Tiers 1 and 2, these activities culminate in the development of clean-up levels and, at all tiers, a determination of the nature and extent of necessary corrective action activities; and

- Corrective action activities that ensure human health and the environment are adequately protected from site-specific impacts under both current and reasonably anticipated future activities on and near the site.

Figure 2-1 illustrates the activities discussed above. Although these activities are fundamentally technical and rely on a variety of different scientific disciplines (geology, hydrology, engineering, chemistry, toxicology, land use planning, etc), they also entail making assumptions and policy choices that must be consistent with the policies and regulations established by MDNR. These policy choices and the specific steps of the MRBCA process are described in this section. Subsequent sections of this document describe the details of each step.

2.2 RISK-BASED CORRECTIVE ACTION PROCESS

The overall RBCA process for a site where a release of petroleum from an UST/AST system(s) is suspected or confirmed is illustrated in the flowchart at Figure 2-2 and is discussed below.

(Note: Generally, the word "site" is used to refer to the property where one or more tanks were located, and "offsite" refers to nearby properties. However, please note that certain terms used in this Guidance Document – e.g., "Site Characterization" and "Site Conceptual Model" – are intended to refer to multiple properties and include all areas which are or may be impacted by the petroleum release.)

2.2.1 Release Discovery

The MRBCA process begins with the discovery of a release at a UST/AST site. A release might be discovered and reported to the MDNR under a variety of circumstances including, but not limited to, (i) system closure, (ii) a site check investigation resulting in confirmation of a release, and (iii) identification of an imminent hazard (e.g., vapors in sewers or buildings, etc.). Releases might also be identified during investigations conducted as a part of real estate transactions, investigations conducted in anticipation of land development, and the occurrence of accidents and spills.

The release discovery process should generally result in the identification of affected media at a site and generate analytical data. This initial data should, ideally, represent the point or points of release, the chemicals of concern (COCs), and the maximum concentrations of the COCs.

The process of site discovery and reporting is discussed in further detail in Section 3.0 of this document.

2.2.2 Comparison with Default Target Levels

This step involves the comparison of maximum site concentrations with the default target levels (DTLs – found at Table 3-1 of this document) and occurs after a release has been confirmed and affected media have been identified and sampled. If the maximum media-specific concentrations at a site are less than the DTLs, and provided the site poses no obvious risk to ecological receptors, MDNR will issue a NFA letter pertaining to the site. In such case, an ecological screening assessment as per subsections 5.5.5 and 6.6 of this guidance will not be required.

If the maximum soil or groundwater concentrations exceed the DTLs, the person performing the evaluation may either adopt DTLs as the cleanup levels and develop a Corrective Action Plan (CAP) to achieve those levels, or perform a tiered risk assessment.

Since MDNR may issue a NFA letter for the release based on a comparison of concentrations of COCs found on the site with the DTLs, the data available for the comparison must accurately represent the maximum media-specific COC concentrations. A NFA determination at this step means that the concentrations of COCs present at the site do not pose an unacceptable risk to human health or the environment, regardless of how the site may be used or developed in the future.

Note that "maximum concentration" refers to the current maximum concentration of a COC. At sites where remedial activities or additional releases may have occurred since the time samples were collected, new data will be necessary to represent current conditions.

2.2.3 Development and Validation of Site Conceptual Model

If the relevant maximum concentrations of COCs exceed the DTLs and the DTLs are not selected as the cleanup levels, a site conceptual model (SCM) must be developed and validated. A SCM provides the framework for the overall management of a site and should help guide data collection and, subsequently, corrective action activities at the site. The SCM is conceptual rather than tangible, though the evaluator might find written notes, diagrams, and flow charts beneficial in developing the SCM. While the SCM will not be submitted to MDNR, the data resulting from SCM validation will be.

Key elements of the SCM include (i) release scenario, contaminant source, and COCs, (ii) an exposure model (EM) that focuses on the receptors, pathways and routes of exposure under current and reasonably anticipated future land use conditions, (iii) site stratigraphy and hydrogeology, and (iv) spatial and temporal distribution of COCs. An important part of this step is the validation of the SCM through the collection of site-specific data. The validation process is similar to the traditional site investigation step in that it may involve, for instance, installation and sampling of monitoring wells and collection of soil data both on-site and off-site. Additionally, validation involves the determination of land use and the development of an EM. At sites that are currently undergoing investigation or corrective action, this step may involve the compilation of relevant historic data, identification of data gaps, and the collection of missing data so that a tiered risk assessment can be completed.

Data needs for a tiered risk assessment are presented in Section 5.0.

2.2.4 Tier 1 Risk Assessment

A Tier 1 risk assessment requires the (i) selection of relevant Tier 1 risk-based target levels (RBTLs) from lookup tables developed by MDNR, and (ii) comparison of these levels with representative concentrations (note that, at Tier 1, representative rather than maximum concentrations are compared to the target levels, except for surficial soil in a residential setting, for which maximum concentrations are used). Tier 1 RBTLs will be selected for each COC, each complete pathway, and each media of concern identified in the EM. The Tier 1 RBTLs can be found in Tables 7-1 through 7-6(c) in Section 7.0 of this document.

Based on the comparison of representative concentrations and Tier 1 RBTLs, one of the following three decisions is possible:

- Request a NFA letter from MDNR if the representative concentrations (or, for surficial soil in a residential setting, maximum concentrations) do not exceed the RBTLs and other conditions for issuance of a NFA have been met (e.g., necessary activity and use limitations (AULs) in place, no ecological concerns, etc.),

- Adopt Tier 1 RBTLs as the cleanup levels and prepare and submit a CAP to achieve these levels, or

- Perform a Tier 2 risk assessment.

The specific decision made must be documented and provided to MDNR. Upon completion of the Tier 1 risk assessment, the person who conducted the evaluation or who is responsible for the site shall provide their recommendations to MDNR. Note, however, that if a Tier 2 evaluation immediately follows the Tier 1 assessment, the evaluator need not submit a report pertaining solely to the Tier 1 assessment. Rather, the Tier 1 and Tier 2 assessments may be combined into a single report that is submitted at the conclusion of the Tier 2 assessment.

Details of Tier 1 risk assessment are provided in Section 7.0.

2.2.5 Tier 2 Risk Assessment

Depending on site-specific conditions and the availability of data, conducting a Tier 2 risk assessment might depend on the collection of additional site-specific data. In preparation for a Tier 2 risk assessment, the EM should be revised, if necessary, and, as appropriate, additional data collected. This data would be used to develop Tier 2 site-specific target levels (SSTLs) in accordance with the provisions of Section 8.0 of this guidance.

After the Tier 2 SSTLs have been developed, they will be compared with representative COC concentration data from the site. Depending on the comparison, the following three options are possible:

- Request a NFA letter from MDNR if the representative concentrations (or, for surficial soil in a residential setting, maximum concentrations) do not exceed the Tier 2 SSTLs for all complete routes of exposure and other conditions for issuance of a NFA have been met (e.g., AULs in place, no ecological concerns, etc.),

- Adopt Tier 2 SSTLs as cleanup levels and develop a CAP to achieve these levels, or

- Develop a work plan to perform a Tier 3 risk assessment.

Details of Tier 2 risk assessment are presented in Section 8.0.

2.2.6 Tier 3 Risk Assessment

A Tier 3 risk assessment allows considerable flexibility to the person conducting the evaluation. Because of the myriad options available at Tier 3, MDNR requires that a work plan be prepared for MDNR's review and approval prior to a Tier 3 risk assessment.

Once Tier 3 SSTLs have been developed, they are compared to representative COC concentrations from the site. This comparison will result in one of the following two options:

- Request a NFA letter from MDNR if the representative concentrations (or, for

surficial soil in a residential setting, maximum concentrations) do not exceed the Tier 3 SSTLs and other conditions for NFA have been met (e.g., AULs in place, no ecological concerns, etc.), or

- Adopt Tier 3 SSTLs as cleanup levels and develop and implement a CAP.

Details of Tier 3 risk assessment are presented in Section 9.0.

2.2.7 Development and Implementation of Corrective Action Plan

This step involves the development and implementation of a Corrective Action Plan (CAP) to achieve the cleanup levels approved by MDNR. Typically, a CAP will be developed after media-specific cleanup levels have been approved by MDNR. The CAP may include a combination of active and passive remedial options and/or AULs and a description of what reports will be submitted and when. As appropriate, the plan should include (i) the type of technology to be used, (ii) an explanation of AULs being proposed, if any, and justification of their use, (iii) an estimate of the time needed to implement the CAP, (iv) data that will be collected to monitor the effectiveness of the CAP, (v) the manner in which the data will be evaluated, and (vi) steps that will be taken if the CAP is not effective. During implementation of the CAP, sufficient data must be collected and analyzed to allow for an appropriate evaluation of the performance of the plan so that modifications can be made as appropriate. The CAP should not be implemented without the approval of MDNR.

The data collected during implementation of the CAP should be carefully evaluated and a determination made whether the CAP is progressing as anticipated. The data and the evaluation shall be submitted to MDNR. If the CAP is not progressing as anticipated and as predicted in the work plan, a proposal for modifying the CAP should be developed and submitted to MDNR. Modifications of the CAP shall not be implemented without the concurrence of MDNR.

CAP details are presented in Section 10.0.

2.2.8 No Further Action under the MRBCA Program

The overall objective of all CAPs is to ensure protection of human health and the environment under current and reasonably anticipated future conditions. When MDNR is satisfied that cleanup levels have been met or risks have been otherwise managed, MDNR will issue a NFA letter for the site. MDNR's issuance of a NFA letter indicates that, based on the MRBCA evaluation submitted and the information available to MDNR at the time, no further action is necessary to protect human health and the environment. However, if in the future additional information becomes available that indicates that the site poses unacceptable risk to human health or the environment, MDNR may rescind their decision and require further action at the site.

2.3 RISK-BASED TARGET LEVELS WITHIN THE MRBCA PROCESS

Any of the following may be used as corrective action standards, subject to the restrictions described below:

DTLs are the most conservative chemical and medium-specific concentrations that allow unrestricted (residential) use of the property. For each COC and each medium, the DTL is the lowest of the Tier 1 RBTLs. Since DTLs are the most conservative levels, their application does not require evaluation of site-specific exposure pathways, the development of a site conceptual model, any activity and use limitations, or the determination of whether groundwater is used, or is likely to be used, as a water supply source. DTLs are convenient screening levels to use, for example, in Phase II assessments.

Tier 1 RBTLs are generic target levels developed by MDNR using conservative default parameters that depend on the receptor, media, pathway, route of exposure, and whether impacted or threatened groundwater is used, or is likely to be used, as a water supply source. Use of RBTLs may require AULs.

Tier 2 SSTLs are site-specific target levels that are calculated using site-specific data and the guidelines included in this document. Tier 2 SSTLs differ from Tier 1 RBTLs in that the Tier 2 SSTLs are based on site-specific fate and transport parameter values whereas the Tier 1 RBTLs use default, generic fate and transport parameters. Typically but not always Tier 2 SSTLs will be higher than Tier 1 RBTLs. *Because Tier 2 SSTLs are based on actual site conditions, once developed, Tier 2 SSTLs will apply even if they are lower than the Tier 1 RBTLs for that property.* If the Tier 2 SSTLs are higher than the Tier 1 RBTLs, either Tier 1 RBTLs or Tier 2 SSTLs may be used. As with the Tier 1 RBTLs, depending on the circumstances, AULs may be required when SSTLs apply.

Tier 3 SSTLs are site-specific target levels that are calculated using data collected at the site and the guidelines included in this document. Compared with Tier 2 SSTLs, Tier 3 SSTLs may be based on the application of fate and transport models other than those used to calculate the Tier 1 RBTLs and Tier 2 SSTLs. *As with Tier 2 SSTLs, if the Tier 3 SSTLs developed for a site are lower than the Tier 2 SSTLs or the RBTLs, the Tier 3 SSTLs must be applied.* The application of Tier 3 SSTLs might also require the use of AULs, depending on the specific circumstances.

Table 2-1 presents the differences between the different target levels within this framework.

2.4 DOCUMENTATION OF THE MRBCA PROCESS

To facilitate and allow decisions to be made that are protective of human health and the environment, the MRBCA process requires the collection and analysis of a considerable amount of data. The outcome of the MRBCA process is of considerable interest to a variety of stakeholders, including but not limited to, MDNR, land owners, developers, lending agencies, and cities and municipalities. Therefore, the process by which data is collected and

analyzed and important decisions potentially affecting human health and the environment are made must be as transparent as possible via adequate and clear communication between the person responsible for a site and the MDNR. Such communication must occur throughout the MRBCA process, from release discovery to issuance of a NFA letter, so that interested parties can determine if decisions made and activities undertaken during the MRBCA process at a site were sufficient to adequately protect human health and the environment.

The method and format by which the owner/operator reports data developed under the MRBCA process must be consistent (across the state) and unambiguous so that interested parties can readily understand the:

- Nature and extent of the problem at a site,
- Sequence of actions taken to address the problem,
- Data collected to quantify and analyze the problem,
- Process used to develop a plan of action to address the problem,
- Results of the actions taken, and
- Finally, whether the actions taken are adequately protective of human health and the environment under current and reasonably anticipated future conditions.

To facilitate this type of reporting, Table 2-2 was developed. Table 2-2 presents a comprehensive list of reports that would typically be submitted to MDNR, an approximate schedule for submittal of the various reports, and a description of the format in which these reports would be submitted. Detailed discussions of these reports are presented in Section 12.0 of this document. Section 12.0 identifies:

- The specific reports that must be submitted to MDNR,
- Data that must be included in each report,
- The required reporting format for each report, and
- A schedule for submission of the reports to MDNR.

Table 2-1
Comparison of Risk Assessment Options

Factors	DTL	Tier 1	Tier 2	Tier 3
Exposure Factors[1]	Default	Default	Default	Site-specific
Toxicity Factors[1]	Default	Default	Default	Most current
Physical and Chemical Properties[1]	Default	Default	Default	Most current
Fate and Transport Parameters[1]	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-See Appendix E	Representative Concentrations-See Appendix E	Representative Concentrations-See Appendix E
IELCR	1×10^{-5}	1×10^{-5}	1×10^{-5}	1×10^{-5}
Hazard Quotient	1	1	1	1
Cumulative Effects	Not considered	Not considered	Not considered	Not considered
Groundwater Ingestion Pathway Complete	MCL or equivalent	MCL or equivalent	MCL or equivalent	MCL or equivalent
Ecological Risk	NA	Evaluate	Evaluate	Evaluate
Outcome of Evaluation	NFA, Tier 1, CAP	NFA, Tier 2, CAP	NFA, Tier 3, CAP	NFA, CAP
Land Use	No	Yes	Yes	Yes
Activity and Use Limitations	None	Depend on land use, groundwater use, and assumption in risk assessment		

DTL: Default Target Level
IELCR: Individual Excess Lifetime Cancer Risk
MCL: Maximum Contaminant Level
NFA: No Further Action
CAP: Corrective Action Plan

[1] Refer to Appendix B

Table 2-2
Comprehensive List of Reports to be Submitted to MDNR*

	REPORT	SCHEDULE
1	Closure Notice	As requested by the owner/operator, no less than 30 days prior to closure
2	Closure Report	Within 60 days of closure
3	Release/Suspected Release	As soon as practical but no later than 24 hours of discovery
4	Initial Hazard Abatement Measures	20 days from release confirmation
5	Site Check	To be performed within 7 days from suspected release, report within 60 days of completion of site check
6	System Tests	To be performed within 7 days from suspected release, report within 20 days of the test
7	Work Plans for Site Characterization & Monitoring	as requested and agreed to by MDNR or as requested by MDNR (typically 30 days of request)
8	Periodic Monitoring Reports	As stipulated by MDNR or as requested and agreed to by MDNR
9	Site Characterization Report(s)	As per the schedule in the work plan or stipulated by MDNR
10	Soil Vapor Measurement Work Plan and Reports	As per the schedule in the work plan or stipulated by MDNR
11	Tier 1 Risk Assessment Report	As stipulated by MDNR
12	Tire 2 Risk Assessment Report	As stipulated by MDNR
13	Tier 3 Work Plan	As stipulated by MDNR or as proposed and agreed to by MDNR
14	Tier 3 Risk Assessment Report	As per the schedule in the work plan or stipulated by MDNR
15	Corrective Action Plan (CAP)	As stipulated by MDNR
16	Interim Corrective Action Work Plan and Report	As stipulated by MDNR
17	LNAPL (light non-aqueous phase liquid) Removal Work Plan and Report	As stipulated by MDNR
18	Activity and Use Limitations Work Plan and Report	As stipulated by MDNR
19	Corrective Action Plans and Report(s)	As stipulated by MDNR
20	CAP Performance Monitoring Plans and Report	As stipulated by MDNR

* Reports requiring submission to MDNR dependent on site conditions.

3.1 INTRODUCTION

The MRBCA process starts with the initial suspicion of release followed by activities that either confirm or refute the release. If the release is confirmed, the MRBCA process continues until MDNR issues a "No Further Action" (NFA) letter for the release. Note, however, as previously stated, the MRBCA process does not include emergency response activities conducted under 260.500 through 260.550 RSMo and the regulations promulgated thereunder.

A number of different events may trigger site-specific activities that may ultimately lead to release discovery. These include but are not limited to:

- Observation of petroleum products on or near a site, e.g., in utilities, on or adjacent to surface water bodies, in observation wells, etc.,
- Unusual underground storage tank (UST) system operating conditions, e.g., sudden loss of product in tanks, erratic behavior of product dispensing equipment, etc.,
- Monitoring results from a leak detection system,
- Phase I or phase II investigations associated with real estate transactions,
- Accidental release, e.g., during refueling of UST's by tankers, and
- Complaints of odors at or adjacent to a site.

In each of the above cases, the owner/operator of the UST system must report in writing to MDNR within 24 hours of suspicion and/or confirmation of release ***(10 Code of State Regulations (CSR) 20-10.050 Reporting of Suspected Releases),*** as directed at 3.2 below. Once a release has been confirmed, a site characterization will be necessary to collect relevant data to perform a risk-based evaluation (also refer to Section 5.0). Note, however, that MRBCA data collection activities are secondary to addressing all imminent threats and hazardous conditions posed by a release.

3.2 INVESTIGATION OF IMMINENT THREAT

In all of the above cases the first step upon suspicion and/or confirmation of a release is to report the release to MDNR at the earliest practical moment.

The following points briefly summarize the requirements of Sections 260.500 through 260.550, Revised Statues of Missouri (RSMo). Note that MDNR's Environmental Services Program (ESP) administers the referenced requirements.

- Any release of petroleum in excess of 50 gallons (25 gallons for USTs), constitutes a hazardous substance emergency,
- Releases shall be reported to the MDNR at (573) 634-2436 at the earliest practical moment,

- MDNR will evaluate whether an imminent threat exists,
- MDNR may require a person having control over a hazardous substance emergency to clean up the release and take any reasonable actions to end the hazardous substance emergency,
- MDNR may require such persons to take such actions as may be reasonably required to prevent recurrence of the hazardous substance emergency, and
- In the event such persons fail to act, MDNR may take action and pursue recovery of its costs.

Upon completion and documentation of the emergency response activities, and if the release of petroleum hydrocarbon is confirmed, additional data may have to be collected to perform a risk-based evaluation.

In no case will MDNR approve a risk assessment or Corrective Action Plan (CAP) if a hazardous substance emergency exists or is likely to occur, unless such conditions are specifically addressed either through interim corrective actions or through measures contained in the CAP.

Table 3-1
Default Target Levels

Chemicals of Concern	Soil (mg/kg)		Groundwater (mg/L)	
Benzene	5.61E-02	GWP	5.00E-03	DGW
Toluene	2.98E+01	GWP	1.00E+00	DGW
Ethylbenzene	3.99E+01	GWP	7.00E-01	DGW
Xylenes (mixed)	2.47E+01	INH	1.00E+01	DGW
Ethylene Dibromide (EDB)	4.73E-04	GWP	5.00E-05	DGW
Ethylene Dichloride (EDC)	2.06E-02	GWP	5.00E-03	DGW
Methyl-tert-butyl-ether(MTBE)	3.98E-01	GWP	1.28E-01	DGW
Acenaphthene	1.74E+02	GWP	1.65E-01	DGW
Anthracene	3.06E+03	GWP	6.96E-01	DGW
Benzo(a)anthracene	6.12E+00	GWP	1.03E-04	DGW
Benzo(a)pyrene	6.20E-01	SDC	1.02E-05	DGW
Benzo(b)fluoranthene	6.19E+00	SDC	6.27E-05	DGW
Benzo(k)fluoranthene	6.20E+01	SDC	6.46E-04	DGW
Chrysene	5.99E+02	SDC	1.03E-02	DGW
Dibenzo(a,h)anthracene	6.20E-01	SDC	4.21E-06	DGW
Fluoranthene	2.28E+03	SDC	1.64E-01	DGW
Fluorene	2.11E+02	GWP	1.03E-01	DGW
Napthalene	3.25E-01	GWP	1.09E-03	DGW
Pyrene	1.50E+03	GWP	9.61E-02	DGW
TPH-GRO	3.85E+02	INH	1.81E+01	DGW
TPH-DRO	4.15E+03	INH	3.43E+01	DGW
TPH-ORO	1.24E+05	SDC	3.18E+01	DGW
>C6 - C8 (Aliphatics)	2.53E+02	INH	9.94E+00	INH
>C8 - C10 (Aliphatics)	5.24E+01	INH	3.40E-01	INH
>C10 - C12 (Aliphatics)	2.60E+02	INH	2.27E-01	INH
>C12 - C16 (Aliphatics)	1.18E+03	INH	5.23E-02	INH
>C16 - C35 (Aliphatics)	1.22E+05	SDC	3.13E+01	DGW
>C8 - C10 (Aromatics)	4.12E+01	GWP	1.72E-01	DGW
>C10 - C12 (Aromatics)	6.49E+01	GWP	1.72E-01	DGW
>C12 - C16 (Aromatics)	1.29E+02	GWP	1.72E-01	DGW
>C16 - C21 (Aromatics)	1.11E+03	GWP	4.69E-01	DGW
>C21 - C35 (Aromatics)	1.72E+03	SDC	4.69E-01	DGW
Tertiary-amyl-methyl-ether (TAME)	6.77E-01	GWP	8.28E-02	DGW
Tertiary-butyl- alcohol (TBA)	5.58E-01	GWP	2.86E-01	DGW
Ethyl-tert-butyl-ether (ETBE)	1.06E-01	GWP	1.44E-02	DGW
Diisopropyl ether (DIPE)	4.12E+00	GWP	3.51E-01	DGW
Ethanol	7.73E+02	GWP	5.15E+02	DGW
Methanol	2.08E+01	GWP	7.81E+00	DGW
Arsenic	3.89E+00	SDC	1.00E-02	DGW
Barium	2.04E+03	GWP	2.00E+00	DGW
Cadmium	9.31E+00	GWP	5.00E-03	DGW
Chromium (III) total chromium	7.46E+04	SDC	1.00E-01	DGW
Chromium (VI)	1.59E-03	GWP	3.37E-06	DGW
Lead	3.74E+00	GWP	1.50E-02	DGW
Selenium	6.27E+00	GWP	5.00E-02	DGW

Notes:
SDC : Direct contact pathway NA: Not Applicable
GWP: Protection of domestic groundwater use pathway
DGW: Groundwater Domestic Use INH: Indoor inhalation (vapor intrusion) pathway

4.1 INTRODUCTION

This section presents requirements for tank closures that are regulated under Chapter 319 RSMo and 10 CSR 26-2.060 – 2.064. Closure of an underground storage tank (UST) means that the tank has been removed or filled with an inert solid material and has had all tank openings (e.g., tank tubes, vent pipes, pipelines) permanently sealed or capped according to the requirements of this section. This guidance may also be used to close above ground storage tanks (ASTs) that contain petroleum products. Owners of hazardous substance tanks must submit a plan for approval prior to conducting closure.

Implementation of the guidance presented in this document will fulfill the requirements of 10 CSR 26-2.061(5). However, the entity performing tank closure may present alternative written procedures to MDNR that may be more appropriate based on site conditions. Similarly, procedures presented in this document may not address all actions that MDNR may determine are necessary. MDNR may require additional actions to achieve compliance with applicable laws and regulations.

The tank closure process generally includes the following activities:

- Submission of Storage Tank Closure Notice;
- Removal of tank(s) and piping or in-place tank closure;
- Collection and analysis of soil and groundwater samples;
- Disposal of any waste streams (tank, soil, tank contents, and water) generated; and,
- Submission of a tank closure report.

The closure of tanks is the responsibility of the owner/operator of the tank and all correspondence from MDNR shall be addressed to the owner/operator. However, upon written request of the owner, MDNR will facilitate the closure process by working with the company hired by the owner/operator to close the tank.

4.2 SUBMISSION OF UST CLOSURE NOTICE

The process of tank closure begins when an entity submits a "Storage Tank Closure Notice" to MDNR. This notice must be submitted at least 30 days prior to initiating closure activities, unless tank removal is necessary to abate an emergency. In this case, the tank closure notice shall be submitted at the earliest possible time after abatement of the emergency. A blank copy of the form can be downloaded from http://dnr.mo.gov/forms/780-2121-f.pdf .

MDNR will review the tank closure notice and return a signed copy to the owner to acknowledge receipt.

4.3 CLOSURE OF TANKS BY EXCAVATION OR CLOSURE IN PLACE

Tanks may be closed either by excavation and removal or closed in-place, the latter by filling the tank(s) with an inert material. In either case, MDNR requires that storage tanks be cleaned, removed or filled, and disposed in accordance with recommended industry practices developed by organizations such as US EPA or American Petroleum Institute (API). For tanks closed in-place, a property deed notice must be executed to provide notice to future purchasers and lessees of the details (location, size, date of closure etc.) of the tanks closed on site.

For in-place closures, all vents, pipelines, and fill tubes must be sealed with cement or concrete grout. The tanks must be cleaned and emptied of all hydrocarbon liquids or sludges before being filled with an inert material with properties similar to those of rock and soil. If fly ash is used to fill tanks, a beneficial use request must be submitted to MDNR's Solid Waste Management Program (SWMP) in accordance with 10 CSR 80-2.020(9)(B) for review and approval, unless a general use exemption has been approved. For the latter, the fly ash must be handled in accordance with the terms and conditions of the exemption.

4.4 SOIL SAMPLING DURING UST CLOSURES

This section presents the sampling and analysis requirements for the tank removal and closure process. The number and location of samples to be collected as part of a UST closure depends on the (i) volume of the UST, (ii) layout of the UST system, and (iii) the presence of physical encumbrances in the tank excavation. Physical encumbrances include (i) groundwater that rapidly fills a tank pit and prevents soil sampling, (ii) concrete pads beneath the tanks, and (iii) bedrock in the tank excavation. The number and locations of soil samples to be collected is presented in Section 4.4.2.

4.4.1 Collection of Soil Samples

All soil samples must be collected from undisturbed native soils, generally about a foot below the fill material. It may not be necessary to remove all backfill from the tank pit to collect the required samples. During the tank closure process, color photographs must be taken to document closure activities; the photographs and a description of each must be included in the closure report. Photographs should include:

- Condition of the site before and after the closure is complete
- The ends, sides and interior of each tank
- The excavation floor and sidewalls
- Tank pad if present
- Bedrock if exposed
- Product lines and dispenser trenches
- Sealed underground tanks/lines that are closed in place

Note: all borings and monitoring wells equal to or greater than 10 feet deep are subject to the Missouri Water Well Drillers Act and regulations.

All soil and ground water samples sent for laboratory analysis must be analyzed for the appropriate chemicals of concern (COCs) using the laboratory methods listed in Table 5-1.

If the sampling requirements presented in this section cannot be met due to site-specific conditions, an alternative plan must be submitted to MDNR and approved.

4.4.2 Number and Location of Soil Samples

This section presents sampling requirements for projects where fewer than 200 cubic yards of native soil (not including the backfill material) are excavated. For sites where more than 200 cubic yards of native soil have been contaminated, refer to Section 4.4.4 for proper sampling requirements.

4.4.2.1 Soil Sampling for UST Removals with No Physical Encumbrances

Samples have to be collected from beneath the tank (tank pit floor) and along the tank pit wall in the direction COCs or petroleum product is most likely to migrate. Exhibit 4-1 presents the number of samples and Figures 4-1(a) to 4-1(d) present the locations where the samples shall be collected.

Exhibit 4-1
Tank Excavation Sampling for UST Removals with No Physical Encumbrances

Sample Location	Sample Requirement
Beneath a UST that is 110 to 1,000 gallons capacity	One grab sample required under each tank. Sample beneath the center of the UST or its former location [Figure 4-1(a)].
Beneath a UST that is greater than 1,000 gallons capacity	Two grab samples required under each tank. One sample beneath each end of the tank or its former location [Figure 4-1(b)]. One sample should be from beneath the fill port.
Downgradient Wall	One grab sample from each 20-foot section required. Collect the sample from the hydraulic downgradient wall of the excavation pit at the point of greatest visible contamination. If no contamination is visible, collect the sample from the wall at a level 12" below the bottom of the UST or its former location [Figures 4-1(c) and 4-1(d)].

4.4.2.2 Soil Sampling Requirements if Groundwater is Encountered During UST Removal

If the pit recharges with water so quickly that it is not possible to obtain the samples listed above (Section 4.4.2.1), soil samples must be collected from native soil adjacent to each of the four sides of the UST at the mean low water level (MLWL). As shown in Exhibit 4-2 and Figures 4-2(a) to 4-2(d), the number and location of samples depend on the size of the tank and whether the pit has single or multiple USTs. Note the grab sample must be collected 12" below the bottom of the UST or its former location if the MLWL is not discernible.

Exhibit 4-2
Required Soil Sampling for Tank Excavation Filled with Groundwater

Closure Removal Scenario	Sampling Requirements
Single UST $\leq$ 8,000 Gallons	One grab sample from each wall of the tank excavation at the mean low water level [Figure 4-2(a)].
Single UST > 8,000 Gallons	One grab sample from each wall of the tank excavation along the end of the tank and two grab samples from each wall along each side of the tank at the mean low water level [Figure 4-2(b)].
Multiple USTs $\leq$ 8,000 Gallons	One grab sample from each wall of the tank excavation along each side and end of a tank at the mean low water level [Figure 4-2(c)].
Multiple USTs > 8,000 Gallons	One grab sample from each wall of the tank excavation along each end of the tank and two grab samples from each wall along each side of the tank at the mean low water level [Figure 4-2(d)].

4.4.2.3 Soil Sampling Requirements for USTs Resting on Concrete

If the UST is resting on a concrete pad and the pad is to be left in the ground, the pad must be cleaned and examined for cracks and petroleum staining. Soil samples must be taken from all sides of the pad. The number of samples will depend on the size and number of tanks, as presented in Exhibit 4-3 and Figures 4-3(a) to 4-3(d). If the pad is cracked, a soil sample must be taken beneath the cracked area.

4.4.2.4 Sampling Requirements when Bedrock is found in the Excavation

If bedrock is encountered in the tank excavation and soil samples cannot be collected in accordance with Section 4.4.2.1, one grab sample must be collected from along each side of the tank at the interface of the bedrock and the native soil of the walls of the tank pit. Exhibit 4-4 and Figures 4-4(a) to 4-4(d) present the number and location of the samples.

Exhibit 4-3
Required Soil Sampling for Tanks Resting on Concrete Pad

Closure Removal Scenario	Sampling Requirements
Single UST ≤ 8,000 Gallons	One grab sample from along each side of the pad [Figure 4-3(a)].
Single UST > 8,000 Gallons	One grab sample from each end of the tank and two grab samples from each side of the tank along the concrete pad [Figure 4-3(b)].
Multiple USTs ≤ 8,000 Gallons	One grab sample from each side of the pad at the ends and sides of each tank [Figure 4-3(c)].
Multiple USTs > 8,000 Gallons	One grab sample from each side of the pad at the ends of each tank and two grab samples from each side of the pad along the sides of each tank [Figure 4-3(d)].

Exhibit 4-4
Required Soil Sampling for Tanks Resting on Bedrock

Closure Removal Scenario	Sampling Requirements
Single UST ≤ 8,000 Gallons	One grab sample from each wall of the tank excavation at the bedrock soil interface [Figure 4-4(a)].
Single UST > 8,000 Gallons	One grab sample from each wall of the tank excavation along the end of the tank and two grab samples from each wall of the tank excavation from each side of the tank at the bedrock soil interface [Figure 4-4(b)].
Multiple USTs ≤ 8,000 Gallons	One grab sample from each wall of the tank excavation along each side and end of a tank at the bedrock soil interface [Figure 4-4(c)].
Multiple USTs > 8,000 Gallons	One grab sample from each wall of the tank excavation along each end of the tank and two grab samples from each wall of the tank excavation along each side of a tank at the bedrock soil interface [Figure 4-4(d)].

The samples must be collected from native soil exhibiting the heaviest staining at a depth at or beneath the bottom of the tank. If bedrock or coarse gravel prevents collection of soil samples from native soil at a depth beneath or equivalent to the bottom of the tank (i.e. tanks blasted into bedrock) or if contamination extends into bedrock, a geologist or a qualified professional engineer registered in the State of Missouri must perform a geologic assessment to determine the potential for product migration and groundwater contamination.

At a minimum the geologic assessment should include the following information:

- The type of bedrock and formation;
- Soil type and soil morphological features;
- The competence of bedrock (i.e., weathered zone, degree of fracturing, etc.);
- A description of potential karst development at the site;
- The potential for perched groundwater within or on top of bedrock;
- The presence or absence of water in the tank pit and the water source;
- The depth to groundwater;
- The direction of groundwater flow;
- Downgradient receptors within 1/4 mile;
- The construction, depth, and static water level for all monitoring wells on site, any private wells within 1/4 mile radius of the site, and any public water supply wells within one mile of the site;
- The highest levels of soil contamination near the bedrock surface;
- A professional opinion regarding the potential for product migration and groundwater contamination;
- High resolution color photographs of bedrock surface exposed during assessment and areas which were exposed to excessive contamination; and,
- A description of the stratigraphy present in the areas of question, i.e. known regional aquifers, confining layers, etc.

4.4.2.5 Soil Sampling Requirements for in-place UST Closures

Soil samples for in-place UST closures must be collected along the center of each side and end of the UST. Field screening must be used on a continuous core to the total depth. Any interval above the target depth which shows contamination must be sampled as a separate grab sample. Exhibit 4-5 and Figures 4-5(a) to 4-5(d) show the number and location of the samples that depend on the size and number of tanks.

If the tank(s) are on a concrete pad, these samples shall be collected as close to the pad as possible.

4.4.2.6 Additional Soil Sampling Requirements for All UST Closures

In addition to sampling the tank excavation described above, samples must also be collected from (i) the product piping, (ii) dispensers, (iii) any remote fill ports associated with the tank system, and (iv) soil excavated from the tank pit that is to be used to refill

the tank pit or as clean fill. If a waste oil tank is being closed, site background conditions must be determined. Exhibit 4-6 shows the number and location of the additional samples.

Exhibit 4-5
Required Tank Excavation Soil Sampling for In-Place Closures

In-place Closure Scenario	Sampling Requirements
Single UST ≤ 8,000 Gallons	One grab sample from each side and end of the tank [Figure 4-5(a)].
Single UST > 8,000 Gallons	One grab sample from each end of the tank and two grab samples from each side of the tank [Figure 4-5(b)].
Multiple USTs ≤ 8,000 Gallons	One grab sample from each end and side of a tank [Figure 4-5(c)].
Multiple USTs > 8,000 Gallons	One grab sample from each end of a tank and two grab samples from each side of a tank [Figure 4-5(d)].

Sampling of Excavated Soil: All backfill material and native soil that is removed or disturbed during excavation is excavated soil for the purposes of this document. All excavated soil must be sampled and analyzed to (i) determine if the material can be placed back into the excavation or (ii) characterize it for disposal. Field screening may be used as a tool for separating contaminated soil from non-contaminated soil. However, field screening may not be used to document that soil can be placed back into the excavation.

If excavated soil is to be placed back into the excavation, samples of the soil must be analyzed for all applicable COCs listed in Table 5-1. A minimum of one composite sample must be collected from each 100 cubic yards. The composite sample should be composed of soil from no more than 4 separate locations collected from at least 2 feet into the pile.

If the excavated soil is to be placed back into the excavation, the soil must meet the cleanup target levels applicable to the site. Excavated soil that does not meet the cleanup target levels may not be returned to the excavation. Such soil must either be disposed off-site at an approved disposal facility or otherwise managed in accordance with state laws and regulations.

If the soil is disposed at an approved sanitary landfill, the landfill should be contacted to determine their requirements for sampling.

Sampling Background Conditions: If heavy metals, volatile organic compounds (VOCs), or polynuclear aromatic hydrocarbons (PAHs) are detected at a waste oil tank excavation, a sample must be collected upgradient of the excavation at a location not affected by the contamination to verify naturally occurring background conditions. If an upgradient sample is not provided, MDNR will assume any elevated levels are due to a release from the waste oil tank.

Exhibit 4-6
Additional Sampling Required for All Closures

Sample Locations	Sampling Requirements*
All Product Lines	One grab sample per piping trench from each twenty-foot section. In doing so, sample preferentially under joints, flex connectors and pipe elbows. If piping trench is less than five feet in length, no sample is required. Piping sample is required even if the piping is to remain in use.
All Dispensers	One grab sample from beneath each dispenser is required, unless the dispenser is directly above the UST. Soil must be sampled even if the dispenser is to remain in use.
Remote Fill Ports	One grab sample at connection and an additional grab sample for each twenty-foot section of pipe.
Excavated Soil	One composite sample required from each 100 cubic yards.
Site Background Conditions – Used Oil Only	One grab sample collected upgradient of the tank excavation, if metals contamination is detected in the tank excavation

* The samples must be collected 12" into native soil.

4.4.3 Groundwater Sampling Requirements for UST Closures

Impact to groundwater must also be evaluated as a part of the closure activities. The number and location of samples will depend on whether or not water is encountered in the tank excavation during the tank closure activities. The sampling requirements under these conditions are presented below. For UST closures, groundwater is defined as water from the first saturated zone or water-bearing unit capable of measurable recharge within 12 hours.

4.4.3.1 Sampling Groundwater Encountered During UST Excavation and Removal

If water is encountered in the pit, it is assumed to be groundwater unless it is removed to determine whether it is groundwater or trapped surface water. If the water is not removed from the tank excavation or the pit recharges with groundwater within 12 hours, a grab sample of the water in the excavation must be collected and analyzed. If the groundwater shows COC (refer to Table 5-1) concentrations above the DTLs in Table 3-1, additional site characterization may be required.

4.4.3.2 Groundwater Sampling if Encountered During in-Place Closure

Groundwater must be analyzed if it is encountered during an in-place closure. If the concentrations of COCs in the groundwater are above the DTLs listed in Table 3-1, a minimum of three groundwater monitoring wells or properly constructed piezometers must be installed as described below:

(i) One monitoring well or properly constructed piezometer must be installed immediately adjacent to the UST pit on the hydraulic downgradient side. The well or piezometer should be installed topographically downgradient if the hydraulic downgradient is unknown. The monitoring well must be screened across the first saturated zone. The others should be placed in such a manner as to determine groundwater flow and elevation.

(ii) Regulations require that the wells be drilled and constructed in accordance with the Missouri Geological Survey (MGS) Monitoring Well Construction Rules (10 CSR 23-4.010-4.080). Contact the MGS Wellhead Protection Section at (573) 368-2165 for more information.

(iii) Following well development and purging, representative groundwater samples must be collected and analyzed for COCs per Table 5-1. The boring log, chain of custody, and analytical results must be included as part of the closure documentation. All auger flight cuttings must be properly disposed.

(iv) Contact the Tanks Section if groundwater sampling is not possible.

4.4.3.3 Groundwater Sampling if Not Encountered During UST Excavation and Removal

This section discusses the circumstances under which groundwater sampling is required even though groundwater was not encountered in the tank pit. Figure 4-1 shows the flow chart to determine the need for groundwater investigation during tank closure. For the purposes of this section, the volume of materials in the original tank excavation zone or pit and in the piping trench is not considered in determining the volume of soil excavated due to contamination. Further, soils that exist beyond that original tank pit and piping trench are considered excavated soils regardless of whether the material is a naturally developed soil or the material is a fill that was used to elevate or level the site surface.

A groundwater investigation is required for any site where the volume of excavated soils, ignoring the tank pit and piping trench, exceeds 200 cubic yards, regardless of final soil sample results. In this situation, the department assumes the excavated soils to be contaminated and believes that a volume exceeding 200 cubic yards is indicative of a significant petroleum release and a heightened threat of groundwater contamination.

A groundwater investigation is not required where the excavation is less than 200 cubic yards and the final soil sample results do not exceed the values are listed on Table 4-1, Column A.

The values in Table 4-1, Column B may be substituted for the default target levels provided that a registered geologist or qualified professional engineer has determined that the groundwater use pathway is incomplete. This determination is documented using the process described at Section 6.3. Again, provided that soil excavation, beyond the tank pit and line trench, does not exceed 200 cubic yards, no groundwater investigation is required.

If the groundwater use pathway is determined to be complete, then the values in Table 4-1, Column A shall be used.

If the values in Table 4-1 cannot be met, then a groundwater investigation is required. In all other instances, a groundwater investigation is required.

4.4.4 Sampling Sites after Excavation of Contamination

This section applies to sites where more than 200 cubic yards of contaminated native soil have been removed, or further excavation is necessary to remove the affected soil. These 200 cubic yards of native soil do not include backfill material that must be removed prior to closure sampling. The sampling specified in this section may be used to verify that excavation of the contaminated areas has been successfully completed.

The following sampling plan applies any time contaminated native soil is removed from the tank pit, piping run and underneath dispensers. Samples must be taken from (i) each excavation wall; (ii) the floor of the excavation; and, (iii) areas where a potential migratory pathway exists (e.g. utility conduits). If the sampling requirements presented in this section cannot be met due to site-specific conditions, an alternative plan must be submitted to MDNR and approved prior to implementation.

4.4.4.1 Excavation Walls

Samples must be taken from each wall of the excavation. If the wall is less than twenty feet in length one grab sample is required. If the wall is more than twenty feet long, it must be divided into equal sections of no more than twenty feet with one grab sample collected from each section. If contamination is present, take the sample in the area of greatest staining. If contamination is not obvious, the sample must be taken from the wall within one foot of the excavation floor in the center of the section [Figure 4-5(a)].

4.4.4.2 Excavation Floor

Divide the excavation floor into thirty-foot grid sections (a square with thirty-foot sides). Take one grab sample from each grid square. The sample should be taken from the area of the grid section with the greatest staining. If there is no obvious staining, take the sample from the center of the grid section [Figure 4-6(b)].

4.4.4.3 Sampling near Potential Pathways

Samples must be taken at all potential pathways, including, but not necessarily limited to, buried pipelines, sewers, water lines or other utility conduits.

4.4.4.4 Groundwater Sampling

In addition to the requirements of Section 4.4.3 above, groundwater must be assessed at the site if more than 200 cubic yards of native soil (or other fill materials outside the tank/piping excavation zone) were contaminated above the DTLs. If water is not present in the pit, then the assessment must be completed in accordance with Section 4.4.3.3.

4.4.4.5 Location of Wells

If more than 100 cubic yards of native soil (or fill material outside the tank/piping excavation zone) were contaminated above the DTLs, a land use map must be submitted showing any drinking water wells located within one thousand feet (1,000') of the site.

4.5 WASTE DISPOSAL AND TREATMENT

During UST closure activities, several types of waste might be generated (e.g. sludge and rinsate, contaminated soil, contaminated water, unusable product, etc.). These wastes require proper management to ensure that human health and the environment are protected.

For all activities that result in generation of waste, MDNR prefers to utilize pollution prevention technologies to reduce the amount of waste generated. However, pollution prevention methods cannot eliminate all wastes generated during UST closure. MDNR recommends that, whenever possible, wastes be recycled rather than disposed.

The owner/operator of the UST bears the responsibility of ensuring that wastes generated during UST closure activities are properly managed. Wastes must be properly characterized before being shipped off-site to a facility that is approved/permitted to accept the wastes. Waste transporters must possess all applicable licenses required to transport the waste. In addition, the UST owner/operator must ensure that all relevant and applicable OSHA and NIOSH safety standards are followed during UST closure activities.

Exhibit 4-7
Requirements for Proper Management of Hazardous Waste Based on the Quantity Generated or Accumulated

Amount of Hazardous Waste Generated per Month or Accumulated at Any One Time	Actions Required
< 100 kg (220 lbs.)	Responsible party is a "conditionally exempt small quantity generator." a) characterize the waste b) dispose of the waste at a permitted disposal facility
100 to 1000 kg (220 to 2200 lbs.)	Responsible party must comply with all standards set forth for small quantity generators: a) characterize the waste b) complete Notification of Regulated Waste Activity form to obtain generator identification numbers* c) meet all applicable storage requirements d) send the waste for disposal within the required time frames (180 days, 270 days if transported greater than 200 miles) e) properly manifest the waste f) dispose of waste at a permitted disposal facility g) report the waste disposed on the Generator's Hazardous Waste Summary Report*
> 1000 kg (2200 lbs.)	Responsible party must comply with all standards set forth for large quantity generators: a) characterize the waste b) complete Notification of Regulated Waste Activity form to obtain generator identification numbers* c) meet all applicable storage requirements d) send the waste for disposal within the required time frames (90 days) e) use the manifest system f) dispose of waste at a permitted disposal facility g) report the waste disposed on the Generator's Hazardous Waste Summary Report*

- Contact the MDNR's Hazardous Waste Program at (573) 751-3176 for further information.

4.5.1 On-site Storage of Excavated Soil

Excavated soil must be placed on and covered with plastic or a similar impermeable material. A permit to stockpile contaminated soil on site is required if these requirements cannot be met. On-site storage should be for the minimum period necessary to arrange for appropriate management of the soil.

4.5.2 Recovered Product

Product recovered from a UST may be managed by using or selling the material for its intended use, returning the material to the distribution system (e.g. pipeline or terminal), or sending the material off-site for fuel blending or disposal. Recovered product sent for disposal is assumed to be a hazardous waste and is subject to the testing requirements of 40 CFR Part 261 and 10 CSR 25-4.010 (see Exhibit 4-7). In order to demonstrate that recovered product has been properly managed, the closure report must include documentation signed by a representative of the facility to which the material was sent attesting to the use, recycle or disposal of the material. Please direct questions regarding proper waste characterization to MDNR's Hazardous Waste Program (HWP) at (573) 751-3176.

4.5.3 Disposal of Petroleum Contaminated Pit Water

Petroleum contaminated water that accumulates in the UST excavation pit but that has not come in contact with the interior of the UST is deferred from hazardous waste management for the toxicity characteristics represented by the waste codes D018 through D043 (refer to 40 CFR 261 for a list of the toxicity characteristic waste codes). However, the pit water must still be assessed for toxicity characteristics represented by the waste codes D001-D017. After the hazardous waste determination has been made, disposal options include: i) disposal at a municipal wastewater treatment facility; ii) direct discharge under a general permit; and, iii) disposal at a permitted hazardous waste disposal facility. These three options are further discussed below.

4.5.3.1 Disposal at a Municipal Wastewater Treatment Facility

A municipal wastewater treatment facility, otherwise known as a Publicly Owned Treatment Works (POTW), may accept petroleum-contaminated water, but is not required to do so. Permission to discharge wastewater to the POTW must be obtained from the POTW before the water may be discharged. The closure report must include appropriate documentation demonstrating that the water was accepted by the POTW.

If an on-site connection to a sanitary sewer is present and written permission from the POTW has been obtained to place the wastewater into the sanitary sewer, the wastewater is exempt from solid and hazardous waste regulations. However, if the wastewater is determined to be hazardous prior to discharge to the sanitary sewer, it must be managed according to all applicable hazardous waste rules and regulations.

If the POTW will not accept untreated wastewater, the POTW might agree to accept the wastewater after it has been treated on-site to minimize contaminant concentrations. If the wastewater is to be treated on-site, a hazardous waste treatment permit must first be obtained from MDNR's HWP. Note, however, that a hazardous waste treatment permit is not required if the wastewater is treated on-site solely via gravity separation, simple filtration, or the use of an oil/water separator. (Note: the separated product and filter media may be a hazardous waste after the on-site treatment is completed and, if so, must be managed appropriately.)

4.5.3.2 Discharge Under a General Permit

Wastewater cannot be discharged to the environment except under a General Permit for Fuel Spill Cleanup (MO-G940000) issued by MDNR's Water Protection Program (WPP). The generator does not need to obtain a permit if wastewater is discharged directly into a sanitary sewer in accordance with 40 CFR 261.4(a)(1)(ii) (as above, prior approval from the municipal wastewater treatment facility is required), or if the wastewater is hauled directly to a treatment facility. However, to document proper disposal, MDNR requires that a signed statement from the receiving facility be included in the closure report.

4.5.3.3 Disposal at a Waste Disposal Facility

If the discharge limits of the general permit or the POTW cannot be met, then wastewater that is hazardous (see Exhibit 4-7) must be sent to a permitted disposal facility. The wastewater must be transported to the facility under manifest by a licensed hazardous waste transporter. A list of licensed hazardous waste transporters may be obtained from MDNR's HWP at (573) 751-3176.

Non-hazardous wastewater that does not meet the discharge limits of the general permit or the POTW may be sent to a disposal facility that is permitted to accept it. If transported, the wastewater must be managed according to all applicable Department of Transportation (DOT) regulations.

4.5.4 Disposal of UST Wastes

All waste from the interior of an UST is assumed to be hazardous waste and is subject to a hazardous waste determination. In addition, any media or debris that comes in contact with the interior of the UST or with waste removed from the interior of the UST is assumed to be hazardous, unless laboratory analyses indicate otherwise (see Exhibit 4-8). If UST wastes are managed under an exemption, appropriate documentation must be submitted to MDNR to verify proper disposal. For more information regarding the proper management of UST wastes, contact the MDNR's HWP at (573) 751-3176. MDNR's technical bulletin "Management of Petroleum Storage Tank Wastes" is available at http://dnr.mo.gov/pubs/index.html.

4.5.5 UST Disposal/Recycling

Before being transported off-site, USTs must be emptied, cleaned and purged in accordance with all applicable industry practices. Once emptied, cleaned and purged, the UST may be disposed as solid waste or recycled (e.g. scrapped or salvaged). The closure report must include a signed statement from the owner of the UST(s) or the receiving facility attesting to the fate of the UST.

Exhibit 4-8
Toxicity Characteristic Information Sheet

Media and Debris that are Deferred from the RCRA Toxicity Characteristics Rule for Analysis for the Hazardous Waste Codes D018 – D043*	
Deferred**	**Not Deferred**
Materials outside of an UST: • Soil (before & after treatment) • Groundwater (before and after treatment) • Floating Plume • Surface Water • Rock, Grass and Stumps • Empty USTs • Empty Piping	Materials from inside the UST: • Sludge • Water • Unusable Product • Waste Materials/Rinsate from UST Cleaning • Spent Carbon or Waste from Treatment

Minimal Sampling Required to Properly Characterize Petroleum-Contaminated Waste for Disposal***	
Deferred**	**Not Deferred**
• Ignitability • Lead	• Ignitability • Lead • Benzene

* Refer to 40 CFR 261 for hazardous waste codes.

** The deferral only applies to media and debris that are contaminated by petroleum from USTs subject to corrective action under 40 CFR Part 280.

*** Laboratory analytical data must be submitted to document that the waste is not a hazardous waste under the Toxicity Characteristic Rule. Additional analyses may apply dependent on the waste generated and site specific conditions.

4.5.6 Recording of USTs Closed In-Place

The existence of an UST closed in place must be recorded on the property deed pursuant to 10 CSR 80-2.030(2). A "Statement of Closure" form may be used to comply with this requirement (contact MDNR's Tanks Section at (573) 751-6822 for a copy of the "Statement of Closure" form). During any potential property transaction, it is the property owner's responsibility, under Missouri Solid Waste Management Law (260.213 RSMo), to inform a potential buyer that a solid waste is located on the property and that the potential buyer may incur liability for that waste under State and Federal laws.

4.5.7 Disposal of Petroleum Contaminated Soil

Soil contaminated with petroleum, provided that it is not a hazardous waste and does not contain free liquid, may be taken to a permitted sanitary landfill as a special waste, provided the landfill is willing to accept it. Prior to disposal, a "Special Waste Disposal Request" (contact the MDNR's Solid Waste Management Program at (573) 751-5401 for a copy of the "Special Waste Disposal Request" form) must be submitted to and approved by the landfill. A copy of the form and analytical data for the soil must also be included in the closure report. The closure report must also include a copy of the shipping papers or the landfill disposal receipts to document the landfill's receipt of the material. Questions regarding proper disposal of petroleum contaminated soil should be directed to MDNR's SWMP at (573) 751-5401.

4.5.8 Treatment of Petroleum Contaminated Soil

Prior to implementation of an alternative or on-site soil treatment option (e.g., landfarming, in-situ biological treatment, thermal treatment, etc.), a Corrective Action Plan (CAP) must be submitted to MDNR's Tanks Section for review and approval. If treatment will be via on-site landfarming, approval must be obtained from MDNR's Tanks Section as part of the CAP for the petroleum release. Off-site landfarms require a permit issued by MDNR's WPP; for information concerning landfarming permits, contact MDNR's WPP at (573) 751-1300.

4.5.9 Reusing Excavated Soil as Fill

Excavated soil intended for placement back into the UST excavation pit must meet the cleanup target levels applicable to the site. Excavated soil that does not meet the cleanup target levels may <u>not</u> be returned to the excavation. Such soil must either be disposed off-site at an approved disposal facility or otherwise managed in accordance with state laws and regulations. Refer to Section 4.4.2.6 for further information.

Excavated soil intended for use as fill material other than via replacement into the excavation pit must be managed in accordance with all applicable state solid and hazardous waste laws and regulations. Soil used as fill (except when replaced in the excavation pit) must meet the SWMP's clean fill criteria or be managed under a beneficial reuse request. Review the MDNR technical bulletin "Beneficial Use of

Petroleum Contaminated Soil" available on-line at http://dnr.mo.gov/pubs/pub2177.pdf or contact MDNR's SWMP at (573) 751-5401 prior to using excavated soil as fill material.

4.5.10 Applicability of the Toxicity Characteristic Rule

Under the Toxicity Characteristic (TC) Rule, media and debris from closure or cleanup of a petroleum UST that is subject to corrective action under 40 CFR Part 280 are deferred from being managed as hazardous waste for the toxicity characteristic for the hazardous waste codes D018 through D043 (refer to 40 CFR 261 for a list of the toxicity characteristic waste codes). The term "media" includes naturally occurring materials such as soil, groundwater, surface water, and air that are contaminated with substances released from USTs. The term "debris" refers to solid material that is a manufactured object, plant or animal matter, or natural geologic material.

To properly characterize deferred media and debris, the applicability of the hazardous waste characteristics designated by the hazardous waste codes D001 through D017 must be determined. In most cases, deferred petroleum contaminated media and debris should be analyzed for the characteristic of ignitability. Where the USTs contained leaded gasoline, analysis should also be performed for the toxicity characteristic of lead. If contaminated media and debris do not exhibit any of the applicable hazardous characteristics, the wastes may be managed as non-hazardous solid waste.

Wastes that come in contact with the interior of the UST are not deferred from the toxicity characteristics for the hazardous waste codes D018 through D043. These wastes (e.g. rinsate, cleaning materials, sludge, scale, water, unusable product, etc.) are hazardous when disposed, unless analytical testing indicates otherwise or they are managed according to an exemption. These wastes must be characterized to ensure disposal in accordance with hazardous waste laws and regulations. Documentation indicating that the waste is non-hazardous should include laboratory analytical data for the hazardous characteristics of ignitability, benzene and lead.

4.6 SUBMISSION OF THE CLOSURE REPORT

A closure report must be submitted to MDNR within 60 days of completion of closure activities, unless otherwise approved in writing by MDNR, using MDNR's "Closure Report for Petroleum Releases at Underground Storage Tank Sites" available on-line at http://dnr.mo.gov/forms/780-2120-f.pdf.

FIGURES

NOTE: For soil sampling, in each case illustrated by the figures below, if field screening indicates that contamination is present on the floor or walls of an excavation, a sample shall be collected from the area where contamination is present. When contamination is present, MDNR recommends collecting a sufficient number of samples to define the extent of the contamination.

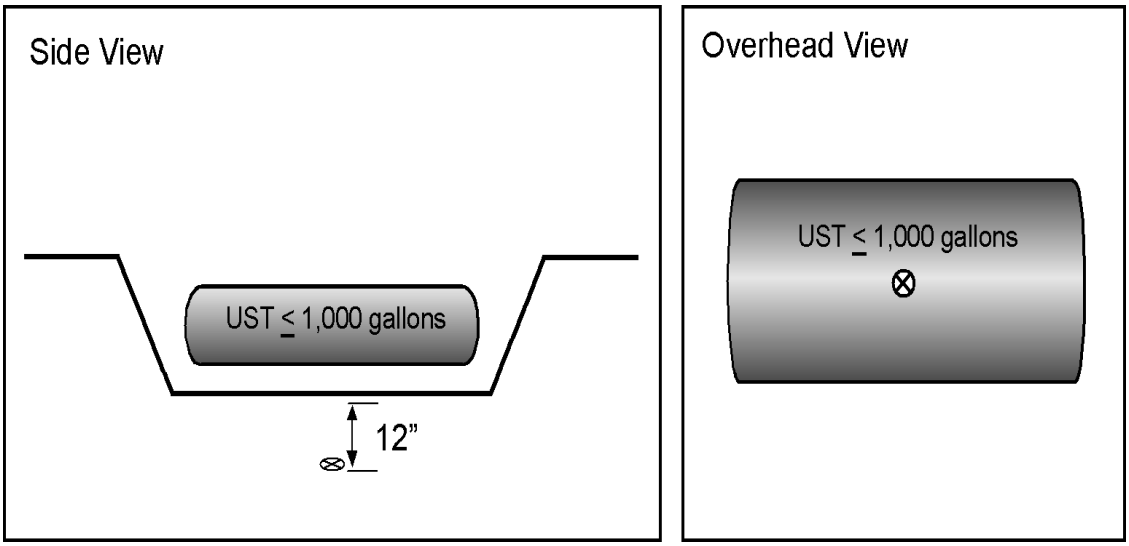

Figure 4-1(a). Tank Floor Sampling Where No Physical Encumbrances Exist for Tanks 1,000 Gallons or Less

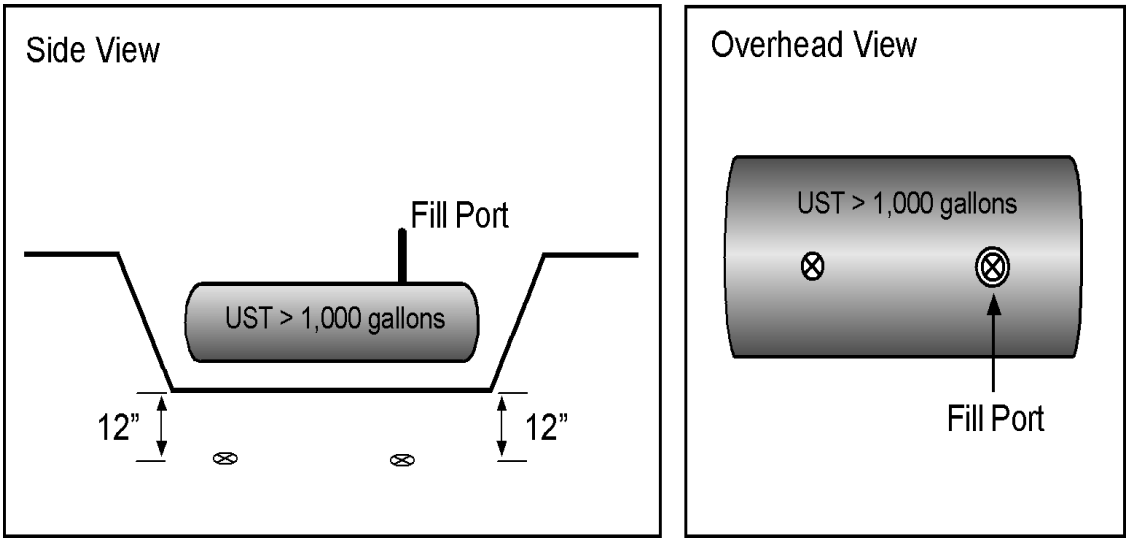

Figure 4-1(b). Tank Floor Sampling Where No Physical Encumbrances Exist for Tanks Greater than 1,000 Gallons

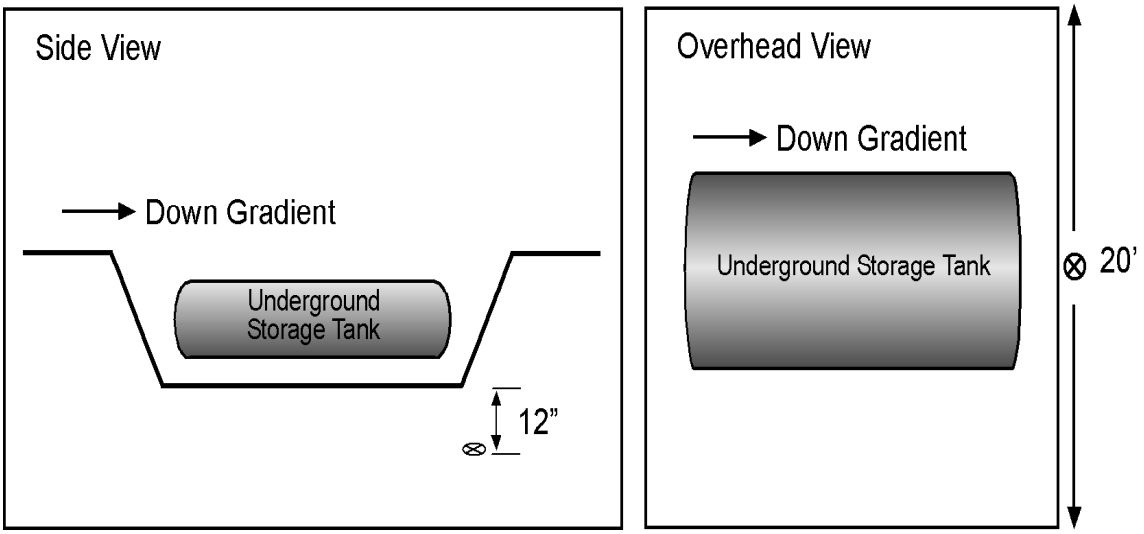

Figure 4-1(c). Hydraulic Downgradient Wall Sampling, 20 Feet of Wall or Less

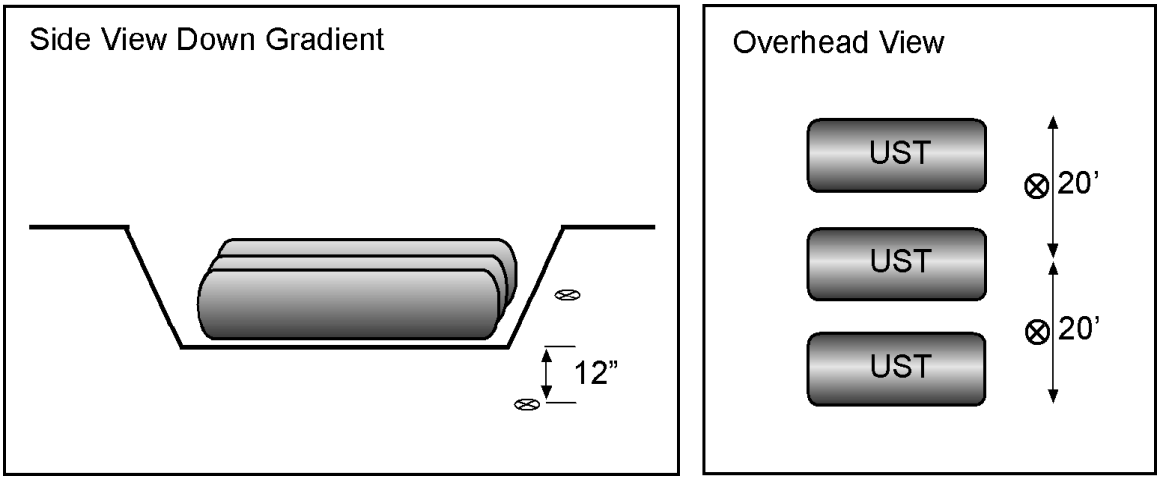

Figure 4-1(d). Hydraulic Downgradient Wall Sampling, Greater than 20 Feet of Wall

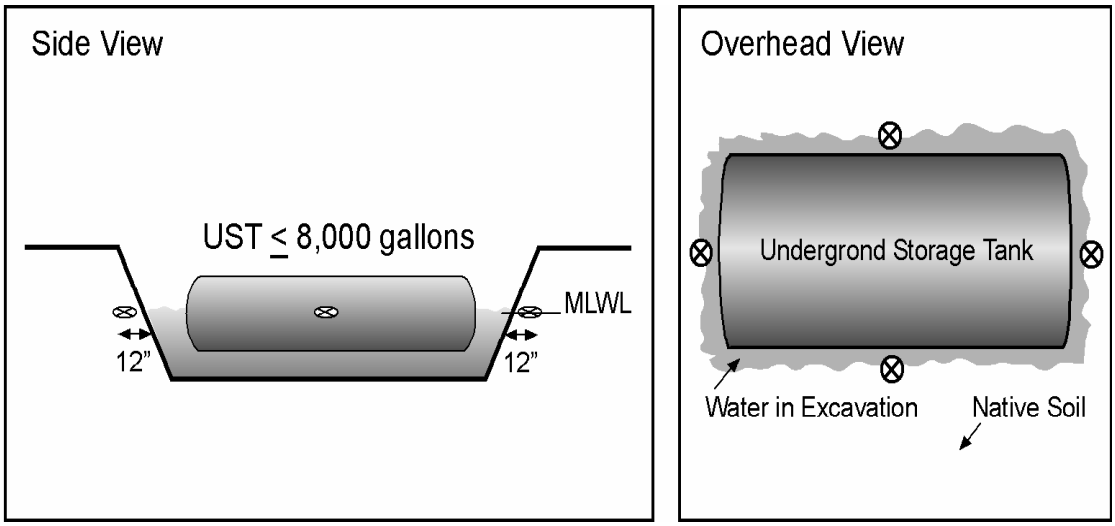

Figure 4-2(a). Tank Excavation Soil Sampling for Single Tanks 8,000 Gallons or Less when Groundwater is Encountered

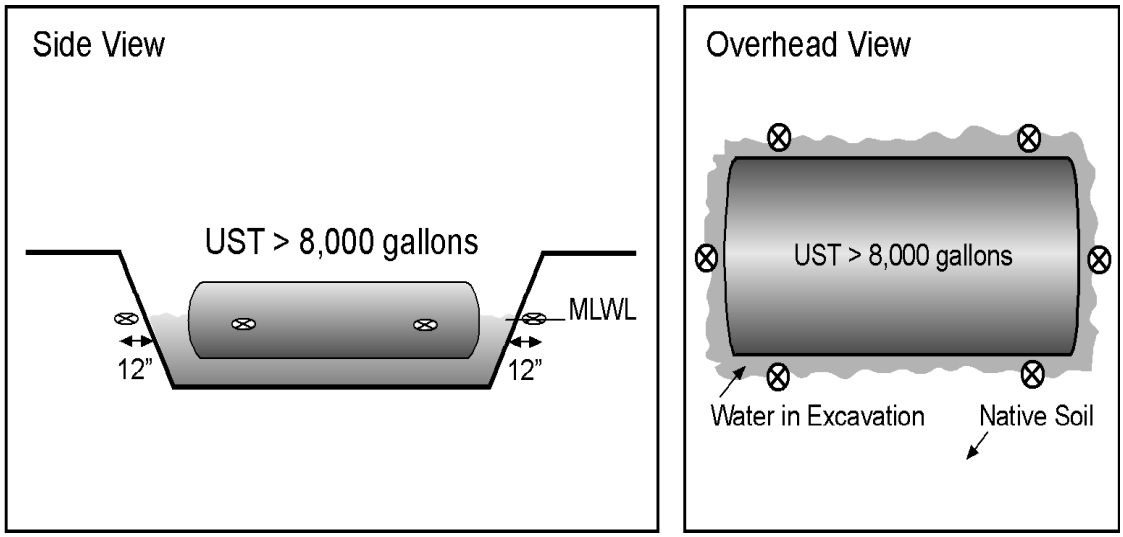

Figure 4-2(b). Tank Excavation Soil Sampling for Single Tanks Greater Than 8,000 Gallons when Groundwater is Encountered

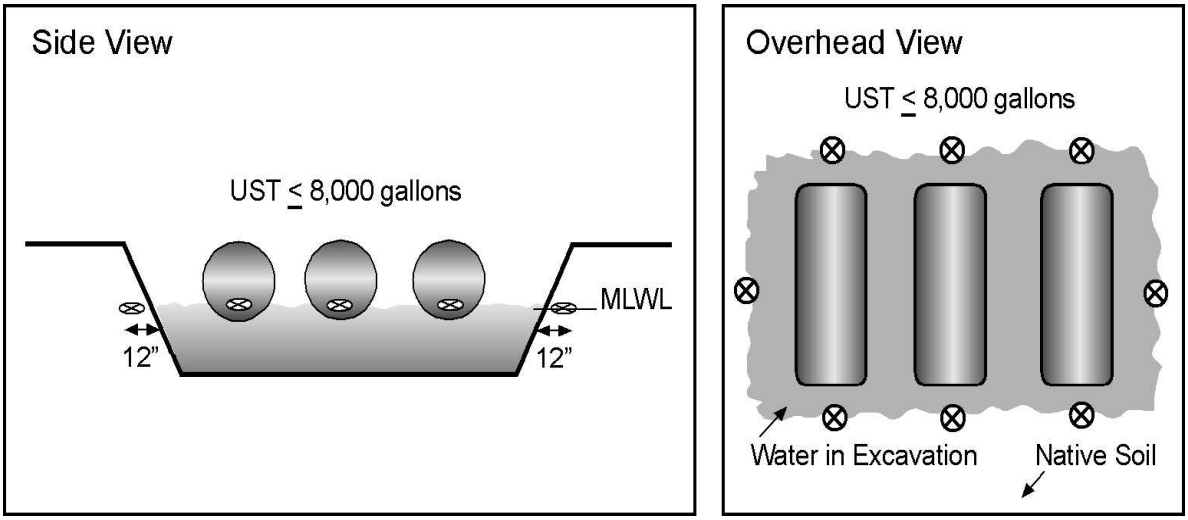

Figure 4-2(c). Tank Excavation Soil Sampling for Multiple Tanks 8,000 Gallons or Less when Groundwater is Encountered

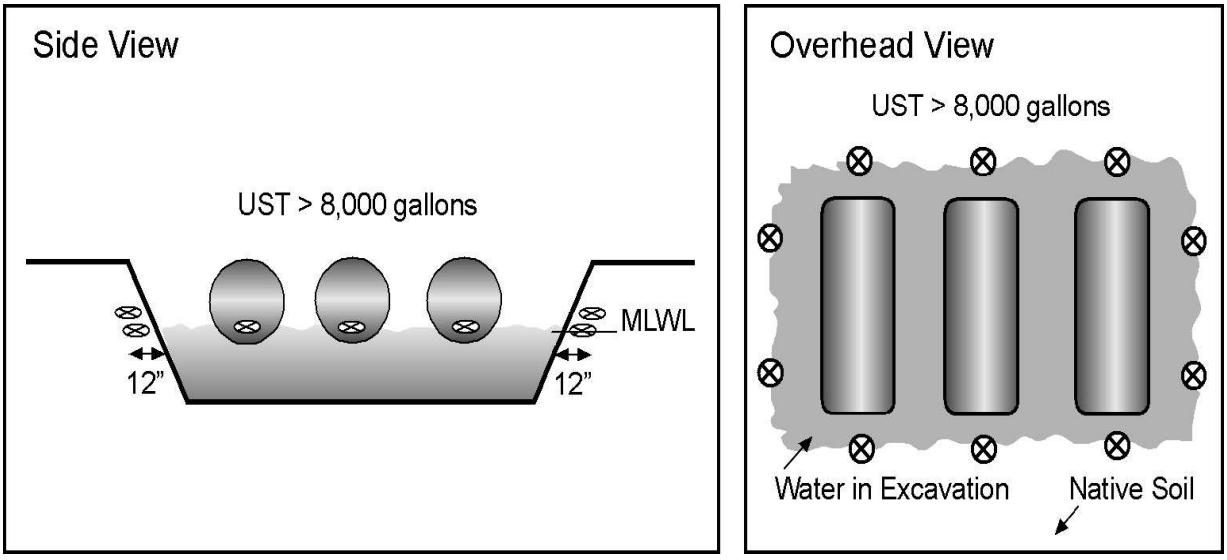

Figure 4-2(d). Tank Excavation Soil Sampling for Multiple Tanks Greater Than 8,000 Gallons when Groundwater is Encountered

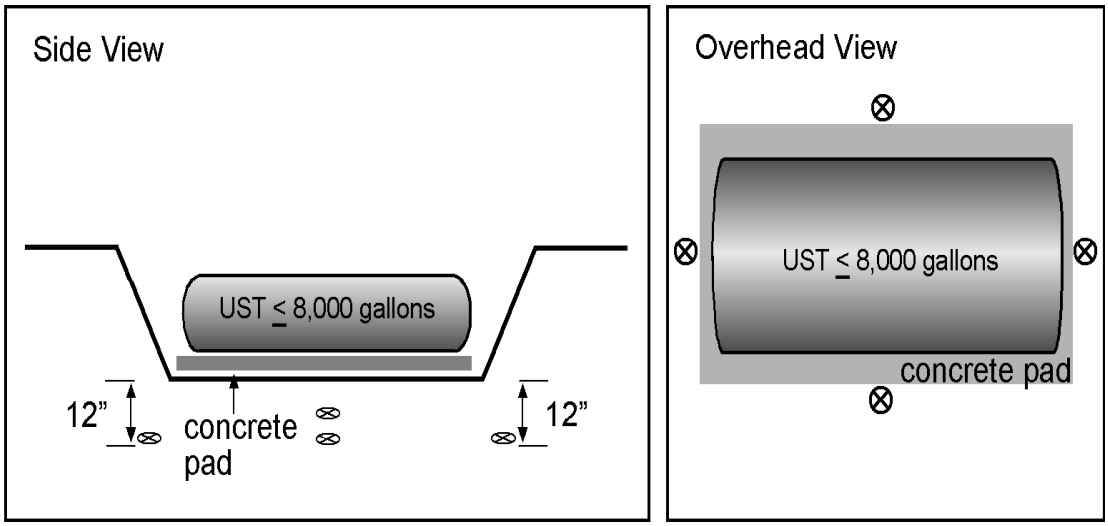

Figure 4-3(a). Tank Excavation Sampling for a Single Tank 8,000 Gallons or Less Resting on a Concrete Pad

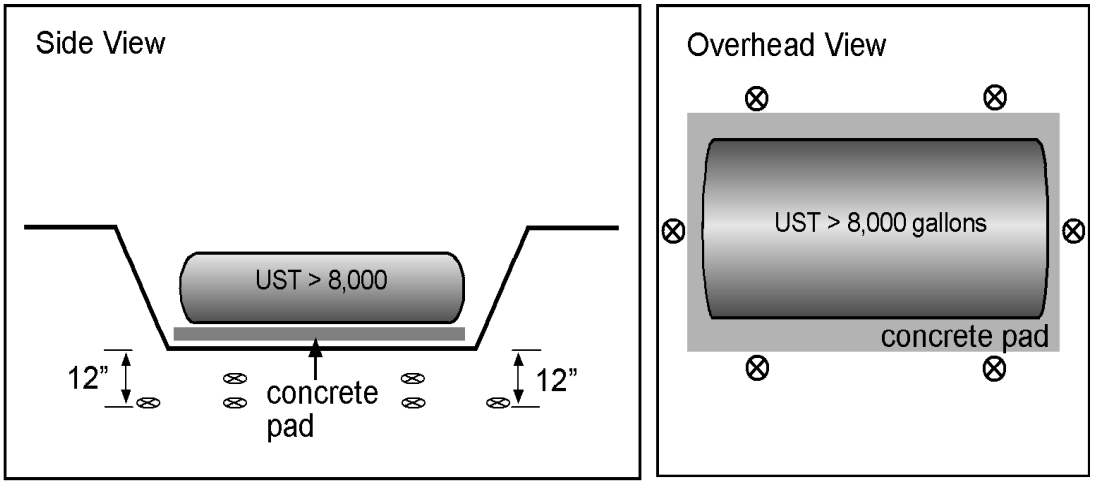

Figure 4-3(b). Tank Excavation Sampling for a Single Tank Greater Than 8,000 Gallons Resting on a Concrete Pad

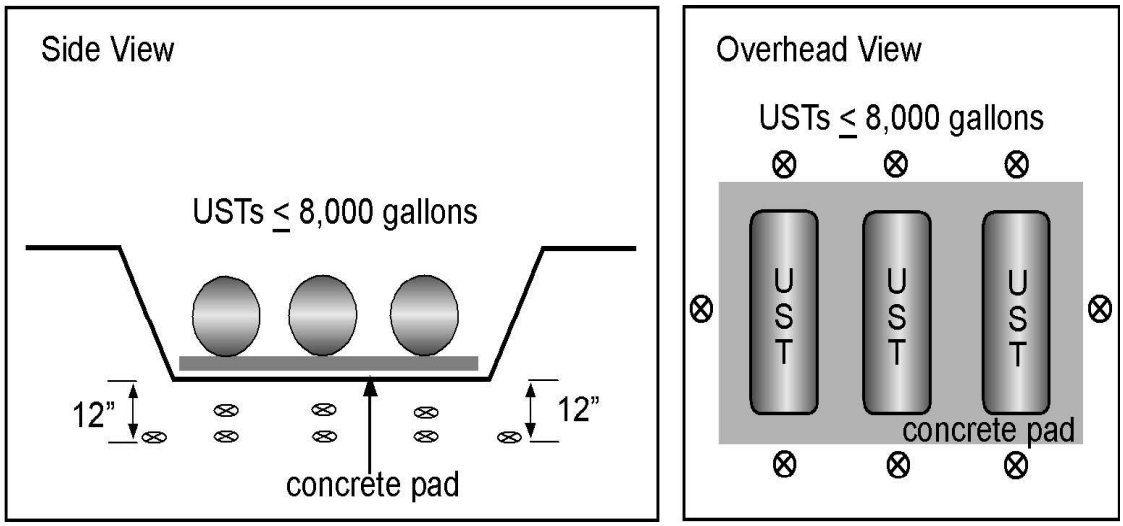

Figure 4-3(c). Tank Excavation Sampling for Multiple Tanks 8,000 Gallons or Less Resting on a Concrete Pad

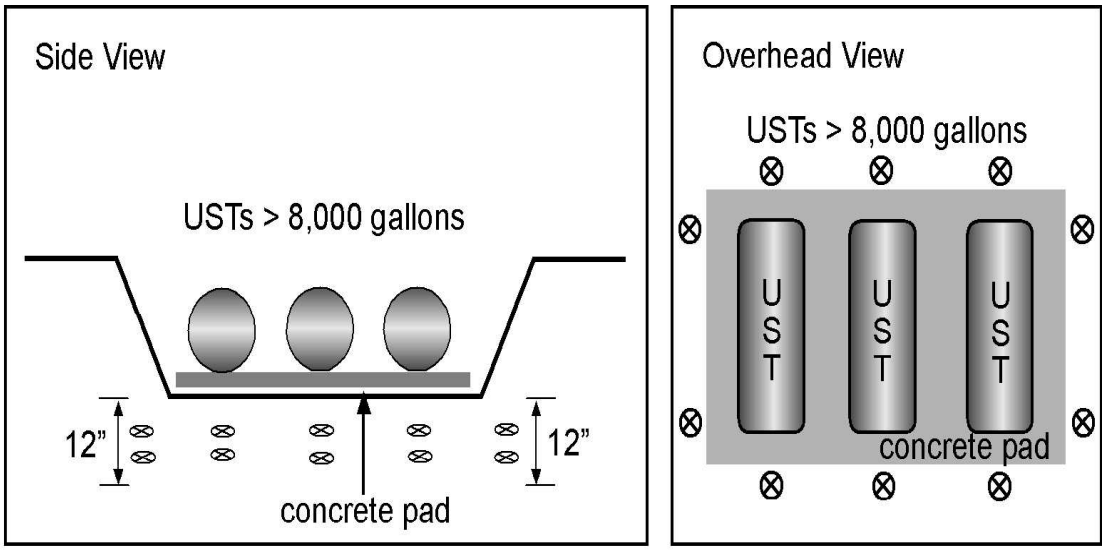

Figure 4-3(d). Tank Excavation Sampling for Multiple Tanks Greater Than 8,000 Gallons Resting on a Concrete Pad

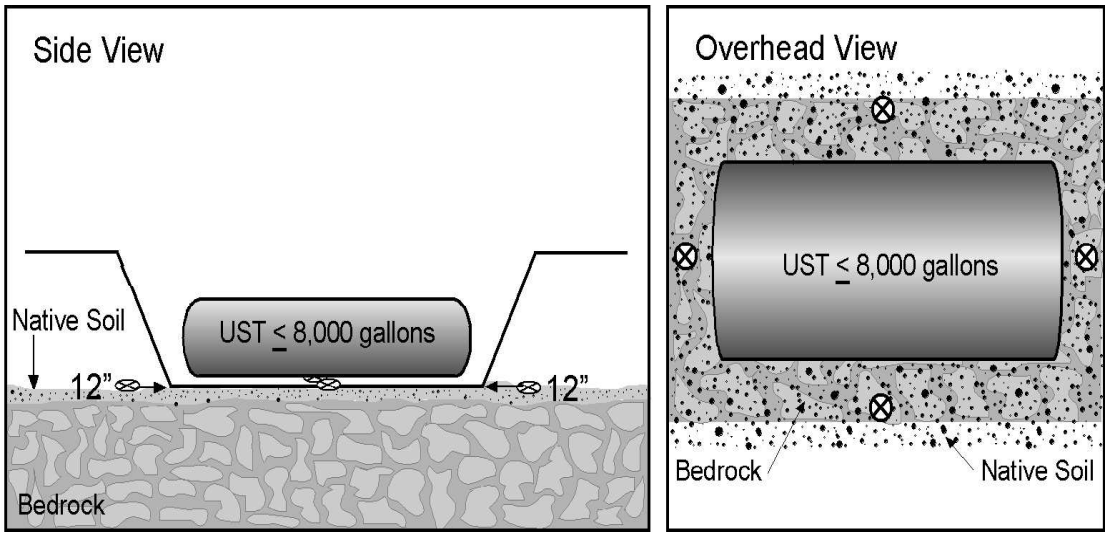

Figure 4-4(a). Soil Sampling for a Single Tank 8,000 Gallons or Less Resting on Bedrock

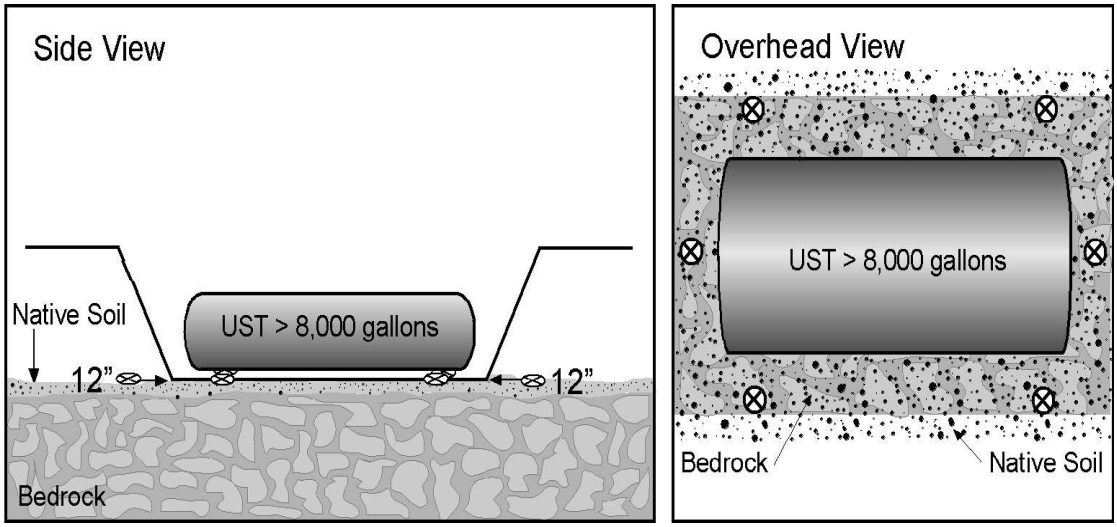

Figure 4-4(b). Soil Sampling for a Single Tank Greater Than 8,000 Gallons Resting on Bedrock

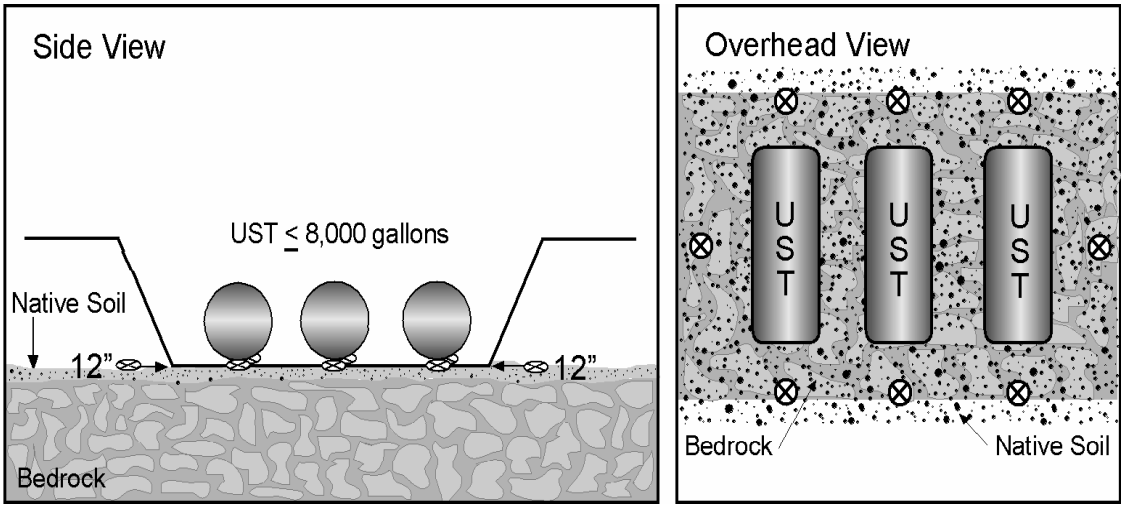

Figure 4-4(c). Soil Sampling for Multiple Tanks 8,000 Gallons or Less Resting on Bedrock

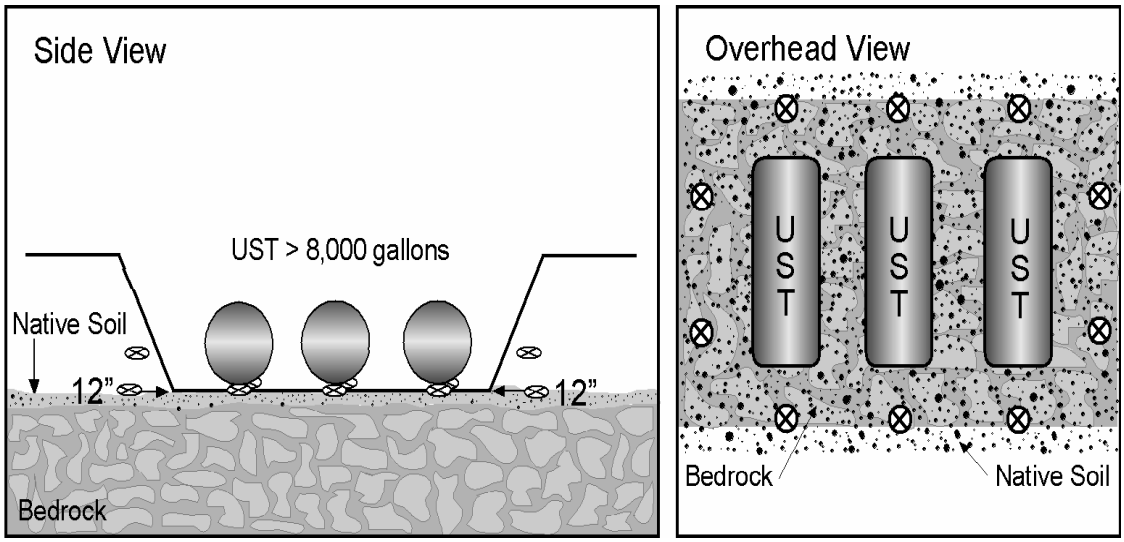

Figure 4-4(d). Soil Sampling for Multiple Tanks Greater Than 8,000 Gallons Resting on Bedrock

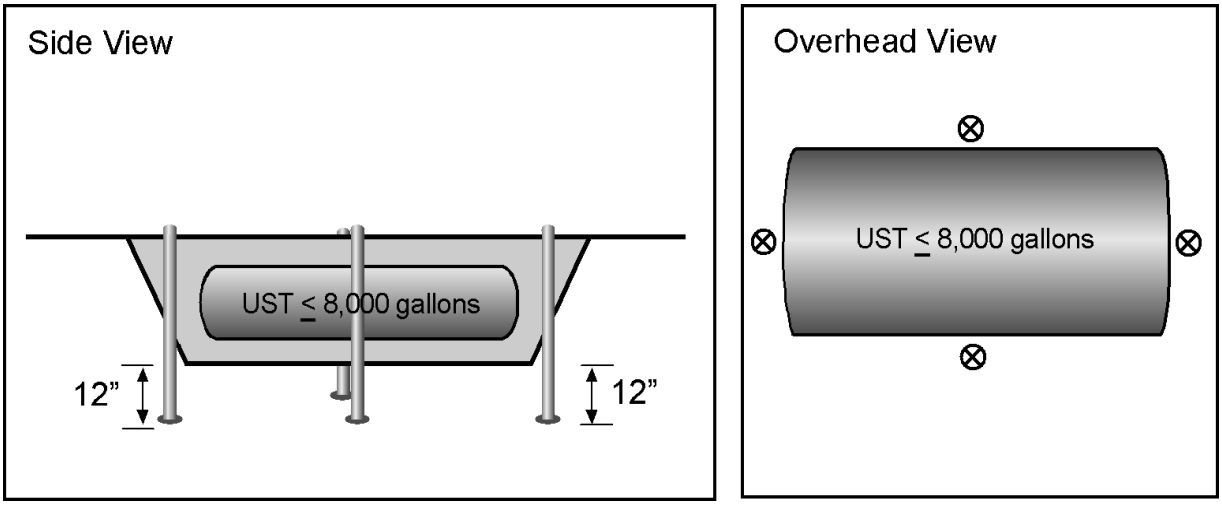

Figure 4-5(a). Soil Sampling for In-Place Closure of a Single Tank 8,000 Gallons or Less

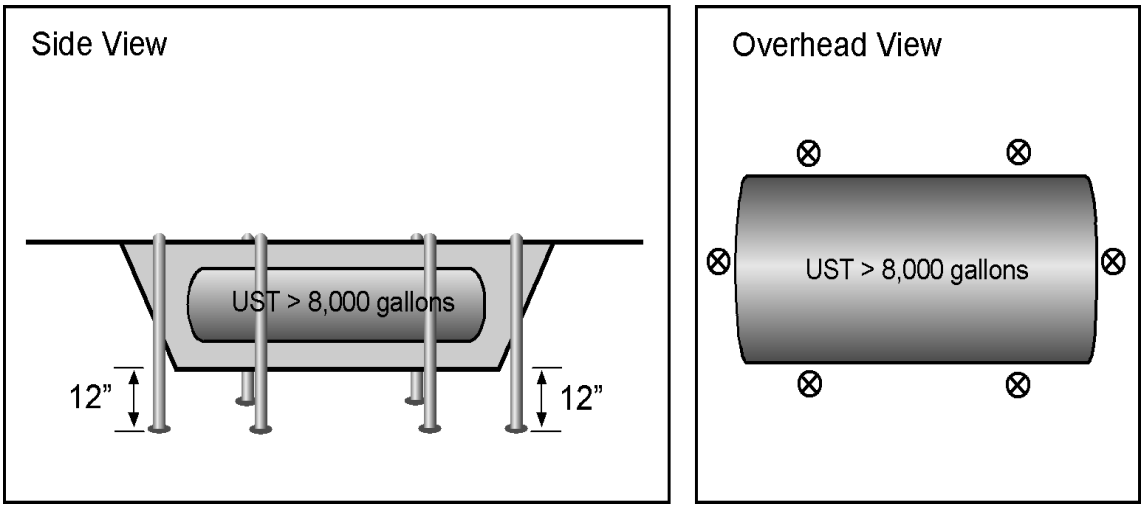

Figure 4-5(b). Soil Sampling for In-Place Closure of a Single Tank Greater Than 8,000 Gallons

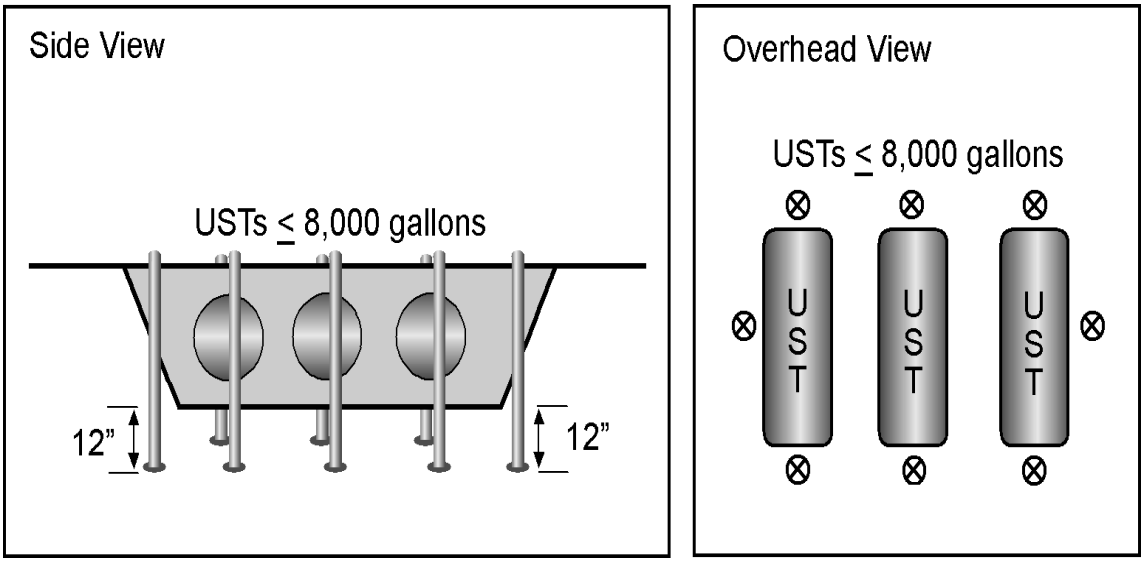

Figure 4-5(c). Soil Sampling for In-Place Closure of Multiple Tanks 8,000 Gallons or Less

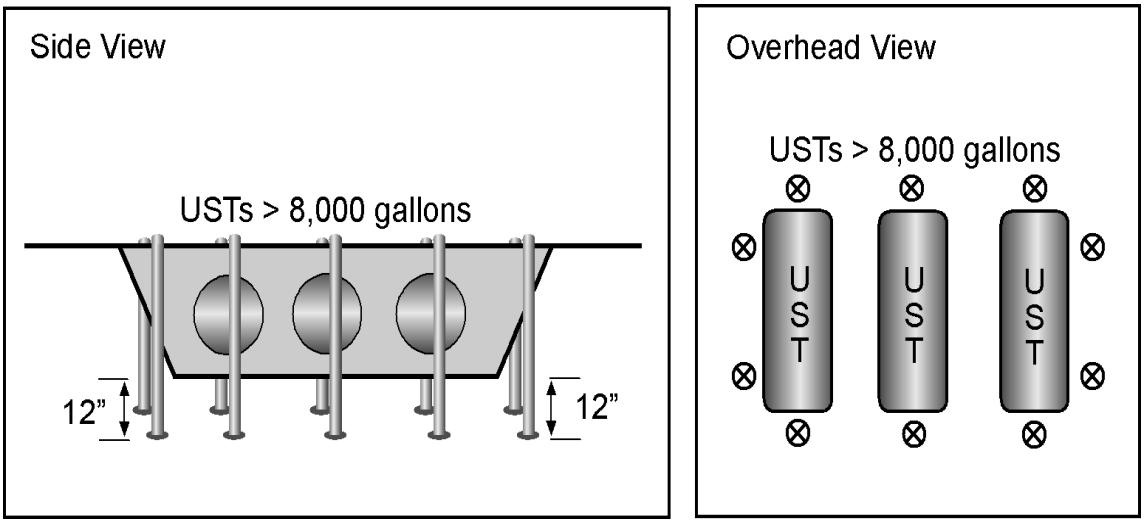

Figure 4-5(d). Soil Sampling for In-Place Closure of Multiple Tanks Greater Than 8,000 Gallons

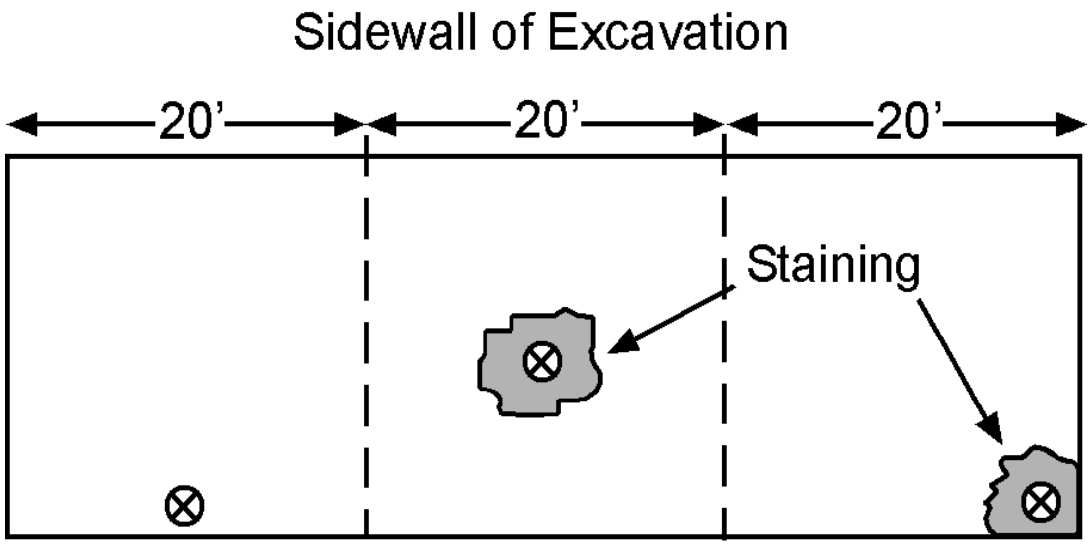

Figure 4-6(a). Sidewall Soil Sampling After Excavation of Contamination

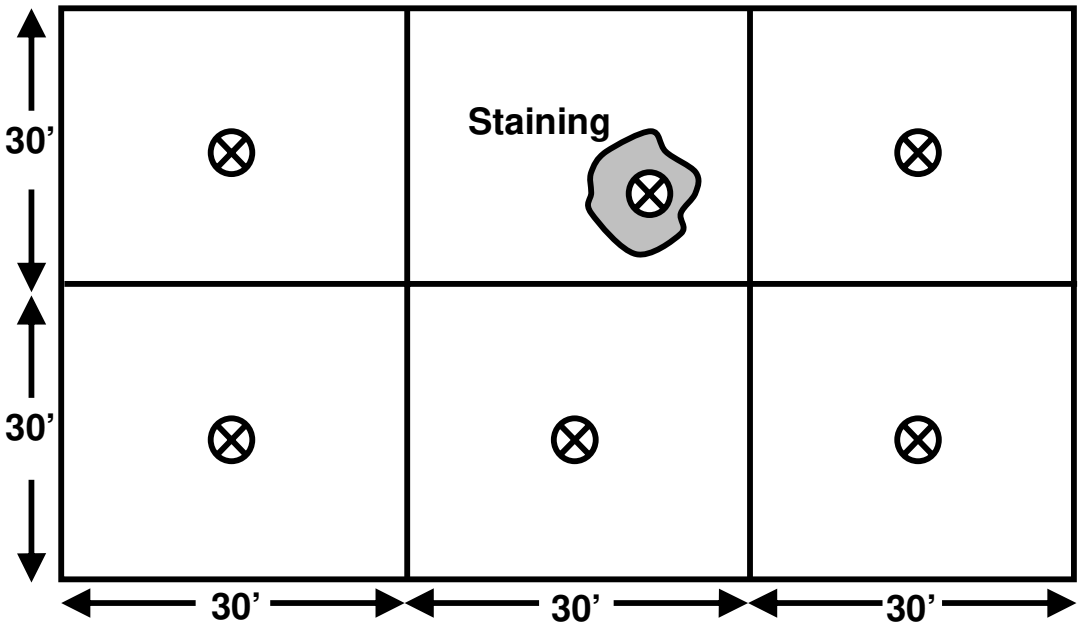

Figure 4-6(b). Floor Sampling After Excavation of Contamination.

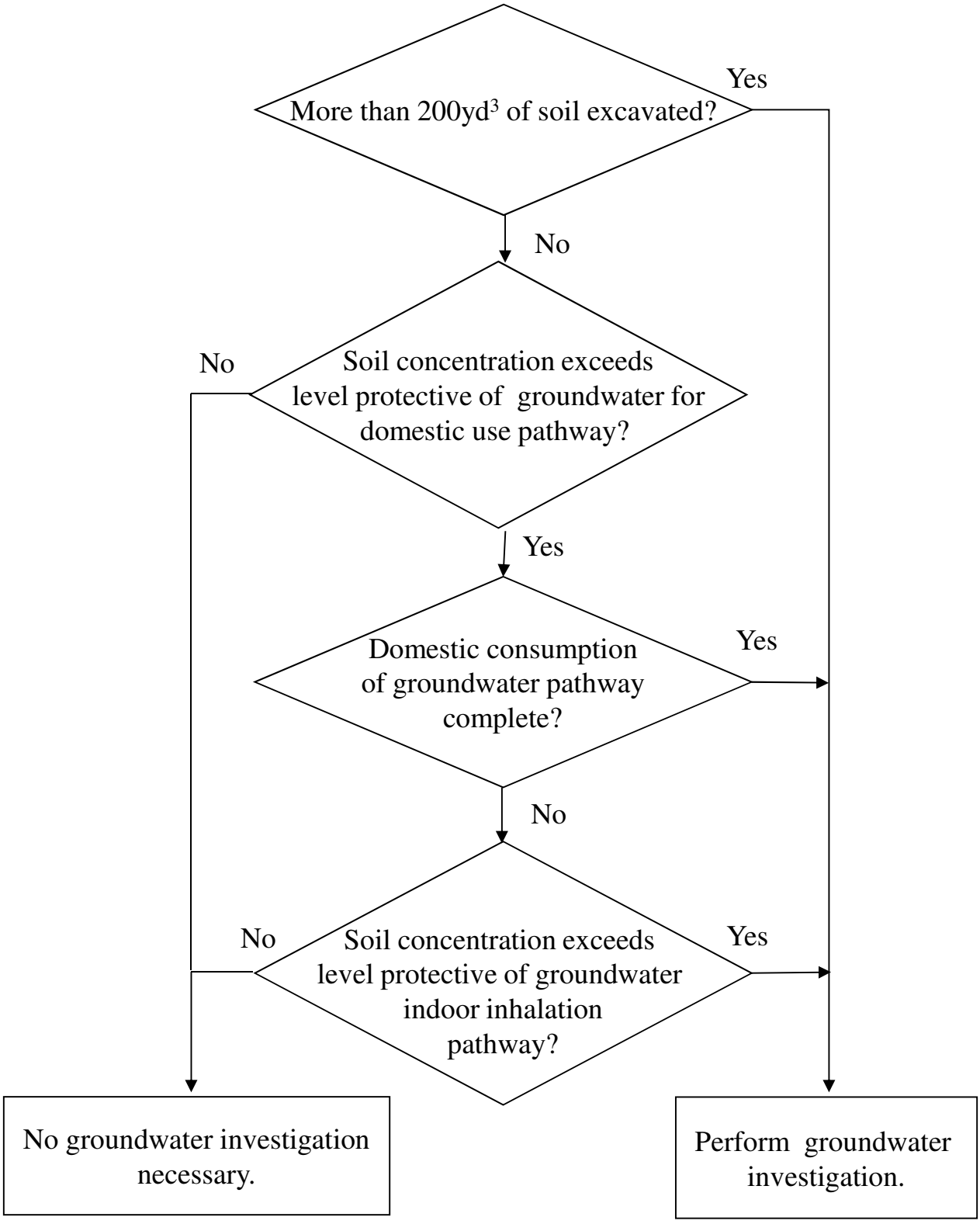

Figure 4-1: Flowchart to Determine Need for Groundwater Investigation During Tank Closure Activities.

Table 4-1
Soil Concentration Levels to Determine the Need for Groundwater Evaluation During Tank Closure

Chemicals	Domestic Consumption of Groundwater Pathway			
	Complete		Incomplete	
Benzene	5.61E-02		1.12E+01	
Toluene	2.98E+01	#	1.51E+04	#
Ethylbenzene	3.99E+01	#	5.89E+03	#
Xylenes (mixed)	6.34E+02	#	7.48E+02	#
Ethylene Dibromide (EDB)	4.73E-04		2.18E+00	
Ethylene Dichloride (EDC)	2.06E-02		3.54E+00	
Methyl-tert-butyl-ether (MTBE)	3.98E-01		5.62E+02	
Acenaphthene	1.74E+02		1.69E+06	
Anthracene	3.06E+03	#	1.00E+07	#
Benzo(a)anthracene	6.12E+00	#	6.55E+06	#
Benzo(a)pyrene	3.04E+01	#	5.66E+06	#
Benzo(b)fluoranthene	1.15E+01	#	1.40E+06	#
Benzo(k)fluoranthene	1.18E+02	#	1.72E+08	#
Chrysene	6.12E+02	#	4.84E+06	#
Dibenzo(a,h)anthracene	2.38E+00		5.57E+08	
Fluoranthene	2.61E+03	#	2.27E+08	#
Fluorene	2.11E+02	#	6.19E+06	#
Napthalene	3.25E-01	#	6.72E+02	#
Pyrene	1.50E+03	#	2.70E+08	#
TPH-GRO	1.81E+04		1.26E+04	
TPH-DRO	2.94E+09	#	1.22E+05	#
TPH-ORO	2.94E+09	#	NA	
>C6 - C8 (Aliphatics)	1.45E+04		8.37E+03	
>C8 - C10 (Aliphatics)	3.48E+03		1.73E+03	
>C10 - C12 (Aliphatics)	2.59E+04		8.61E+03	
>C12 - C16 (Aliphatics)	1.17E+06	#	3.92E+04	
>C16 - C35 (Aliphatics)	2.94E+09	#	NA	
>C8 - C10 (Aromatics)	4.12E+01		2.51E+03	
>C10 - C12 (Aromatics)	6.49E+01		1.26E+04	
>C12 - C16 (Aromatics)	1.29E+02		6.20E+04	
>C16 - C21 (Aromatics)	1.11E+03		NA	
>C21 - C35 (Aromatics)	8.79E+03		NA	
Tertiary-amyl-methyl-ether (TAME)	6.77E-01		1.68E+02	
Tertiary-butyl- alcohol (TBA)	5.58E-01		2.59E+04	
Ethyl-tert-butyl-ether (ETBE)	1.06E-01		7.28E+02	
Diisopropyl ether (DIPE)	4.12E+00		9.63E+02	
Ethanol	7.73E+02		1.80E+05	
Methanol	2.08E+01		7.39E+05	
Arsenic	NA		NA	
Barium	NA		NA	
Cadmium	NA		NA	
Chromium	NA		NA	
Lead	NA		NA	
Selenium	NA		NA	

Notes:
All concentrations are in mg/kg. #: Concentration greater than effective soil saturation concentration.
NA: Not Available

5.0
SITE CHARACTERIZATION AND OTHER DATA REQUIREMENTS FOR MRBCA PROCESS

5.1 INTRODUCTION

This section presents:

- An explanation of the data necessary to implement the MRBCA process for petroleum underground and above ground storage tank (UST/AST) sites,
- A brief discussion of the techniques used to collect the data, and
- A description of the manner in which the data should be documented and reported to MDNR.

The data discussed herein will typically be collected subsequent to the confirmation of a release as part of the initial and comprehensive site characterization efforts. The objective of the data collection effort is to ensure that data of sufficient quality and quantity are available to:

- Develop a site conceptual model,
- Compare maximum site concentrations with the default target levels (DTLs, see Table 3-1),
- Compare representative concentrations or, for surficial soil under residential use, maximum concentrations, with Tier 1 risk-based target levels (RBTLs, see Tables 7-1through 7-6(c)),
- Develop Tier 2 and Tier 3 site-specific target levels (SSTLs), if necessary,
- Compare the SSTLs with representative (or maximum, as discussed above) chemical of concern (COC) concentrations, and
- Develop a Corrective Action Plan (CAP), if necessary.

The risk assessment should be completed only after all relevant data has been collected and a site conceptual model has been developed.

To accomplish the above objectives, the following information is required:

- Chronology of site events,
- Nature, magnitude, and location of release (including identification of COCs),
- Site information (e.g., physical features, land use, etc.),
- Adjacent land use and receptor information,
- Vadose zone soil characteristics,
- Saturated zone and groundwater characteristics,
- Characteristics of nearby surface water bodies,
- Distribution of the COCs in soil,
- Distribution of the COCs in groundwater, and
- Information about corrective action measures conducted and are planned.

Note: Additional data beyond that discussed herein might be required to develop a Corrective Action Plan (CAP) or to complete a Tier 3 risk assessment. For instance, the collection of natural attenuation parameters or data from vapor extraction or pump and treat pilot tests might be required to design an active remediation system. Due to the variability in the type of data that might be needed, the collection of this type of data is not discussed here. Rather, requirements for and collection of such data will be determined on a site-specific basis.

5.2 CHRONOLOGY OF SITE EVENTS

As part of the MRBCA evaluation, the person undertaking the evaluation must carefully review all existing data and identify any data gaps.Only after all the necessary data have been collected and full site characterization is complete should the person undertaking the evaluation proceed with the development of target levels.

The first step in the MRBCA evaluation is to develop a comprehensive chronology of events related to the aforementioned activities. A chronology of events will help create a comprehensive picture of the activities conducted at the site and identify gaps in those activities. The chronology shall include information regarding events such as:

- The date tanks were installed, removed and/or upgraded,
- Whether any contaminated soil was excavated and disposed of off-site,
- Date(s) when monitoring wells were drilled, sampled and gauged,
- Date(s) when soil samples were collected, and
- Dates when remedial activities were conducted.

Note that the intent of this exercise is to develop a clear understanding of historic site activities as they may impact current and potential future risk. Development of the chronology is not the "end in itself," but rather a means to understand site conditions.

5.3 NATURE, MAGNITUDE, AND LOCATION OF RELEASE

Knowledge about the nature, location, and magnitude of a release(s) is necessary to (i) identify the soil and/or the groundwater source(s) at the site, and (ii) identify the COCs. The person performing the work shall collect as much of the following information as is available for each release that has occurred at the site:

- Location and date of the release,
- Quantity of the release,
- Type of product released, and
- Any interim corrective action measures already performed with respect to each release.

Release-related information can be obtained by a variety of means, including (i) reviewing inventory records, (ii) interviewing past and current on-site employees, and (iii) reviewing historic spill incident reports filed with MDNR.

5.3.1 Location and Date of Release

Identifying the location of a release helps define the soil and groundwater source area(s). Likely release locations at petroleum UST sites include (i) corroded or damaged tanks, (ii) piping, especially at pipe bends and joints, (iii) dispenser islands, and (iv) accidental releases while filling the USTs/ASTs. A release may occur within the surficial soil (0-3 feet below the ground surface (bgs)), subsurface soil (from 3 feet bgs to the water table), or, if the groundwater is shallow (less than about 15 feet bgs), below the water table.

Identifying the date of a release is necessary to identify the COCs, as discussed in Section 5.3.3 (the COCs are listed in Table 5-1). Based on the chronology, the entity performing the work shall review the operational history of the site to determine the location and date of the release(s). Often the exact location and date of the release will not be known. In such cases, soil and groundwater sampling (including field screening using a photoionization detector (PID) and visual observations) shall be used to identify the likely location and extent (vertical and horizontal) of the soil and groundwater sources. The exact number and location of samples to be collected will be determined on a case-by-case basis using professional judgement. Sampling plans must be approved by MDNR prior to implementation.

5.3.2 Quantity of Release

The MRBCA process does not necessarily require knowledge of the exact quantity of the released petroleum. Often this information is not known. However, having a general idea of the amount released can assist in evaluating the severity of soil and groundwater contamination and the extent of the residual source. Information regarding the amount released is typically based on inventory records.

5.3.3 Product Released and Chemicals of Concern

MDNR's Tanks Section regulates releases of "regulated substances" from USTs and ASTs used for the sale of petroleum products. "Regulated substances" are defined as "petroleum, including crude oil or any fraction thereof, which is liquid at standard conditions of temperature and pressure, sixty degrees Fahrenheit and fourteen and seven-tenths pounds per square inch absolute, respective." (Section 319.00 RSMo). This may include:

- Gasoline,
- Diesel/Light Fuel Oils,
- Jet Fuel,
- Kerosene, or
- Used Oil.

Knowing what was released can simplify the process of identifying relevant COCs.

Each of the products listed above is a mixture of numerous hydrocarbon compounds and additives whose physical and chemical properties and percent composition vary. The environmental behavior (mobility, persistence, and inter-media transport) of these products and any adverse environmental and human health effects depend on (i) the properties of the individual compounds, (ii) their concentration in the product, and (iii) their degradation by-products and analogous compounds. Table 5-2 presents the range and average weight percent of a few of the constituents of different products.

The MRBCA process focuses on a limited set of chemicals specific to various petroleum products that pose the greatest risks to human health and the environment. These are known as the **chemicals of concern (COCs)**. Table 5-1 lists the major products and the corresponding COCs for which the impacted soil and groundwater shall be sampled and for which target levels shall be developed. Figure 5-1 is a flowchart that can be used to identify COCs. Depending on the petroleum product released, soil and groundwater samples at a site must be sampled for the COCs indicated in Figure 5-1 using the analytical methods listed in Table 5-1. Excluding COCs or using analytical methods other than those specified in Table 5-1 is allowed only with prior approval of MDNR. For releases other than gasoline, samples with detectable levels of total petroleum hydrocarbon-diesel range organic (TPH-DRO) or total petroleum hydrocarbon-oil range organic (TPH-ORO) shall also be analyzed for the polynuclear aromatic hydrocarbons (PAHs) listed on Table 5-1. The intent is to identify site-related PAHs, hence additional sampling may be necessary to distinguish between site-related and background PAHs.

If the release at a site can be identified as consisting of a single product based on release reports, free product analysis, or location of impacts (e.g. the bottom of a particular product tank), COCs for that product only need be analyzed. If the product spilled or released cannot be conclusively identified based on these methods, then COCs corresponding to all products known or suspected to have been stored at the site shall be included in the initial analysis. Once the product or the COCs have been identified, the list of parameters for which samples are analyzed may be modified accordingly.

If data collected in the past does not include all the suspected COCs at a site, additional sampling might be necessary to quantitatively evaluate the missing COCs. The need to do so will be determined on a case-by-case basis.

5.3.4 Interim Corrective Actions

Typical interim corrective actions include the excavation and off-site disposal of contaminated soil, removal of free product, soil vapor extraction, and pump and treat. Interim corrective actions performed at a site could have removed all or part of the product spilled or released. Therefore, soil and groundwater data collected prior to the completion of such activities might not be representative of current conditions and shall not be used in the site risk assessment. At such sites, additional soil and groundwater concentration data representative of current conditions shall be collected after the completion of the interim corrective action. Data collected before completion of interim corrective action may be used to determine where additional data shall be collected.

5.4 SITE INFORMATION

The following information is necessary to complete the MRBCA evaluation:

- An area map
- A land use map
- A site map,
- An understanding of ground surface conditions,
- Location of utilities on and adjacent to the site,
- On-site and nearby off-site groundwater use, and
- Regional hydrogeology and aquifer characteristics.

A brief discussion of each of the above items is presented below. Note that relevant site information can be obtained by various means, including (i) a site visit, (ii) review of engineering drawings showing the layout of the site, (iii) review of regional information, and (iv) review of files at MDNR related to the site or adjacent sites.

5.4.1 Required Maps

An area map shall be prepared using a United States Geological Survey (USGS) 7 ½ minute scale topographic map as a base. The site location should be centered on the topographic map and clearly marked.

A land use map shall be prepared documenting the results of the Land Use Survey. The map shall identify all structures and roads within a 500 foot radius from the tank system (refer to Subsection 6.1.1.1 for information on how to identify and describe land uses on the map).

A detailed map of the tank site showing property boundaries and the layout of past and current site features such as USTs, ASTs, piping, dispenser islands, paved and unpaved areas, canopy, station building, etc. shall be prepared. The map shall also show the locations of (i) on-site monitoring wells (including those that have been abandoned, lost or destroyed), (ii) water wells (public and private), (iii) soil borings, (iv) soil vapor extraction wells, (v) soil excavation areas, and (vi) area of release (refer to Section 5.8). As appropriate, multiple maps showing these features may be prepared. Site maps shall be made to scale, with a bar scale and a north arrow. MDNR will reject maps that are not to scale or without a north arrow.

5.4.2 Ground Surface Conditions

Determine the portion of the site that is paved, unpaved, or landscaped. Note the type, extent, and general condition of the pavement, and describe the unpaved areas (e.g., vegetated, gravel, bare soil, etc.). Determine the direction in which the surface is sloping and note relevant topographic site features (e.g., swales, drainage ditches, etc.).

5.4.3 Location of Utilities On and Adjacent to the Site

Due to the potential for preferential flow of impacted groundwater and vapors into underground utility lines/conduits, a thorough assessment of potential and actual migration and impact of COCs to underground utilities must be performed. Utilities include, but are not limited to, phone lines, water lines, sanitary sewers, storm sewers, and natural gas lines. A combination of site observations, knowledge of buried utilities, and discussions with utility representatives and the site owner shall be used to determine the locations of site utilities. At a minimum, perform the following:

- Locate all underground utility lines and conduits within the area of known or likely soil and groundwater impact, both on-site and off-site, where the release may have migrated or may migrate in the future.
- Determine the direction of flow in the utilities (water, storm water, and sewage).
- Identify the utility lines/conduits on a base map that also shows the extent and thickness of free product, if any, and soil and groundwater contamination.
- Determine depth of the utility lines/conduits relative to the depth of groundwater. Seasonal fluctuations of the groundwater levels (relative to the depth of utilities) shall be carefully evaluated. Where such would assist in the evaluation and understanding of site conditions, a cross-sectional diagram shall be provided illustrating the depth to groundwater and the locations and depths of the utility lines/conduits. At a minimum, a cross-section diagram would be required at sites where deeper water bearing zones are used for drinking water and where utilities may be preferential pathways.
- Determine the types of materials used for lines/conduits (i.e., PVC, terra-cotta, concrete, steel, etc.) and backfill around the utilities.
- Determine any past impacts to utilities and whether any complaints have been previously filed with MDNR or the property owner.
- As appropriate, sample the utilities and vaults using either an explosimeter, PID, or organic vapor monitor (OVM) or by taking air samples. If explosive conditions are encountered, immediately inform the local fire department and MDNR (contact MDNR at (573) 634-2436).
- Where a utility is threatened, or where the possibility of an explosion exists, appropriate measures to eliminate fire, explosive, and vapor hazards must be undertaken immediately.

5.4.4 On-site Groundwater Use

The current and former site owners and operators should be interviewed to determine whether a water well is/was located on site. If a water well is identified, construction details of the well shall be obtained to the extent such are available. At a minimum, the total depth of the well, screen (if present) interval, and use of water from the well shall be determined. If an identified well is not currently in use or likely to be used in the future, it shall be properly abandoned in accordance with MDNR requirements, unless it is to be used for future sampling as part of a corrective action plan for the site. In addition to water wells, dewatering wells on or adjacent to the facility shall also be identified.

5.4.5 Regional Hydrogeology and Aquifer Characteristics

Published literature, especially USGS publications and United States Department of Agriculture (USDA) soil surveys, and reports for any investigations conducted at adjacent or nearby release sites, shall be reviewed to determine regional hydrogeology, soil types, and aquifer characteristics. This evaluation shall be used to determine the type and depth of aquifers in the area and whether they are confined, semi-confined, or unconfined. General aquifer characteristics such as yield and total dissolved solids will help determine whether the groundwater ingestion exposure pathway is a concern. Regional information will assist the entity conducting the work to better understand site-specific soil and groundwater conditions.

Two valuable sources of regional hydrogeology and aquifer characteristic information are the Well Information Management System, which contains all records of known wells in Missouri and is available at http://dnr.mo.gov/mowells/publicLanding.do, and Center for Applied Research and Environmental Systems or "CARES" maps, available at http://ims.missouri.edu/moims/step1.aoi/countylist.asp. .

The review discussed above shall also locate surface water bodies (e.g., creeks, lakes, rivers, etc.), seeps, and springs within 500 feet of the site (unless MDNR requires a different distance based on site conditions) that could be or are affected by the site release. If a surface water body is identified and it is determined that it may be impacted by site-specific COCs, collect information regarding the type (perennial vs. intermittent), flow rate, flow direction, depth, width, and use of the surface water body. The water body must be identified on the area map discussed at 5.4.1. In karst areas, MDNR may require that the minimum search area radius be increased and the identification of springs, seeps, sink holes, and other karst features be included.

5.5 ON-SITE AND OFF-SITE LAND USE AND RECEPTOR INFORMATION

Land use information is used to identify the (i) location and type of receptors, (ii) routes of exposure by which the receptors might be exposed to the COCs, and (iii) presence of any activity and use limitations (AULs) pertaining to the site. This information is critical in developing a site exposure model as discussed in Section 6.1. The following information shall be collected:

- Current land use,
- Potential future land use,
- Local ordinances and restrictions that affect land use and/or groundwater use,
- Water well survey, and
- Ecological receptor survey.

A land use and receptor survey covering a radius of 500 feet from the area of release will generally be adequate. At sites where the plume might be much longer due to the magnitude of the spill or other site-specific conditions, MDNR may require that the minimum survey radius be increased and will require submittal of a land use map covering the entire impacted and potentially impacted area.

5.5.1 Water Well Survey

A water well survey shall be conducted to locate all public water supply wells within an approximately one-mile radius of the site and all private water wells within an approximately quarter-mile radius of the site. Information sources include the USGS, the Missouri Environmental Geology Atlas (available from MDNR's Missouri Geological Survey), water system operators, and interviews with local residents. In areas where private water use wells are likely, MDNR may require that a door-to-door survey of businesses and residents within a quarter-mile radius of the site be conducted. To the extent such information is available, well characteristics including age, depth to water and total well depth, water use, screen (if present) interval, construction, depth of casing(s), and mode of operation (continuous vs. intermittent) shall be documented.

5.5.2 Ecological Receptor Survey

Ecological receptors include specific species and general populations of flora and fauna and their habitats, including, but not limited to, wetlands, surface water bodies, sensitive habitats, and endangered species. The checklist at Attachment A of this section must be completed for each site, except those where initial sampling indicates concentrations of COCs are below the DTLs and the site poses no obvious threat to ecological receptors. If the answer to any of the questions on the checklist at Attachment A is yes, then the Attachment B checklist must be completed. Completion of either checklist might require that the area within an approximately 500-foot radius of the site be visually surveyed for specific ecological receptor criteria as identified on the checklists. MDNR will require that such a survey be conducted if the checklists cannot be completed based on existing information. For any site where ecological receptors might be affected by contamination from a site being evaluated under this guidance, as determined by completion of the checklists in Attachments A and B, consultation with MDNR will be required. Refer to Section 6.6 for further information regarding ecological receptor evaluations.

5.6 VADOSE ZONE SOIL CHARACTERISTICS

Vadose zone soil is the media through which COCs migrate to groundwater and vapors move upward to the ambient air or into an enclosed space. The following vadose zone parameters and their variability across the impacted area significantly affect the movement of chemicals through vadose zone soil:

- Thickness of vadose zone and depth to groundwater,
- Porosity,
- Water content,
- Fractional organic carbon content, and
- Bulk density.

In developing the DTLs and Tier 1 RBTLs, MDNR assigned conservative values to these parameters as shown in Table B-4. For Tier 2 and Tier 3 risk assessments, these parameters may be assigned site-specific values based on data collected from the site.

Please note: When collecting site-specific geotechnical data (i.e., volumetric water content, fractional organic carbon, bulk density, and porosity), careful consideration must be given to the location of contaminants relative to receptors and the effect of the specific geotechnical parameter on transport of the contaminant to a receptor. For instance, to develop SSTLs for the vapor intrusion pathway, geotechnical data from the soil zone between the area of impact and the receptor (e.g., building foundation) is needed to properly assess the degree to which volumetric water content and fractional organic carbon impede the upward transport of vapors. However, to develop SSTLs for the leaching pathways, the geotechnical data of most relevance are from the zone below the area of soil impact. These types of considerations must be kept in mind when collecting and using geotechnical soil data.

In the event that circumstances at a site are such that the geotechnical properties discussed below cannot be determined because of sampling limitations, the evaluator shall use appropriate, justifiable literature values. Where such literature values cannot be found or do not exist, the evaluator shall contact MDNR's Tanks Section.

5.6.1 Thickness of Vadose Zone and Depth to Groundwater

The thickness of the vadose zone can be determined from boring logs and is representative of the distance from the ground surface to the top of the water table, not including the thickness of the capillary fringe. Depth to groundwater is used in estimating the vapor emissions from groundwater and to determine the vadose zone dilution attenuation factor.
Where the water table fluctuates considerably, available data shall be evaluated to determine whether the fluctuations are seasonal or represent a consistent upward or downward regional trend. For sites with seasonal fluctuations, average thickness of the vadose zone (as determined by groundwater elevation measurements) must be used in developing Tier 2 SSTLs. At sites with a consistent upward or downward water level trend, the most recent data will be used to estimate the depth to groundwater.

Generally, collection of samples for the four parameters discussed below will require the advancement of more than one boring or probe, depending on site conditions and recovery volumes. Ultimately the number of borings or probes advanced to obtain adequate samples for these parameters will be a site-specific decision of the driller and environmental consultant based on professional experience and judgment. Boring logs must be detailed, accurate, and carefully reviewed. Each soil type must be identified and geotechnical characteristics for that soil type must be determined.

Note that in situations where undisturbed samples cannot practically be collected but disturbed samples can be, samples should be collected for those parameters not requiring an undisturbed sample (i.e., fractional organic carbon, gravimetric water content, and particle density [a value required for determining porosity]).

5.6.2 Dry Bulk Density (g/cc)

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

Dry bulk density is estimated using the American Society for Testing and Materials (ASTM) Method D2937-94, "Standard Test Method for Density of Soil in Place by the Drive-Cylinder Method."

5.6.3 Porosity (cc/cc-soil)

Porosity is the ratio of the volume of voids to the volume of the soil sample. Many laboratories use dry bulk density and specific gravity to calculate porosity using the following:

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

where,

n = porosity (cc/cc)
ρ_b = dry bulk density (g/cc)
ρ_s = specific gravity or particle density (g/cc).

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

The "Standard Test Method for Specific Gravity of Soil," ASTM Method D854, may be used to determine specific gravity. If specific gravity or particle density is not available, then 2.65 g/cc can be assumed for most mineral soils. Note, however, that use of this value must be justified.

If a site-specific porosity value cannot be determined, literature values consistent with the site lithology may be used, provided the source(s) of the value(s) is cited and appropriately justified. Where the total and effective porosities differ, the effective porosity value must be used.

5.6.4 Volumetric Water Content/Moisture Content (cc/cc)

Volumetric water content is the ratio of the volume of water to the volume of soil. ASTM Method D2216-92, "Standard Test Method for Laboratory Determination of Water [Moisture] Content of Soil and Rock," is a gravimetric oven drying method that may be used to measure the water content of vadose zone soils. However, the water content value used in most models is the volumetric water content. Hence, if a gravimetric method is used to measure water content, the following conversion equation should be used to obtain the volumetric value:

$$\theta_{wv} = \theta_{wg} \times \frac{\rho_b}{\rho_l} \quad (5\text{-}2)$$

where,

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

Multiple samples from across the site and at varying depths must be analyzed for water content to estimate a representative water content value for the vadose zone. To accomplish this, each soil sample analyzed for one or more COCs must be analyzed for water content; since the lab must provide COC concentrations on a dry weight basis, water content data are readily available for these samples. In addition, water content values representative of each of the lithologic units that comprise the vadose zone must be determined.

Water content data should be carefully reviewed prior to being used to calculate Tier 2 SSTLs. The VWC of a sample cannot exceed the porosity of that same sample or another sample collected from the same soil. If the laboratory report indicates this to be the case, the consultant should make inquiry of the lab to determine which value is in error.

Refer to Subsection 5.8 for developing a sampling plan. Because VWC varies over time most significantly in surficial soil, VWC data should not be collected from surficial soil (i.e., 0 – 3') except when the foundation of an existing building is less than 3' deep.

5.6.5 Fractional Organic Carbon Content in Soil (g-C/g-soil)

Fractional organic carbon (FOC) content is the weight of organic carbon in the soil divided by the weight of the soil and is expressed either as a ratio or as a percent. FOC must be determined using soil samples not impacted by petroleum or other anthropogenic chemicals. Therefore, FOC samples must be collected from soil borings or probe holes away from areas of contamination. Prior to collecting samples for FOC analysis, a PID reading should be taken to confirm that the sample has not been impacted by petroleum products or other anthropogenic contaminants. As an alternative, lab data from the same boring or a nearby boring may be used to confirm that contamination is not present.

Unless drinking water or vapor intrusion risks are being evaluated at a point of exposure outside the area of impact and the saturated zone has a different type of soil than the vadose zone, no soil samples from the saturated zone need be collected for FOC analysis.

Data from multiple borings or probe holes from non-impacted locations are required to accurately determine FOC for the site. In addition, multiple samples from each boring or probe hole may be required if there are different types of soils in the vadose zone.

Prior to shipping samples to the lab for analysis, subsamples of the same soil type collected from different borings or probes may be combined into a single composite sample for laboratory analysis. For instance, if three different soil types underlie a site and a sample of each is collected from four different borings, the samples from each soil type may be combined into a single composite sample for that soil type. This would result in three samples for FOC analysis rather than twelve.

Fractional organic carbon content may be estimated using the Walkley Black Method (Page et al., 1982) or the method outlined in *Determination of Total Organic Carbon in Sediment (Lloyd Kahn Method)*, July 27, 1988, a copy of which is found at the end of this section of the guidance, or a similar method. However, some labs may not be familiar with these methods. If the lab is not equipped to conduct either of these methods, an alternative, though less preferred, method is ASTM Method 2974 (*Standard Test Method for Moisture, Ash, and Organic Matter of Peat and Other Organic Soils*). Method 2974 measures the organic matter content of a sample. When using the method, the result must be divided by 1.724 to get fractional organic carbon content. If the laboratory results are reported as a percent, fractional organic carbon content may be obtained by dividing by 100. The FOC analytical method must be identified in the site characterization report submitted to MDNR.

FOC analytical data should be carefully reviewed prior to being used to calculate Tier 2 SSTLs and prior to submission to MDNR. Data indicating unexpectedly high FOC should be verified through discussion with the analytical laboratory and, if warranted, via collection and analysis of additional samples.

5.7 SATURATED ZONE CHARACTERISTICS

COCs that reach the water table primarily travel horizontally in the saturated zone. Vertical transport is also possible when a vertical gradient exists between shallow and deeper saturated zones. Saturated zone characteristics that determine the travel time for the COCs as well as the travel direction include:

- Horizontal hydraulic conductivity,
- Hydraulic gradients (magnitude and direction),
- Saturated zone soil characteristics (fractional organic carbon content, porosity, and bulk density), and
- Occurrence and rate of biodegradation.

Of the four characteristics mentioned above, the most important aquifer properties are horizontal hydraulic conductivity and hydraulic gradient. Each of these is discussed below, along with a brief discussion regarding the capillary fringe.

Note that quantification of the above characteristics will be required only at sites where it is necessary to quantify the movement of water or the COCs by using a model. If a quantitative evaluation is not necessary, a qualitative understanding of these parameters is sufficient.

5.7.1 Hydraulic Conductivity (cm/sec)

Hydraulic conductivity is the discharge of water per unit area per unit hydraulic gradient in a subsurface formation. Reliable estimates of site-specific hydraulic conductivity can be obtained by pump tests or slug tests. In the absence of these tests, literature values corresponding to the type of soil in the saturated zone may be used. When a literature value is used, adequate reference and justification for the value chosen must be provided. When using literature values, all predominant soil types composing the saturated zone must be considered. Hydraulic conductivity may also be estimated based on the grain size distribution of the porous formation.

5.7.2 Hydraulic Gradient (cm/cm)

The magnitude and direction of the hydraulic gradient is estimated by comparing water levels measured in monitoring wells across a site. A contour map shall be prepared, either manually or using a computer program, using field measured water level data. These contour maps can be used to estimate both the direction and magnitude of the hydraulic gradient. When drawing the contour maps, care shall be taken to ensure that measurements from monitoring wells screened in the same interval or hydrologic unit are used. For sites where wells are screened in multiple zones, a contour map for each zone shall be developed. For sites that have seasonal variation in hydraulic gradient and/or predominant flow direction, estimate the average hydraulic gradient for each season and each flow direction.

At sites where a "deeper" groundwater zone is used as a water supply, vertical gradients must be determined by comparing water levels in adjacent wells screened in different intervals. MDNR will consider exceptions to this requirement on a site-specific basis.

5.7.3 Thickness of Capillary Fringe (cm)

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

5.7.4 Saturated Zone Soil Characteristics

The saturated zone soil characteristics include fractional organic carbon content, porosity, and bulk density. These parameters are required to estimate the retardation factor that "slows" the movement of chemicals within the saturated zone and are also useful when estimating future concentrations using models that include a finite source and/or biodecay. Laboratory methods to measure these parameters are discussed in Section 5.6.

5.7.5 Occurrence and Rate of Biodegradation

By measuring several indicators (chemical concentrations, geo-chemical indicators, electron acceptors, microorganisms, carbon dioxide, etc.), the occurrence of natural attenuation can be measured at a site. These indicators can be broadly classified into three groups: (i) primary, (ii) secondary, and (iii) tertiary lines of evidence. The collection of biodegradation data need not occur at every site. Generally, this data will be required only when biodegradation is a principal element of the RMP. Data collected under each line of evidence is used to qualitatively evaluate the occurrence of biodegradation.

- The primary line of evidence is developed by demonstrating that reductions in chemical concentrations are occurring at a site via the evaluation of COC concentrations in groundwater. The primary line of evidence is best determined by (i) plotting concentrations of COCs as a function of distance along the plume center line, (ii) plotting concentrations of COCs in each well as a function of time, and (iii) comparing COC concentration contour maps at various times.

- The secondary line of evidence involves measuring geo-chemical indicators including (i) dissolved oxygen, (ii) dissolved nitrates, (iii) manganese, (iv) ferrous iron, (v) sulfate, and (vi) methane. These indicators shall be measured in at least three wells located along the plume flow line. The wells must be located to represent conditions at (i) a background or upgradient location, (ii) an area within the plume near the source, and (iii) an area within the plume downgradient of the source. Developing a secondary line of evidence is necessary when the primary line of evidence is inconclusive, or when such information is necessary to design a remedial system (e.g., the addition of oxygen).

- Developing a tertiary line of evidence involves identifying and quantifying microorganisms within and near the plume via the performance of microbiological studies. A tertiary line of evidence is seldom developed at petroleum hydrocarbon impacted sites. MDNR has found that, in most cases, microbial populations at sites having petroleum contamination are adequate.

The commonly used methods to estimate biodegradation include (i) mass balance analysis for expanding, stable, or shrinking plumes and (ii) plume concentration vs. distance plots.

At most UST/AST sites, the development of secondary and tertiary lines of evidence is usually not necessary. However, at most sites, groundwater sampling data should be plotted to evaluate temporal trends. These trends can be used to determine whether the plume is expanding, stable, or decreasing. MDNR will require that the groundwater plume be stable or decreasing prior to issuing a No Further Action (NFA).

5.8 DISTRIBUTION OF COCs IN SOIL

The objective of soil characterization is to (i) delineate the extent of site-related COCs, (ii) compare representative concentrations, or, for surficial soil at a residential site, maximum concentrations, for each complete pathway to the target levels, and (iii) define the area of release in the event that fate and transport modeling is necessary.

Within the MRBCA program, distinction is made between surficial soil and subsurface soil. Surficial soil is defined as soil extending from the surface to 3 feet below the ground surface (bgs). Subsurface soil is defined as soil that extends from 3 ft bgs to the top of the water table. A key difference between surface and subsurface soil is that, for surficial soil, the direct contact pathway (ingestion, dermal contact, and inhalation of vapors and particulates) is considered complete for both the residential and non-residential receptors. For the subsurface soil, this pathway is considered incomplete for the subsurface soil except for the construction worker who may be involved in excavation activities below the surficial zone and hence come in direct contact with subsurface soil. In fact, for the construction worker, no distinction is made between the surface and subsurface soil.

Because of the differences in exposure pathways for surface and subsurface soils, an adequate number of soil samples from each zone has to be collected to meet the soil characterization objectives listed above. Surficial soil (as well as subsurface soil) may include fill material - the distinction between surface and subsurface soil is one of depth rather than composition.
Note that, when volatile organic compounds (VOCs) are COCs at a site, soil samples for VOC analysis must be collected and analyzed in accordance with SW-846 Method 5035.

The following discussion is intended to assist the person conducting the work in determining where soil samples shall be collected.

5.8.1 Delineation Criteria, Area of Release, and Point of Release

The underlying basis of delineation is that chemical impacts at a site should be delineated to levels that are protective of human health and the environment. To the extent that COC concentrations protective of human health and the environment depend on the complete routes of exposure, the delineation criteria depend on land use. Because delineation is necessary to develop risk-based target levels, some iteration in delineation sampling may be necessary.

The delineation criteria are the lowest MRBCA Tier 1 RBTLs for each media. For soils these levels depend on the land use (residential vs. non-residential). Note that target levels for surface soils (0-3 ft bgs) are different than target levels for subsurface soils (>3 ft bgs). Note also that, when delineation criteria are lower than the Required Reporting Limits (RRLs) listed in Table 5-3, the RRLs or, if lower, the detection limits of the laboratory conducting the analysis, shall be considered as the delineation criteria.

As applicable, the Tier 1 values in Table 7-1, 7-2, 7-4(a), 7-4(b), 7-4(c), or 3-1 may be used as delineation criteria. If the Tier 1 target levels change, MDNR may adjust the delineation criteria.

To determine a site's applicable delineation criteria, the following steps are necessary:

Step 1: Develop a land use map and determine what land uses (residential or non-residential) apply to on and off-site properties (refer to Sections 5.5.1 and 5.5.2, and Figure 5-2).

Step 2: Determine whether the groundwater ingestion pathway is complete (under both current and reasonably anticipated future use of the property) for the zones where groundwater is or will be impacted (refer to Section 6.3).

Step 3: Based on the above steps, select soil delineation levels for the COCs listed in Table 5-1 that are applicable to the site.

As discussed in Section 5.3.3, COCs depend on the product released. While, typically benzene, methyl tert-butyl ether (MTBE), and total petroleum hydrocarbon-gasoline range organic (TPH-GRO) will be the primary drivers, delineation is required for all applicable COCs.

A few examples for determining delineation criteria are presented below:

- If the land use both on-site and off-site is non-residential, use non-residential delineation criteria.
- If the land use both on-site and off-site is residential, use residential delineation.
- If either the on-site or the adjacent off-site land use is residential, use residential delineation criteria.

Once the delineation criteria have been established, the number of samples to be collected horizontally and vertically depends on the area of release and the point of release. These terms are defined below:

Area of Release: The vadose zone area through which petroleum product migrated from the point of release to the capillary fringe and the water table below. In the area of release, COC concentrations are elevated in the vadose zone below the point of release and laterally where the petroleum migrated through the soil.

Point of Release: This is the specific location within the area of release at which petroleum product was released to the environment. Typical points of release include holes in USTs, pipe joints or connections, pump island connections, AST spill drains, and fill ports.

Professional judgment is frequently required in determining the point of release.

5.8.2 Determining Area of Release

Step 1: Initially, review site information and site history to make reasonable judgments about the area(s) of release. Within each area of release, identify the point of release and locate a boring at this point. If the point of release within an area cannot be determined, locate the boring near the center of the release area. If the point of release is an active tank or piping run, locating a boring immediately adjacent to the tank or piping might not be practical for safety reasons. In such cases, locate the point of release boring as close to the tank or piping run as is safely possible[1].

Step 2: From the point of release identified in Step 1, step out 25 feet in four opposing directions (e.g., south, north, east, west or southeast, northwest, northeast, southwest, etc.) and install 4 more borings. While installing each boring, screen soil samples continuously with a PID to determine whether or not the boring is within the area of release. This step will require professional judgment of field screening results (e.g., PID readings, evidence of soil staining, perception of odors, etc). If the results of field screening indicate that one or more of the borings are still within the area of release, step out in the same direction another 25 feet from the point of release boring (i.e. it will not be necessary to step out in all directions) and install another boring, screening the core samples as the boring is advanced. Continue to step out in this manner until borings are outside the release area in all directions. Using this protocol, some borings will be within the area of release and some will not. Note that, depending on the distance from the point of release to the edge of the area of release, additional borings might be needed to provide data for the areas between the step-out borings. The number of soil samples collected in each boring shall be determined as follows.

<u>Soil Sampling at the Point of Release</u>

To determine the vertical extent of COCs at each boring or probe advanced at a point of release, four soil samples shall be collected for laboratory analysis as follows:

- In each boring or probe, continuously conduct field screening (using a PID for releases of gasoline and PID and sight and smell for heavier petroleum products). Continue field screening, below the water table if necessary, until PID readings at two consecutive intervals are at or below background levels.
- Collect one soil sample from the 0 to 3' interval (at the point of release, this sample is collected regardless of field screening results).
- Collect one sample from the interval between 3' and the top of the water table, choosing the sample from the interval where field screening indicates COC levels are at their maximum.
- Collect one sample at the interface of the vadose and saturated zones i.e., within the capillary fringe.
- Collect one sample below the water table from the interval where field screening indicates COC levels are at their maximum.

[1] All borings and probe holes 10 feet deep or deeper must be properly plugged in accordance with 10 CSR 23-4.

At sites where bedrock is encountered before reaching the water table, collect a sample at the soil/bedrock interface.

Borings Away from Point of Release but within Area of Release

Borings or probes advanced away from the point of release but within the area of release should be sampled as discussed above for the point of release, except that a sample need not be collected from the 0 to 3' interval unless field screening indicates COC levels are elevated in the interval.

Borings Outside the Area of Release

Soil samples for laboratory analysis will be collected from soil borings and borings advanced for monitoring wells outside of the area of release as follows:

- Collect one sample at the interface of the vadose and saturated zones.
- Collect one sample below the water table from the interval where field screening indicates COC levels are at their maximum.
- Collect one sample from the interval between 3' and the top of the water table only if field screening indicates that elevated COC levels exist in the interval (contamination detected in this zone generally means the boring remains within an area of release).

At sites where bedrock is encountered before reaching the water table, collect a sample at the soil/bedrock interface.

5.8.3 Sampling for Polynuclear Aromatic Hydrocarbons (PAHs) in Soil

As indicated in Table 5-1, analysis of all soil samples for naphthalene is required for all petroleum types, including gasoline; however, analysis for other PAHs is only required when it is known that diesel fuel, jet fuel, kerosene, heavy fuel oils, or waste oil were released, or when the type of petroleum released is unknown.

The following are required for all PAHs except naphthalene:

- PAH analysis for all surficial soil samples in which TPH-DRO or TPH-ORO is detected at a concentration above the laboratory detection limit or the RRL, whichever is lower.

- PAH analysis for a minimum of 25%, or two samples, whichever is greater, of all subsurface soil samples in which TPH-DRO or TPH-ORO is detected at a concentration above the laboratory detection limit or the RRL, whichever is lower. The samples that contain the highest concentrations of TPH-DRO or TPH-ORO must be the ones selected for PAH analysis, except that two samples from the same boring shall not be used.

- PAH analysis for all samples containing TPH-DRO or TPH-ORO at a concentration above the detection limit or RRL, whichever is lower, and which will be used to assess construction worker exposures.

5.8.4 Ethylene Dibromide (EDB) and Ethylene Dichloride (EDC) in Soil

When the product released was or could have been racing fuel, aviation gas, or leaded gasoline, soil samples must be analyzed for EDB and EDC. To determine whether leaded gasoline could have been released, MDNR will assume gasoline sold after December 31, 1986 was unleaded.

In these cases, Method 8260B or Method 8260B-SIM (Selected Ion Monitoring) shall be used, unless another method having detection limits at or below applicable target levels is approved by MDNR.

5.8.5 Soil Sampling and Analytical Methods

All soil sampling must be performed in accordance with the following procedures:

- Soil borings must be extended to the water table or to a specified depth, not less than 20 ft bgs, if water is not encountered and impacts are not observed; this assumes one does not encounter refusal at a shallower depth.
- Field screening shall be conducted at intervals of 2 to no more than 5 feet.
- Soil borings shall be logged . The logs at Figures 5-3(a) and (b) or an equivalent shall be used.
- Samples must be collected, preserved, and analyzed within proper holding times in accordance with the methods presented in Table 5-1, except as follows:
    - Samples to be analyzed for volatile COCs must be collected in accordance with SW846 Method 5035 unless a comparable alternative method is approved by MDNR. When using Method 5035, if the analyzing laboratory purges samples at a temperature equal to or above 80 degrees Celsius, the sample must be preserved using either trisodium phosphate dodecahydrate (TSP) followed by refrigeration or deionized water followed by freezing. Preservation must not result in the loss of volatile COCs.
- Adequate quality assurance/quality control (QA/QC) procedures must be utilized to ensure sample quality and integrity.
- QA/QC samples shall include surrogate and spike recovery and trip blanks whenever possible. The samples must not be cross-contaminated by drilling fluid or by drilling or sampling procedures.
- For samples requiring preservation by refrigeration, the chain of custody form for the samples must indicate the temperature at which the samples were received by the laboratory. MDNR may reject data for samples received by the laboratory at temperatures above 6˚C.

- All sampling equipment must be decontaminated using EPA and standard industry protocols.
- A chain of custody form must accompany all samples. A copy of the completed chain of custody must be submitted with all laboratory analytical reports. MDNR will not accept laboratory data that is not accompanied by a corresponding chain of custody.

5.9 DISTRIBUTION OF COCs IN GROUNDWATER

An adequate number of groundwater samples shall be collected to definitively delineate the extent of dissolved contaminant plumes in all directions and to allow representative COC concentrations to be calculated based on the exposure model. Soil source delineation should serve as a guide in choosing the location of monitoring wells.

5.9.1 Delineation of Groundwater Contamination

The delineation criteria for groundwater depend on whether the groundwater pathway for ingestion is complete or incomplete based on consideration of current and potential future ingestion of the groundwater. Where the groundwater pathway for ingestion is complete, delineation criteria will be the lower of (i) the maximum contaminant levels (MCLs) (in the absence of MCLs, risk-based concentrations that assume ingestion of groundwater and inhalation of vapors due to indoor water use), and (ii) land use-dependent concentrations protective of indoor inhalation.

For groundwater where the groundwater ingestion pathway is incomplete, the delineation criteria are based on the protection of indoor inhalation. The indoor inhalation-protective values depend on whether the land use is residential or non-residential.

Delineation of groundwater contamination should be in accordance with the following:

- At sites where groundwater is, or is reasonably likely to be, used as a source of drinking water, investigations must delineate the extent of groundwater contamination to the applicable MCLs or other relevant standards protective of drinking water or indoor inhalation of vapors, whichever are lower

- If the groundwater ingestion pathway is incomplete, at both residential and non-residential sites, investigations must delineate groundwater contamination to the groundwater target levels protective of land use-specific indoor inhalation.

5.9.2 Groundwater Sampling and Analytical Methods

If groundwater has been contaminated by COCs, temporary sampling points may be used to screen for groundwater contamination and to assist in determining the optimal location of monitoring wells. A sufficient number of monitoring wells shall be installed to fully define the groundwater plume and allow the direction of groundwater flow to be determined. Monitoring wells 10 feet deep and deeper must be installed in accordance with 10 CSR 23-4, and the following procedures:

- An adequate number of monitoring wells must be installed to sufficiently delineate the horizontal and vertical extents of the groundwater plume and the direction of groundwater flow. At a minimum, one monitoring well must be installed in the source area, one upgradient of the source area, and another downgradient of the source area.

- Well placement and design shall consider the concentration of COCs in the source area and the occurrence of light non-aqueous phase liquids (LNAPLs) at the site.

- Well casing and screen materials must be properly selected. The top of the screened interval must be set at least 2-3 feet (preferably 5 feet) above the water table, unless the water table is within 3 feet of the ground surface.

- Wells must be properly developed and gauged after installation.

- A site survey must be conducted to establish well elevations and, by that, groundwater elevations. Based on the groundwater elevations, groundwater flow direction and gradient shall be determined and plotted on a map of the site.

Groundwater samples must be collected in accordance with the following guidelines and procedures:

- Monitoring wells must be purged an adequate number of well volumes prior to collecting a sample, unless a no-purge or low purge sampling technique has been approved by MDNR.

- Samples must be collected utilizing US EPA approved methods and equipment.

- Samples must be adequately preserved according to the requirements of the laboratory analyses and extracted within holding times specified for each analytical method.

- Water samples to be analyzed for MTBE or the other oxygenates listed in Table 5-1 must be preserved with trisodium phosphate dodecahydrate (TSP), followed by refrigeration, or by deionized water followed by freezing, unless the analyzing laboratory purges samples at a temperature below 80 degrees Celsius.

- For samples requiring preservation by refrigeration, the chain of custody form for the samples must indicate the temperature at which the samples were received by the laboratory. MDNR may reject data for samples received by the laboratory at temperatures greater than 6˚C.

- Sample analyses must be conducted in accordance with current MDNR analytical requirements and US EPA Office of Solid Waste and Emergency Response SW846 Methods. Refer to Table 5-1 for a listing of the required analytical methods.

- Adequate QA/QC procedures must be utilized to ensure sample quality and integrity. QA/QC samples shall include surrogate, spike recovery, field blanks, and trip blanks.

- All sampling equipment must be decontaminated using US EPA and industry standard protocols.

- A chain of custody form must accompany all samples. A copy of the completed chain of custody must be submitted with all laboratory analytical reports. MDNR will not accept laboratory data that is not accompanied by a corresponding chain of custody.

- In most cases, for the first year after well installation, quarterly samples will be required. Subsequent monitoring schedules should be designed and proposed to MDNR as part of a site characterization or corrective action plan, with a defined objective and timeframe.

5.9.2.1 Sampling Groundwater for PAHs

As indicated in Table 5-1, analysis of all groundwater samples for naphthalene is required for all petroleum types, including gasoline; however, analysis for other PAHs is only required when it is known that diesel fuel, jet fuel, kerosene, heavy fuel oils, or waste oil were released, or when the type of petroleum released is unknown.

The following are required for all PAHs except naphthalene::

- Samples in which the concentration of TPH-DRO or TPH-ORO is below the laboratory detection limits or the RRLs in Table 5-3, whichever are lower, need not be analyzed for PAHs;

- A minimum of 25%, or two, whichever is greater, of groundwater samples having detectable TPH-DRO or TPH-ORO shall be analyzed for PAHs. Samples selected for PAH analysis shall be those that contain the highest concentrations of TPH-DRO or TPH-ORO; and

- All groundwater samples that will be used to assess construction worker exposure and which contain TPH-DRO or TPH-ORO at a concentration above the detection limit or RRL, whichever is lower, must be analyzed for PAHs.

In certain cases where the solubility of PAHs is or is expected to be increased due to the presence of other contaminants in soil and/or groundwater, a greater number of groundwater samples than specified above may need to be analyzed for PAHs.

5.9.2.2 Ethylene Dibromide (EDB) and Ethylene Dichloride (EDC) in Groundwater

When the product released was or could have been racing fuel, aviation gas, or leaded gasoline, and there is a complete exposure pathway for domestic use of groundwater, groundwater samples must be analyzed for EDB and EDC. To determine whether leaded gasoline could have been released, MDNR will assume gasoline sold after December 31, 1986 was unleaded.

In these cases, Method 8011 shall be used to analyze for EDB and Method 8260B or Method 8260B-SIM (Selective Ion Monitoring) shall be used to analyze for EDC, unless other methods having detection limits at or below applicable target levels are approved by MDNR.

5.9.3 Determination of Plume Stability

To assess plume stability, groundwater monitoring must be conducted for a period of time sufficient to show a reliably consistent trend in contaminant concentrations. For the MRBCA process, such trend must be apparent over a monitoring period of one to three years, with samples collected on at least a quarterly basis. The default assumption is that two years of data will be necessary to make a determination of plume stability, however, in cases where one year of monitoring is sufficient to demonstrate a clearly declining or stable plume, no further monitoring will be required. In some cases where two years of monitoring does not clearly show a stable or declining plume, additional data may be required. Greater than three years of monitoring without a conclusion of stability would indicate that the plume is not stable.

Groundwater monitoring for the purpose of evaluating plume stability must be conducted under a work plan approved by MDNR.

5.10 SURFACE WATER AND SEDIMENT SAMPLING

MDNR may request the collection of surface water samples when site investigation data shows or suggests that COCs have migrated to a surface water body. Such sampling must consider the representativeness of the samples with regard to the flow conditions. Water samples shall be collected both upstream and downstream of each groundwater discharge point. If one or more discrete discharge points cannot be identified even though the data indicates that contaminated groundwater is discharging to surface water, the point of discharge shall be determined based on data pertaining to groundwater flow direction and the horizontal, lateral, and vertical extent of the plume.

In addition, the collection of sediment samples may be required by MDNR if warranted by site conditions. If site investigation data shows or suggests that contaminated groundwater is discharging to a surface water body, sediment samples must be collected from the affected surface water body. The evaluator shall compare the sediment sample data with sediment standards protective of human health and ecological receptors that can be obtained from literature (refer Section 6.6) or develop site-specific levels. The latter

would be considered a Tier 3 activity and would require a pre-approved work plan. Refer to Section 6.4 for further guidance regarding the evaluation of surface water.

5.11 SOIL VAPOR SAMPLING

For sites where soil and/or groundwater concentrations exceed the Tier 1 RBTLs for the vapor migration to indoor air pathway, soil vapor monitoring can be conducted at either Tier 1 or Tier 2 to quantify COC concentrations in the vapor phase in soil. See subsection 6.1.3.1 and Appendix C.

5.12 LABORATORY QA/QC

Laboratory analytical data must be accompanied by QA/QC sample results. The required QA/QC samples include a method blank, a laboratory control sample, a matrix spike, and a duplicate/spike duplicate. Instrument performance samples such as internal standard and surrogate recovery samples must be included in the data package. Laboratories having National Environmental Laboratory Accreditation Program (NELAP) accreditation need not submit full internal QA/QC data packages with their analytical data, however the above mentioned QA/QC sample data must be submitted.

The laboratory must ensure that the portions of the chain of custody form relevant to the laboratory are completed and that the completed chain of custody form accompanies all data packages.

Determination of Total Organic Carbon in Sediment
(Lloyd Kahn Method)
July 27, 1988

Prepared by: Lloyd Kahn, Quality Assurance Specialist

Affiliation: U.S. Environmental Protection Agency, Region II
Environmental Services Division
Monitoring Management Branch
Edison, New Jersey 08837

Determination of Total Organic Carbon in Sediment

1. Scope and Application

    1.1 This method describes protocols for the determination of organic carbon in ocean sediments.

    1.2 Although the detection limit ma vary with procedure or instrument, a minimum reporting value of 100 mg/kg will be required for the ocean dumping/dredging program.

    1.3 Several types of determinations, which are considered equivalent are presented.

    1.4 Data are reported in mg/kg on a dry weight basis.

    1.5 Wet combustion methods are not considered to be equivalent to the pyrolytic methods herein described.

2. Summary of Method

    2.1 Inorganic carbon from carbonates and bicarbonates is removed by acid treatment.

    2.2 The organic compounds are decomposed by pyrolysis in the presence of oxygen or air.

    2.3 The carbon dioxide that is formed is determined by direct nondispersive infrared detection, flame ionization gas chromatography after catalytic conversion of the carbon dioxide to methane; thermal conductivity gas chromatography, differential thermal conductivity detection by sequential removal of water and carbon dioxide; or thermal conductivity detection following removal of water with magnesium perchlorate.

3. Sample Handling and Preservation

    3.1 Collect sediments in glass jars with Teflon or aluminum foil. Cool and maintain at 4ºC. Analyze within 14 days.

4. Interferences

    4.1 Volatile organics in the sediments may be lost in the decarbonation step resulting in a low bias.

    4.2 Bacterial decomposition and volatilization of the organic compounds are minimized by maintaining the sample at 4ºC, analyzing within the specified holding time, and analyzing the wet sample.

5. Apparatus

5.1 Drying oven maintained at 103º-105ºC.

5.2 Analytical instrument options:

5.2.1 Perkin Elmer Model 240C Elemental Analyzer or equivalent.

5.2.1.1 In this instrument, the sample from Section 7.2 is pyrolyzed under pure oxygen, water is removed by magnesium perchlorate and the carbon dioxide is removed by ascarite. The decrease in signal obtained by differential thermal conductivity detectors placed between the combustion gas stream before and after the ascarite tube is a measure of the organic carbon content.

5.2.2 Carlo Erba Model 1106-CHN Analyzer or equivalent.

5.2.2.1 In this apparatus, the sample is pyrolyzed in an induction type furnace, and the resultant carbon dioxide is chromatographically separated and analyzed by a differential thermal conductivity detector.

5.2.3 LECO Models WR-12, WR-112, or CR-12 carbon determinators or Models 600 or 800 CHN analyzers.

5.2.3.1 In the LECO WR-12, the sample is burned in a high frequency induction furnace, the carbon dioxide is selectively adsorbed at room temperature in a molecular sieve. It is subsequently released by heating and is measured by a thermal conductivity detector. The WR-112 is an upgraded WR-12 employing microprocessor electronics and a printer to replace the electronic digital voltmeter.

5.2.3.2 In the LECO CR-12 carbon determinator, the sample is combusted in oxygen, moisture and dust are removed by appropriate traps and the carbon dioxide is measured by a selective, solid state, infrared microprocessor and the carbon content is displayed on a digital readout and recorded on an integral printer.

5.2.3.3 In the LECO CHN-600 and CHN-800 elemental analyzers, the sample is burned under oxygen in a resistance furnace and the carbon dioxide is measured by a selective infrared detector.

5.2.4 Dohrman Model DC-85 Digital High Temperature TOC Analyzer

5.2.4.1 In this instrument, the sample is burned in a resistance furnace under oxygen, the interfering gases are removed by a sparger/scrubber system and the carbon dioxide is measured by non-dispersive infrared detectors and shown on a digital display in concentration units.

5.3 No specific analyzer is recommended as superior. The above listing is for information only and is not intended to restrict the use of other unlisted instruments capable of analyzing TOC. The instruments to be used must have the following specifications:

5.3.1 A combustion boat which is heated in a stream of oxygen or air in a resistance or induction-type furnace to completely convert organic substances to CO_2 and water.

5.3.2 A means to physically or by measurement technique to separate water and other interferants from CO_2.

5.3.3 A means to quantitatively determine CO2 with adequate sensitivity (100 mg/kg), and precision (25% at the 95% confidence level as demonstrated by repetitive measurements of a well mixed ocean sediment sample).

5.4 A strip chart or other permanent recording device to document the analysis.

6. Reagents

6.1 Distilled water used in preparation of standards and for dilution of samples should be ultra pure to reduce the carbon concentration of the blank.

6.2 Potassium hydrogen phthalate, stock solution, 100 mg carbon/liter: Dissolve 0.2128 g of potassium hydrogen phthalate (Primary standard Grade) in distilled water and dilute to 100.0 ml.

6.3 Potassium hydrogen phthalate, standard solutions: prepare standard solutions from the stock solution by dilutions with distilled water.

6.4 Phosphoric acid solution, 1:1 by volume.

7. Procedure

7.1 Weigh the well mixed sample (up to 500 mg) into the combustion boat or cup. Add 1:1 phosphoric acid drop-wise until effervescence stops. Heat to 75ºC.

7.2 Analyze the residue according to the instrument manufacturer's instructions.

7.3 Determine percent residue on a separate sample aliquot as follows:

7.3.1 Heat a clean 25 ml beaker at 103-105ºC for one hour. Cool in desiccator, weigh to the nearest mg and store in desiccator until use.

7.3.2 Add 1 g, weighed to the nearest mg, of an aliquot of the well-mixed sample.

7.3.3 Dry and heat in the 103-105ºC oven for 1 hour. Cool in desiccator. Weigh to the nearest mg.

8. Calibration

8.1 Follow instrument manufacturer's instructions.

8.2 Prepare calibration curve plotting mg carbon vs. instrument response, using 4 standards and a blank covering the analytical range of interest.

9. Precision and Accuracy:

9.1 The precision and accuracy will differ with the various instruments and matrices and must be determined by the laboratories reporting the data. To initiate a control chart, a representative sample of well-mixed sediment should be analyzed 15 times to determine the analytical precision. Set up a control chart showing 3 times the standard deviation limits for precision.

9.2 Subsequently during analysis of environmental samples, take one sample per batch of 20 or less and run in quadruplicate. Calculate standard deviation and report with initial control chart data.

9.3 If the sample being run in quadruplicate exceeds the 3 standard deviation limit, identify error and rerun environmental samples in that batch alone with the quadruplicate sample.

LABORATORY ANALYSIS FACT SHEET
TPH-GRO by Method 8260B

The Missouri DNR has adopted SW-846 method 8260B as the method of choice for the detection and quantitation of TPH-GRO. The following items represent exceptions or clarifications to the method as written.

Sample Introduction

1. Samples are purged onto the GC/MS system using all protocols specified in SW-846 method 5035 or 5035A.

2. Surrogates and internal standards specified by method 8260B are added to water and soil samples prior to purging. Since the surrogate Dibromofluoromethane is not related to compounds detected by this method, it does not have to be reported nor does it have to meet any acceptance criteria.

Sample Analysis

1. The GC/MS system is tuned to BFB tune criteria listed in method 8260B, at the frequency specified in method 8260B. Alternative tuning criteria as specified in section 7.3 of method 8260B is also acceptable, as long as method performance is not adversely affected.

2. The GC/MS operating conditions specified as guidance in Section 7.3 of Method 8260B are acceptable.

3. A 5 point standard curve is used to quantitate TPH-GRO. Quantitation is by external standard.

4. The stock standard solution used to prepare calibration standards is a mixture of unleaded gasoline and Number 2 diesel fuel. The stock solution and all calibration standards use Methanol as the solvent. Each component should be at a concentration of 1000 mg/L in the stock standard.

5. The lowest calibration standard should be at the reporting limit for the method. The highest calibration standard must not exceed the linear range of the system.

6. Retention time windows are defined for TPH-GRO by analyzing a standard containing C6 and C10. The retention time window for TPH-GRO is defined as beginning 0.1 minutes before C6 to 0.1 minutes after C10. The standard containing C6 and C10 must be analyzed every day samples are analyzed in order to verify that the retention time windows are constant.

7. Because the retention time window will be several minutes wide for TPH-GRO, the GC/MS data system may not accurately or appropriately establish the proper baseline

for calibration or quantitation. The analyst **must** visually examine the computer-generated baseline for every analytical run, and manually adjust the baseline when needed. A properly drawn baseline must extend over the entire retention time window and include the area under the entire TPH-GRO series of peaks. It is **not appropriate** to draw the baseline "peak to peak."

8. Individual quantitation ions are not appropriate for TPH-GRO calibration and quantitation. The Total Ion Chromatogram (TIC) must be used to calculate the area under the peak for TPH-GRO calibration and quantitation determinations over the entire retention time window.

9. Area counts for the internal standards and surrogates added during sample preparation must be subtracted from the total area count for TPH-GRO. This is accomplished by subtracting the area count of the method blank from all subsequent calibration and analytical runs.

10. The %RSD for the calibration curve for TPH-GRO must be less than or equal to 20 percent, so that linearity through the origin can be assumed and an average calibration factor used for calculations.

11. A continuing calibration check verification standard (CCV) must be analyzed every 12 hours of sample analysis. The CCV must contain all analytes reported by this method. The standard concentration should be at the mid-point of the calibration curve. If the percent difference (%D) for the CCV is less than or equal to 20%, the initial calibration is assumed to be valid. If the %D is greater than 20%, corrective action must be taken prior to sample analysis.

12. A method blank must be analyzed for every 20 samples analyzed. Additionally minimum quality control samples per every 20 samples include a Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD). Ideally, the spiking solution(s) for the LCS and MS/MSD would contain TPH-GRO, BETX, chlorinated compounds, and oxygenates. It may not be possible however to have every component in the spiking solution(s) for the LCS and MS/MSD samples. It is acceptable to spike the LCS and MS/MSD with different components, as long as TPH-GRO, BETX, chlorinated compounds, and oxygenates are present in either the LCS or the MS/MSD samples.

13. All of the BTEX, chlorinated compounds and oxyenates analyzed by 8260B are by internal standard, using all criteria specified in 8260B. This includes the RSD requirement of 15% for the compounds. If 15% RSD is not achieved, additional calibration options specified in Method 8000B may be employed.

Should questions arise concerning TPH analysis by Method 8270C, feel free to contact either of the following people:

Primary Contact:

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Organic Chemistry Unit
Environmental Services Program
Missouri Department of Natural Resources
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LABORATORY ANALYSIS FACT SHEET
TPH-DRO and TPH-ORO by Method 8270C

The Missouri DNR has adopted SW-846 method 8270C as the method of choice for the detection and quantitation of TPD-DRO and TPH-ORO. The following items represent exceptions or clarifications to the method as written.

Sample Preparation

1. Samples are extracted by the appropriate matrix defined SW-846 extraction methods specified by Method 8270C.

2. Surrogates specified by method 8270C are added to water and soil samples prior to extraction. Only the Base Neutral surrogates need to be added.

3. Internal standards specified by method 8270C are added to sample extracts immediately prior to extract analysis. Only the internal standards specified by 8270C for the PAH compounds are required for analysis and must meet the acceptance criteria.

Sample Analysis

1. The GC/MS system is tuned to DFTPP tune criteria listed in method 8270C, at the frequency specified in method 8270C. Alternative tuning criteria as specified in section 7.3.1.2 of method 8270C is also acceptable, as long as method performance is not adversely affected.

2. The DFTPP tuning standard **is not required** to contain 4,4'-DDT, pentachlorophenol, and benzidine to monitor injection port inertness and GC column performance.

3. The GC/MS operating conditions specified as guidance in Section 7.3 of Method 8270C are acceptable with the exception of mass range. Mass range should be changed from 35-500 amu to 35-550 amu. This is required in order to quantitate and detect C35.

4. A 5 point standard curve is used to quantitate TPH-DRO and TPH-ORO. Quantitation is by external standard.

5. The stock standard solution used to prepare calibration standards is a mixture of unleaded gasoline and Number 2 diesel fuel. The stock standard and all calibration standards use Methylene Chloride as the solvent. Each component should be at a concentration of 1000 mg/L in the stock standard.

6. The lowest calibration standard should be at the reporting limit for the method. The highest calibration standard must not exceed the linear range of the system.

7. Retention time windows are defined for TPH-DRO and TPH-ORO by analyzing a standard containing C10, C21, and C35. The retention time window for TPH-DRO is defined as beginning 0.1 minutes after C10 to 0.1 minutes after C21. The window for TPH-ORO is defined as beginning 0.1 minutes after C21 to 0.1 minutes after C35. The standard containing C10, C21, and C35 must be analyzed every day samples are analyzed in order to verify that the retention time windows are constant.

8. Because the retention time window will be several minutes wide for both TPH-DRO and TPH-ORO, the GC/MS data system may not accurately or appropriately establish the proper baseline for calibration or quantitation. The analyst **must** visually examine the computer-generated baseline for every analytical run, and manually adjust the baseline when needed. A properly drawn baseline must extend over the entire retention time window and include the area under the entire TPH-DRO or TPH-ORO series of peaks. It is **not appropriate** to draw the baseline "peak to peak."

9. Individual quantitation ions are not appropriate for TPH-DRO and TPH-ORO calibration and quantitation. The Total Ion Chromatogram (TIC) must be used to calculate the area under the peak for TPH-DRO and TPH-ORO calibration and quatitation determinations over the entire retention time window.

10. It is highly likely that the calibration standards used for this method will have little presence in the C21 to C35 window. The response factor calculated for the C10 to C21 window must be used for the C21 to C35 window.

11. Area counts for the internal standards and surrogates added during sample preparation must be subtracted from the total area count for TPH-DRO and TPH-ORO. This is accomplished by subtracting the area count of the method blank from all subsequent calibration and analytical runs.

12. The %RSD for the calibration curve for TPH-DRO and TPH-ORO must be less than or equal to 20 percent, so that linearity through the origin can be assumed and an average calibration factor used for calculations.

13. A continuing calibration verification standard (CCV) must be analyzed every 12 hours of sample analysis. The CCV must contain all analytes reported by this method. The standard concentration should be at the mid-point of the calibration curve. If the percent difference (%D) for all CCV compounds is less than or equal to 20%, then the initial calibration is assume to be valid. If the %D is greater than 20%, corrective action must be taken prior to sample analysis.

14. A method blank must be analyzed for every extraction group, with each extraction group not to exceed 20 samples. Additionally minimum quality control samples per extraction group include a Laboratory Control Sample (LCS) and Matrix Spike/Matrix Spike Duplicate (MS/MSD). Ideally, the spiking solution(s) for the LCS and MS/MSD would contain TPH-DRO, TPH-ORO, and the PAH's quantitated by this method. It may not be possible however to have every component in the

spiking solution(s) for the LCS and MS/MSD samples. It is acceptable to spike the LCS and MS/MSD with different components, as long as TPH-DRO, TPH-ORO, and the PAH's are present in either the LCS or the MS/MSD samples.

15. If a sample has a sufficient TPH-DRO or TPH-ORO concentration to require PAH analysis, the same analytical run can be processed against a standard 8270C method containing the PAH's of interest.

16. All calibration and quantitation data for PAH analysis is by internal standard, using all criteria specified in 8270C. This includes the RSD requirement of 15% for the PAH compounds. If 15% RSD is not achieved, additional calibration options specified in Method 8000B may be employed.

Should questions arise concerning TPH analysis by Method 8270C, feel free to contact either of the following people:

Primary Contact:

Curt Lueckenhoff
Organic Chemistry Unit
Environmental Services Program
Missouri Department of Natural Resources
Phone: (573) 526-6972
E-Mail: **curt.lueckenhoff@dnr.mo.gov**

MRBCA LABORATORY REQUIREMENTS

I. REQUIREMENTS FOR ALL ANALYSES

A. Percent moisture determinations must be performed on all soil samples using either the ASTM oven drying method or the Karl Fisher method.

B. Method 5035 must be used for soil sample collection and analysis when Volatile Organic Compounds are to be analyzed.

C. Appropriate standards must be analyzed by the instrumental conditions of Method 8260B to allow the laboratory to complete the Gasoline Range Organics (GRO) quantitations and Method 8270C to complete the Diesel Range Organics (DRO) and Oil Range Organics (ORO) quantitations.

D. Specific quantitation ranges for the GRO, DRO, and ORO determinations are defined in Table F-1 of the guidance document *Missouri Risk-Based Corrective Action Process for Petroleum Storage Tanks*, October 17, 2013. The quantitation ranges are C6 through C10 for GRO, C10 through C21 for DRO, and C21 through C35 for ORO.

II. ADDITIONAL REQUIREMENTS FOR SOURCE DETERMINATION

A. At the direction of MDNR, in addition to the retention time fraction determination, **additional whole fraction standards** must be analyzed with either GC/MS or GC analyses to allow for both qualitative and quantitative identification of the specific type of petroleum product present. Additional standards include: gasoline, #1-#5 diesel, mineral spirits, kerosene, JP4, jet fuel, motor oil, and hydraulic fluid.

B. Quantitation must be accomplished by summing areas of all compounds from the retention time window of each standard that include the fraction pattern of each petroleum product.

C. Results must be reported as ### µg/L as gasoline, ### µg/L as diesel, etc.

III. REPORTING REQUIREMENTS

A. All soil results must be reported as dry weights and clearly identified as such.

B. The method of moisture determination must be clearly identified and reported along with the actual percent moisture result.

C. Source determination results must be reported as indicated in II.C. above.

D. All other results must be reported as specified in the appropriate analytical method.

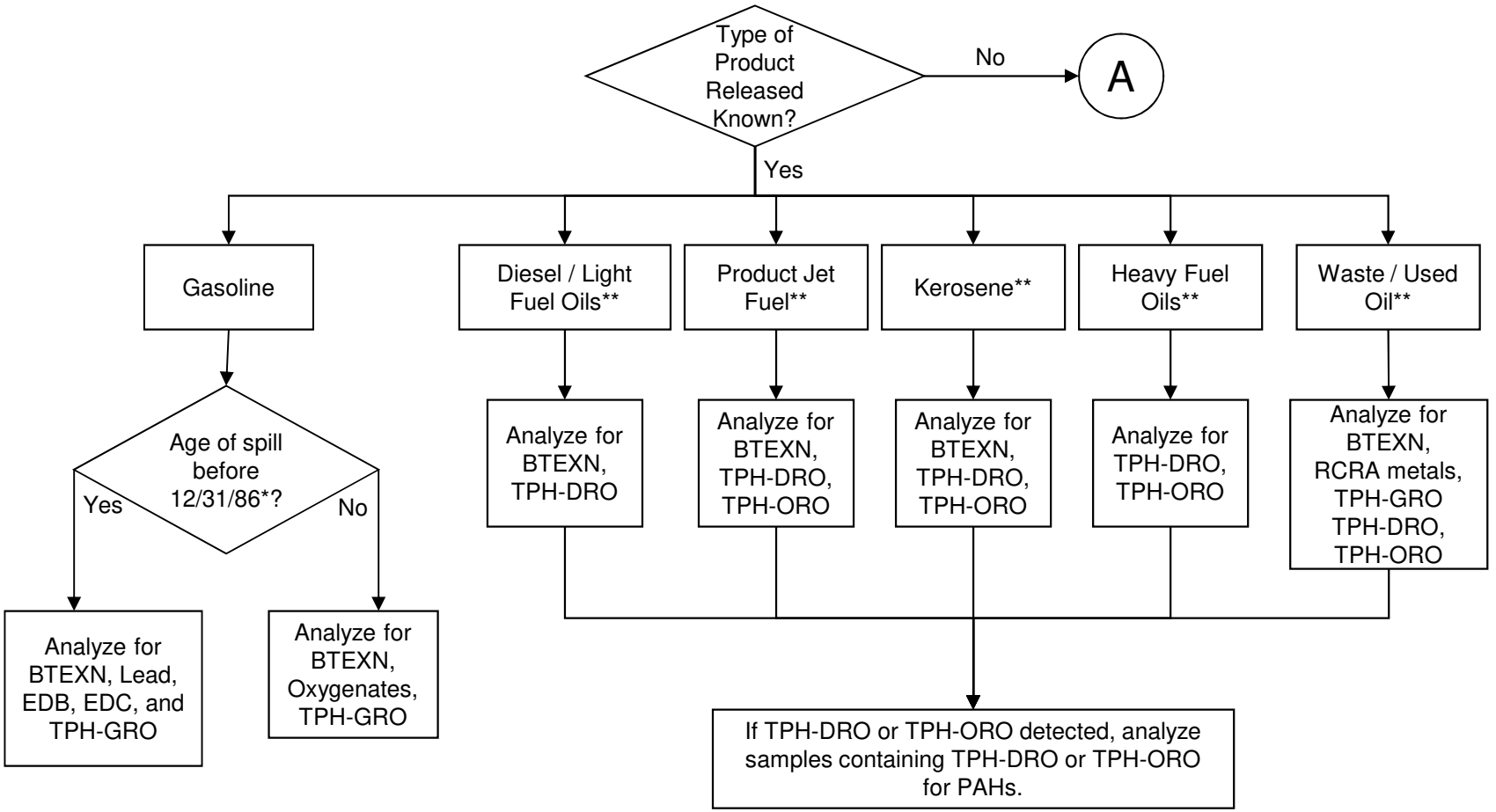
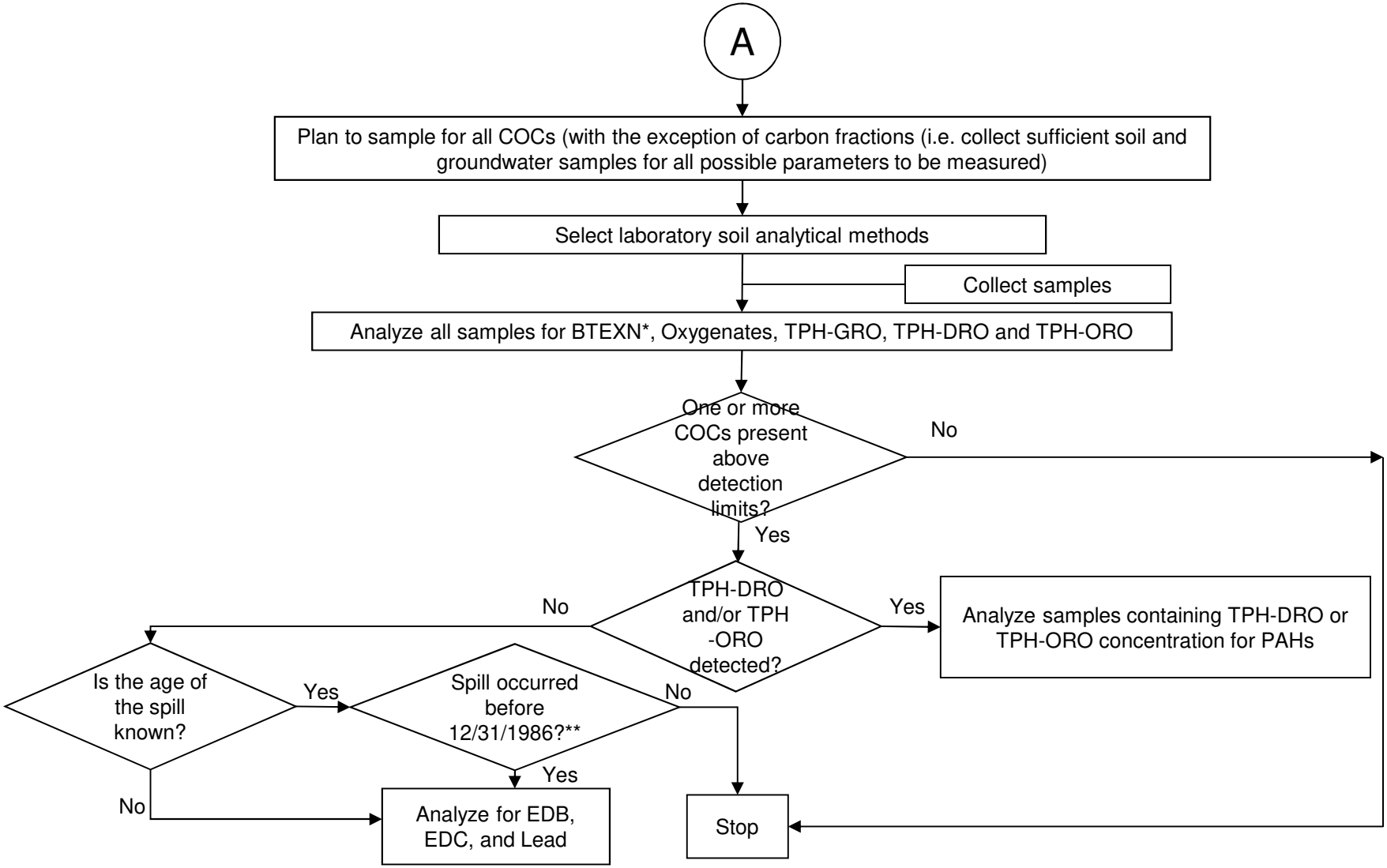


Figure 5-1. Chemicals of Concern Selection and Analysis (*Page 1 of 2*)

Notes:
*: If the age of the spill is unknown it should be assumed that the spill was prior to 12/31/1986, unless site information suggests otherwise (e.g., station operation began only in 1990).
**: Sufficient sample volume should be collected for these products to allow for the possibility of PAH analysis.



* Benzene, toluene, ethylbenzene, xylenes, and naphthalene

**If the age of the spill is unknown it should be assumed that the spill was prior to 12/31/1986, unless site information suggests otherwise (e.g., station operation began only in 1990).

Figure 5-1. Chemical of Concern Selection and Analysis (*Page 2 of 2*)

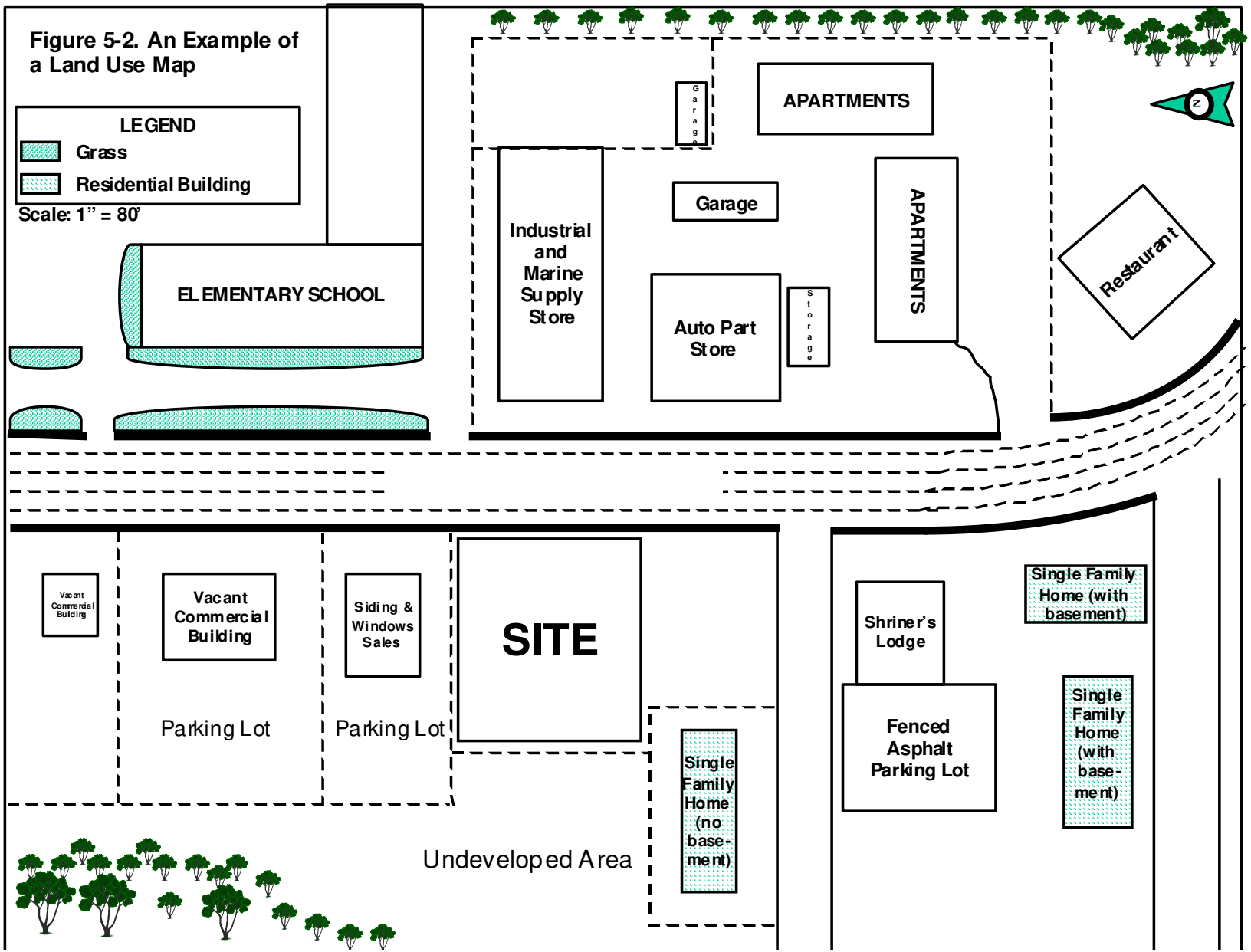
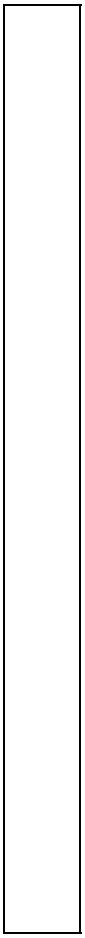


Figure 5-2. An Example of a Land Use Map
LEGEND
Grass
Residential Building
Scale: 1" = 80'
ELEMENTARY SCHOOL
Garage
APARTMENTS
Industrial and Marine Supply Store
Garage
Auto Part Store
Storage
APARTMENTS
Restaurant
N
Vacant Commercial Building
Vacant Commercial Building
Siding & Windows Sales
SITE
Parking Lot
Parking Lot
Undeveloped Area
Single Family Home (no base-ment)
Shriner's Lodge
Fenced Asphalt Parking Lot
Single Family Home (with basement)
Single Family Home (with base-ment)

Figure 5-3(a)

ST #	SOIL BORING LOG	BORING NUMBER
R #	OVERSEEING GEOLOGIST	DRILLER
SITE NAME	DRILLING METHOD	SAMPLING METHOD
SITE ADDRESS	BOREHOLE DIAMETER	SAMPLING INTERVAL
DATE OF BORING	TOTAL BORING DEPTH	STATIC WATER LEVEL

WELL CONSTRUCTION DETAILS	APPROX. DEPTH IN FEET	LITHOLOGIC DESCRIPTION AND REMARKS	PID READING (PPM)	SAMPLE IDENTIFICATION
	0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25			

COMMENTS:

NOTES:

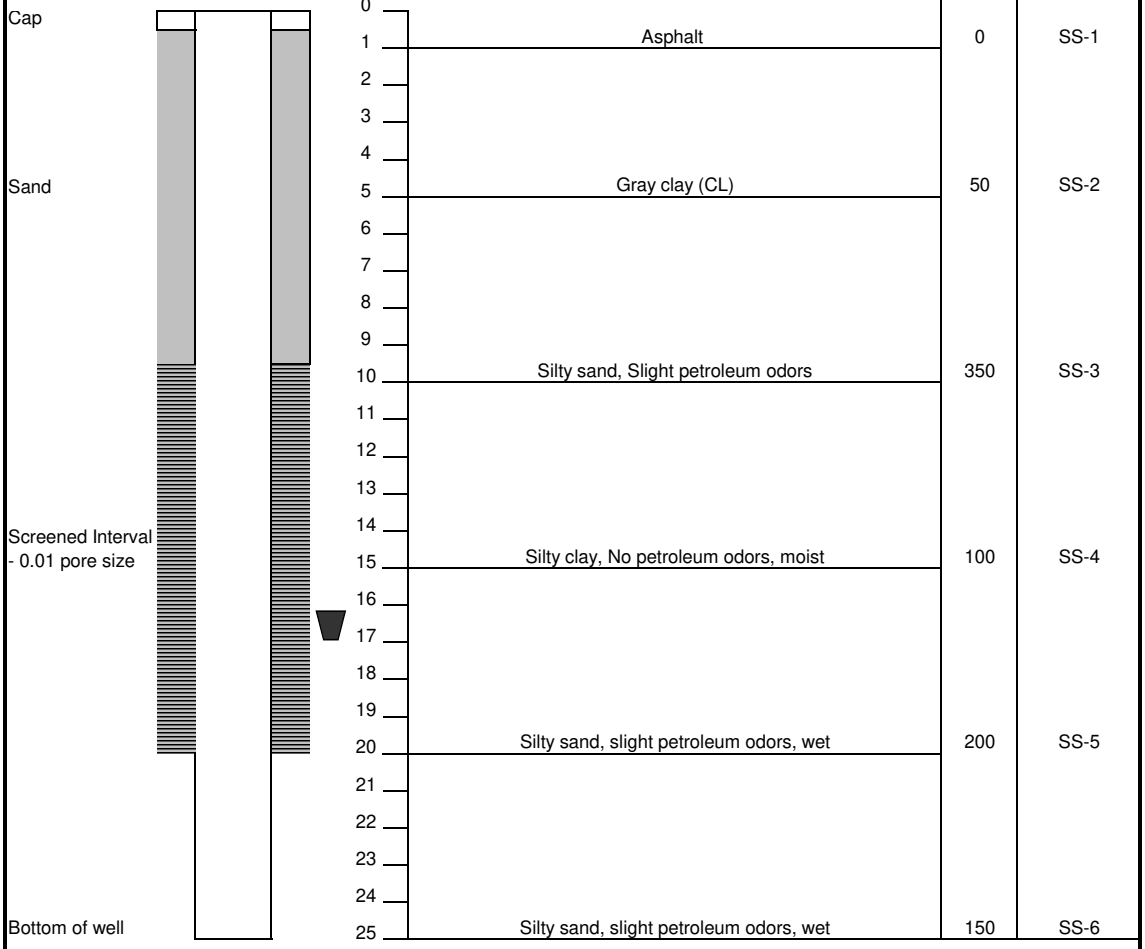
INDICATES SAND SCREEN

INDICATES MONITORING WELL SCREEN

INDICATES OBSERVED WATER LEVEL

Figure 5-3(b)

ST #	SOIL BORING LOG	BORING NUMBER MW-1
R #	OVERSEEING GEOLOGIST	DRILLER
SITE NAME	DRILLING METHOD DIRECT PUSH	SAMPLING METHOD SPLIT SPOON
SITE ADDRESS	BOREHOLE DIAMETER 4 INCHES	SAMPLING INTERVAL CONTINUOUS
DATE OF BORING	TOTAL BORING DEPTH 25.0 ft	STATIC WATER LEVEL 17.0 ft



WELL CONSTRUCTION DETAILS	APPROX. DEPTH IN FEET	LITHOLOGIC DESCRIPTION AND REMARKS	PID READING (PPM)	SAMPLE IDENTIFICATION
	1	Asphalt	0	SS-1
	5	Gray clay (CL)	50	SS-2
	10	Silty sand, Slight petroleum odors	350	SS-3
	15	Silty clay, No petroleum odors, moist	100	SS-4
	20	Silty sand, slight petroleum odors, wet	200	SS-5
	25	Silty sand, slight petroleum odors, wet	150	SS-6

COMMENTS:

Samples sent for laboratory analysis: SS-3, and SS-4.

NOTES:

- INDICATES SAND SCREEN
- INDICATES MONITORING WELL SCREEN
- INDICATES OBSERVED WATER LEVEL

Table 5-1 (*Page 1 of 3*)
Chemicals of Concern for Different Product Releases

Contaminant		Gasoline	Diesel/ Light Fuel Oils	Product Jet Fuel	Kerosene	Heavy Fuel Oils	Waste/ Used Oil	Analytical Methods	
VOLATILES								**Groundwater**	**Soil**
Benzene	a	X	X	X	X	NC	X	8260B	8260B
Toluene	n	X	X	X	X	NC	X	8260B	8260B
Ethylbenzene	n	X	X	X	X	NC	X	8260B	8260B
Xylenes (total)	n	X	X	X	X	NC	X	8260B	8260B
1,2-Dibromoethane / Ethylene dibromide (EDB)	b	X[1]	NC	NC	NC	NC	NC	8011[6]	8260B/8260B-SIM[5]
1,2-Dichloroethane / Ethylene dichloride (EDC)	b	X[1]	NC	NC	NC	NC	NC	8260B/8260B-SIM[6]	8260B/8260B-SIM[5]
OXYGENATES									
Methyl-tert-butyl-ether (MTBE)	n	X	NC	NC	NC	NC	NC	8260B	8260B
Tertiary amyl methyl ether (TAME)		X	NC	NC	NC	NC	NC	8260B	8260B
Tertiary butyl alcohol (TBA)		X	NC	NC	NC	NC	NC	8260B	8260B
Ethyl-tert-butyl-ether (ETBE)		X	NC	NC	NC	NC	NC	8260B	8260B
Diisopropyl ether (DIPE)		X	NC	NC	NC	NC	NC	8260B	8260B
Ethanol		X	NC	NC	NC	NC	NC	Direct injection GC	NA
Methanol		X	NC	NC	NC	NC	NC	Direct injection GC	NA
TPH									
TPH-GRO		X	NC	NC	NC	NC	X	8260B	8260B
TPH-DRO		NC	X	X	X	X	X	8270C	8270C
TPH-ORO		NC	NC	X	X	X	X	8270C	8270C

Table 5-1 (*Page 2 of 3*)
Chemicals of Concern for Different Product Releases

Contaminant		Gasoline	Diesel/ Light Fuel Oils	Product Jet Fuel	Kerosene	Heavy Fuel Oils	Waste/ Used Oil	Analytical Methods	
PAHs[4]								**Groundwater**	**Soil**
Acenaphthene	n	NC	X	X	X	X	X	8270C[3]	8270C[3]
Anthracene	n	NC	X	X	X	X	X	8270C[3]	8270C[3]
Benzo(a)anthracene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Benzo(a)pyrene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Benzo(b)fluoranthene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Benzo(k)fluoranthene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Chrysene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Dibenzo(a,h)anthracene	b	NC	X	X	X	X	X	8270C[3]	8270C[3]
Fluoranthene	n	NC	X	X	X	X	X	8270C[3]	8270C[3]
Fluorene	n	NC	X	X	X	X	X	8270C[3]	8270C[3]
Naphthalene	n	X	X	X	X	X	X	8260B[2], 8270C[3]	8260B[2], 8270C[3]
Pyrene	n	NC	X	X	X	X	X	8270C[3]	8270C[3]
METALS								**Soil and Groundwater**	
Arsenic		NC	NC	NC	NC	NC	X	6010B, 6020	
Barium		NC	NC	NC	NC	NC	X	6010B, 6020	
Cadmium		NC	NC	NC	NC	NC	X	6010B, 6020	
Chromium		NC	NC	NC	NC	NC	X	6010B, 6020	
Lead	b	X[1]	NC	NC	NC	NC	X	6010B, 6020	
Selenium		NC	NC	NC	NC	NC	X	6010B, 6020	

Table 5-1 (*Page 3 of 3*)
Chemicals of Concern for Different Product Releases

Note:
- X Chemical of concern to be analyzed
- NC Not a chemical of concern
- 1 Chemical of concern for leaded gasoline
- 2 When gasoline was the only product released, naphthalene should be analyzed by Method 8260B; if the petroleum released was other than or in addition to gasoline, naphthalene should be analyzed by Method 8270C
- 3 For 8270 where a detection limit lower than the Estimated Quantitation Limit is required, measures to increase the sensitivity of the method should be taken.
- a Human carcinogen (Group A under EPA weight of evidence classification system for carcinogenicity)
- b Probable human carcinogen (Group B1 or B2 under EPA weight of evidence classification system for carcinogenicity)
- n Non-carcinogen
- NA Not Applicable – soil samples need not be analyzed for ethanol or methanol
- 4 Samples must be analyzed for PAHs when TPH-DRO or TPH-ORO are detected in soil at a concentration at or above the RRLs in Table 5-3
- 5 When the product released was or could have been racing fuel, aviation gas, or leaded gasoline, soil samples must be analyzed for EDB and EDC. To determine whether leaded gasoline could have been released, MDNR will assume gasoline sold after December 31, 1986 was unleaded. In these cases, Method 8260B or Method 8260B-SIM (Selected Ion Monitoring) shall be used, unless another method having detection limits at or below applicable target levels is approved by MDNR.
- 6 When the product released was or could have been racing fuel, aviation gas, or leaded gasoline, and there is a complete exposure pathway for domestic use of groundwater, groundwater samples must be analyzed for EDB and EDC. To determine whether leaded gasoline could have been released, MDNR will assume gasoline sold after December 31, 1986 was unleaded. In these cases, Method 8011 shall be used to analyze for EDB and Method 8260B or Method 8260B-SIM (Selective Ion Monitoring) shall be used to analyze for EDC, unless other methods having detection limits at or below applicable target levels are approved by MDNR.

Sources:

- U. S. Environmental Protection Agency, November 1986, *Test Methods for Evaluating Solid Waste*, SW-846, Third Edition. Office of Solid Waste and Emergency Response, Washington D.C.
- U.S. Environmental Protection Agency, March 1983, *Methods for Chemical Analysis of Water and Wastes*, Environmental Monitoring and Support Laboratory, Cincinnati, OH 45263.
- Methods Information Communication Exchange, Office of Solid Waste, (703) 821-4690.
- U.S. Environmental Protection Agency, July 1982, *Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater*, EPA-600/4-82-057. Environmental Monitoring and Support Laboratory, Cincinnati, OH 45263.

Table 5-2
Weight Percents for COCs in Different Products

	Weight Percent (%)									
	Gasoline		Diesel		Jet Fuel (JP-4 & JP-5)		Kerosene		Fuel Oil No. 6	
	Range	Average	Range	Average	Range	Average	Range	Average	Range	Average
VOLATILES										
Benzene	1.6-2.3	1.90	0.0026-0.1	0.029	0.47-0.5	0.47	---	---	---	---
Toluene	6.4-10	8.10	0.0069-0.7	0.180	1.3-1.6	1.6	---	---	---	---
Ethylbenzene	1.4-2	1.70	0.007-0.2	0.068	0.37-0.69	0.66	---	---	---	---
o-Xylene	2.1-3.1	2.50	0.0012-0.085	0.043	---	0.545	---	---	---	---
m-Xylene	3.9-5.4	4.60	0.009-0.255	0.110	---	0.545	---	---	---	---
p-Xylene	1.6-2.3	1.90	0.009-0.255	0.110	---	0.35	---	---	---	---
Xylenes (total)	---	---	---	0.5	---	---	---	---	---	---
1,2-Dibromoethane/Ethylene dibromide (EDB)	---	---	---	---	---	---	---	---	---	---
1,2-Dichloroethane/Ethylene dichloride (EDC)	---	---	---	---	---	---	---	---	---	---
PAHs										
Acenaphthene	---	---	---	---	---	---	---	0.0047		
Anthracene	---	---	3.0E6 -0.02	5.80E-03	---	---	---	0.00012		0.005
Benzo(a)anthracene	---	---	2.0E-6 - 6.7E-4	9.60E-05	---	---	---	---	0.0029-0.15	0.055
Benzo(a)pyrene			5.0E-6 - 8.4E-4	2.20E-04	---	---	---	---		0.0044
Benzo(b)fluoranthene	---	---	1.55E-07 - 9.5E-05	1.55E-04	---	---	---	---		0.022
Benzo(k)fluoranthene	---	---	1.55E-07 - 9.5E-06	1.55E-04	---	---	---	---		0.022
Chrysene	---	---		4.50E-05	---	---	---	---	0.0029-0.31	0.069
Dibenz(a,h)anthracene	---	---	---	---	---	---	---	---		
Fluoranthene	---	---	6.8E-7 - 0.02	0.0059	---	---	---	0.00086		0.024
Fluorene	---	---	0.034-0.15	0.086	---	---	---	---		
Naphthalene	0.15-0.36	0.25	0.01-0.8	0.26	0.25-0.5	0.41	0.15-0.46	0.31	0.00021-0.015	0.0042
Pyrene	---	---	0.000018-0.015	0.0046	---	---	---	0.00024		0.0023
Avg. Molecular Weight (g/mole)	105		230		165		105		NA	

NOTES: Data from Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG), May 1998. TPHCWG Series Volume 2: Composition of Petroleum Mixtures.

1. ---: Not available. For these COCs pure product solubilites and saturated vapor concentrations were used.
See discussion at 6.8.3 and Section B.8

2. Jet Fuel: Average values of JP-4 and JP-5 are taken.

3. Diesel: Values were available for m+p-Xylene. Each was considered 50% composition.

4. Diesel and Fuel Oil No. 6: Values were available for Benzo(b+k)fluoranthene. Each was considered 50% composition.

Table 5-3
Required Reporting Limits

Listed below are the required reporting limits (RRLs) for the methods specified in the MRBCA guidance document. All listed RRL's should be viewed as conservative numbers and do not represent the absolute lowest quantitation levels achievable. Most laboratories should be able to obtain RRL's at or below the listed values.

VOLATILES

Compound	Method	Water PQL	Soil PQL
Benzene	8260B	5 µg/L	25 µg/Kg
Toluene	8260B	5 µg/L	25 µg/Kg
Ethylbenzene	8260B	5 µg/L	25 µg/Kg
Total Xylenes	8260B	10 µg/L	50 µg/Kg
Ethylene Dichloride (EDC)	8260B	5 µg/L	25 µg/Kg
Ethylene Dibromide (EDB)	8260B	5 µg/L	25 µg/Kg

OXYGENATES

Compound	Method	Water PQL	Soil PQL
MTBE	8260B	5 µg/L	25 µg/Kg
TAME	8260B	50 µg /L	250 µg/Kg
TBA	8260B	50 µg/L	250 µg/Kg
ETBE	8260B	5 µg/L	25 µg/Kg
DIPE	8260B	50 µg/L	250 µg/Kg
Ethanol (1)	8015	1 mg/L	(2)
Methanol (1)	8015	1 mg/L	(2)

TPH

Compound	Method	Water PQL	Soil PQL
TPH-GRO	8260B	1 mg/L	20 mg/Kg
TPH-DRO	8270C	1 mg/L	20 mg/Kg
TPH-ORO	8270C	1 mg/L	20 mg/Kg

PAH'S

Compound	Method	Water PQL	Soil PQL
Acenaphthene	8270C	10 µg/L	660 µg/Kg
Anthracene	8270C	10 µg/L	660 µg/Kg
Benzo(a)anthracene	8270C	10 µg/L	660 µg/Kg
Benzo(a)pyrene	8270C	10 µg/L	660 µg/Kg
Benzo(b)fluoranthene	8270C	10 µg/L	660 µg/Kg
Benzo(k)fluoranthene	8270C	10 µg/L	660 µg/Kg
Chrysene	8270C	10 µg/L	660 µg/Kg
Dibenzo(a,h)anthracene	8270C	10 µg/L	660 µg/Kg
Fluoranthene	8270C	10 µg/L	660 µg/Kg
Fluorene	8270C	10 µg/L	660 µg/Kg
Naphthalene	8270C	10 µg/L	660 µg/Kg
Pyrene	8270C	10 µg/L	660 µg/Kg

METALS

Metals	Method	Water PQL	Soil PQL
Arsenic	6010B	50 µg/L	2500 µg/Kg
Barium	6010B	5 µg/L	500 µg/Kg
Cadmium	6010B	5 µg/L	500 µg/Kg
Chromium	6010B	5 µg/L	500 µg/Kg
Lead	6020	5 µg/L	500 µg/Kg
Selenium	6010B	50 µg/L	2500 µg/Kg

(1) These compounds are to be analyzed by direct injection and not purge and trap.

(2) Soil samples will not be analyzed for Ethanol or Methanol.

ATTACHMENT A

Ecological Risk Assessment
Tier 1 Screening Checklist for Potential Receptors and Habitat
Checklist #1

1. Is the site less than (<) ½ mile to a surface water resource (pond, river, lake, etc.)?

2. Are wetlands (e.g., marshes, swamps, fens) on or adjacent to the site?

3. Are contaminated soils uncovered or otherwise accessible to ecological receptors and the elements?

4. Are there karsitic features (see Ecological Risk Assessment Figure #2 for definition) on or within a ½ mile radius of the site?

   Note: A professional opinion may be necessary to make this determination. The Missouri Environmental Geology Atlas (MEGA), published by the Department of Natural Resources, Missouri Geological Survey (MGS), provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format, that can assist in this determination. MEGA, including software to view the data sets, may be obtained from MGS by calling (573) 368-2125.

5. Are there federal or state rare, threatened, or endangered species on or within a ½ mile radius of the site? Note: The ½ mile radius limit does not necessarily apply to situations where a hydrogeological connection exists between the site and karstic features.

6. Are there one or more environmentally sensitive areas (see Ecological Risk Assessment Figure #1 for definition) at or within a ½ mile radius of the site?

7. Are commercially or recreationally important species (fauna or flora) on or within a ½ mile radius of the site?

If the answer is "Yes" to any of the above questions, then complete Ecological Risk Assessment Tier 1 Checklist for Potential Exposure Pathways, Checklist #2.

ATTACHMENT B

Ecological Risk Assessment
Tier 1 Screening Checklist for Potential Receptors and Habitat
Checklist #2

1.a.) Can contaminants associated with the site leach, dissolve, or otherwise migrate to groundwater?
1.b.) Are contaminants associated with the site mobile in groundwater?
1.c.) Does groundwater from the site discharge to ecological receptor habitat?
Question 1: Could contaminants associated with the site reach ecological receptors via groundwater?

2.a.) Is Non-Aqueous Phase Liquid (NAPL) present at the site?
2.b.) Is NAPL migrating?
2.c.) Could NAPL discharge occur where ecological receptors are found?
Question 2: Could contaminants from the site reach ecological receptors via migration of NAPL?

3.a.) Are contaminants present in surface soils?
3.b.) Can contaminants be leached from or be transported by erosion of surface soils?
Question 3: Could contaminants reach ecological receptors via erosional transport of contaminated soils or via precipitation runoff?

4.a.) Are contaminants present in surface soil or on the surface of the ground?
4.b.) Are potential ecological receptors on the site?
Question 4: Could contaminants reach ecological receptors via direct contact?

5.a.) Are contaminants present on the site volatile?
5.b.) Could contaminants on the site be transported in air as dust or particulate matter?
Question 5: Could contaminants reach ecological receptors via inhalation of volatilized contaminants or contaminants adhered to dust in ambient air or in subsurface burrows?

6.a.) Are contaminants present in surface and shallow subsurface soils or on the surface of the ground?
6.b.) Are contaminants found in soil on the site taken up by plants growing on the site?
6.c.) Do potential ecological receptors on or near the site feed on plants (e.g., grasses, shrubs, forbs, trees, etc.) found on the site?
6.d.) Do contaminants found on the site bioaccumulate?
Question 6: Could contaminants reach ecological receptors via ingestion of either soil, plants, animals, or contaminants directly?

7.a.) Are there karstic features (see Ecological Risk Assessment Figure #2 for definition) on or within a ½ mile radius of the site?
7.b.) Is there a hydrogeological connection between the site and karstic features such as seeps, springs, streams or other surface water bodies?

Question 7: Could contaminants reach ecological receptors via transport through a Karst system?

Note: A professional opinion may be necessary to answer 7.a, 7.b, and Question 7. The Missouri Environmental Geology Atlas (MEGA), published by the MDNR, Missouri Geological Survey (MSG), provides several state-wide, karst-related data sets, as well as others related to geology and hydrology, in a geographic information system format, that can assist in answering these questions. The MEGA, and software to view it, can be obtained from MSG by calling (573) 368-2125.

If the answer to one or more of the seven above questions is yes, MDNR may require further assessment to determine whether the site poses an unacceptable risk to ecological receptors.

Ecological Risk Assessment
Figure #1: Environmentally Sensitive Areas

Environmentally Sensitive Areas are areas of special significance due to the flora or fauna found on the area, the sensitive nature of natural features found on the area, historical considerations, or for other reasons associated with the environment of the area.

Examples of environmentally sensitive areas include, but are not necessarily limited to, the following:

- National and state parks,
- Designated and proposed federal and state wilderness and natural areas,
- Endangered, rare, and threatened species habitat as designated by the U.S. Department of the Interior or the Missouri Department of Conservation,
- National monuments,
- National and state historic sites,
- National and state lakeshore and river recreational areas,
- Federal or state designated scenic or wild rivers,
- Habitat of federal or state designated or proposed endangered, rare, or threatened species, and species under review as to their endangered, rare, or threatened status,
- National and state preserves and forests,
- National and state wildlife refuges,
- Critical fish and shellfish spawning areas,
- Critical migratory pathways and feeding areas for anadromous fish species within river reaches or areas in lakes where such species spend extended periods of time,
- Terrestrial areas used for breeding by large or dense aggregations of faunal species,
- State lands designated by the Missouri Department of Conservation for wildlife or game management,
- Wetlands, and
- Outstanding state resource waters as designated by the Missouri Clean Water Commission.

Ecological Risk Assessment
Figure #2: Karst Features

Karst: A distinctive set of geomorphic landforms resulting from the development of extensive subsurface solution channels and caves in carbonate rocks (Boulding, 1995).

6.0
GENERAL CONSIDERATIONS FOR RISK ASSESSMENT

A risk-based evaluation requires the consideration and understanding of several factors common to Tiers 1, 2 and 3. These factors include, but are not limited to:

- Development of an exposure model (EM),
- Calculation of risk-based target levels,
- Evaluation of groundwater use,
- Protection of surface water bodies,
- Estimation of representative chemical of concern (COC) concentrations,
- Ecological risk evaluation,
- Consideration of nuisance conditions,
- Evaluation of free product, and
- Activity and use limitations (AULs).

This section briefly discusses each of these factors and their application to the management of releases from UST/AST sites. Several of these factors include policy decisions made by the Groundwater Rule Stakeholders Group and documented in the draft process document (MDNR, 2003).

6.1 DEVELOPMENT OF AN EXPOSURE MODEL

The objective of an EM is to define the exposure pathways that are complete or may reasonably be expected to become complete under current or reasonably anticipated future conditions.

An EM identifies the (i) media of concern, (ii) receptors of concern, (iii) exposure pathways from the impacted media to the receptor, and (iv) routes of exposure. The EM presents a working hypothesis of the manner by which COCs migrate from the source to the **points of exposure (POEs)** where COCs come in contact with the receptors and exposure occurs. For each complete combination of source-pathway-route of exposure identified in the EM, risk-based levels must be developed for each COC (see Table 5-1 for a list of COCs). If migration of the COCs from the source to the receptors (i.e. the pathway) is not possible under current or reasonably anticipated future site use (e.g., due to engineering controls or AULs), the COCs will not cause any exposure. Without exposure there can be no risk. Thus for risk to be present at a site, at least one exposure pathway must be complete (or have a reasonable chance of becoming complete).

An EM is a qualitative evaluation based on information collected during site investigations (refer to Section 5.0). Typically, EMs for three time periods will be developed for each site: (i) current land use, (ii) short-term future land use, such as a period of construction, and (iii) long-term future land use. Consideration of current and future land use ensures that site-specific decisions will be protective of both. At sites where the current and future land use will be the same, EMs for current and future use would be identical.

Development of an EM requires knowledge of (i) land use, (ii) receptors, (iii) pathways and routes of exposure, and (v) exposure domain(s). Each of these elements is discussed in the following sections.

6.1.1 Land Use

Within the MRBCA process, land use is categorized as (i) residential or (ii) non-residential. Accurately identifying land use is important because target levels depend on the land use. Residential land use results in lower target levels and cleanup to these levels generally allows for unrestricted land use. Prior to issuing a No Further Action (NFA) letter, MDNR will require that certain sites cleaned to non-residential standards have some form of AUL. AULs are further discussed in Section 6.9 and Section 11.

Examples of residential and non-residential land use are presented below:

- **Residential or unrestricted land use –** Includes land uses where persons can be expected to reside for more than 8 hours a day, 7 days a week, such as homes, apartments, hospitals, nursing homes, schools, childcare centers, etc.

- **Non-Residential –** Includes land uses where persons can be expected to be on site less than 10 hours a day and absent on weekends and holidays. Examples include retail facilities, industrial and manufacturing operations, fleet operations, hotels and motels, offices, etc.

(**Note:** When a planned development includes a multi-story building, or mixed use, the presence of a day care facility or apartments on an upper floor does not necessarily mean that the applicable land use is "residential." Reasonable assumptions concerning exposures on the ground floor of the building (and subsurface floors, if such exist) should be used to develop cleanup levels.)

While it is not possible to identify every scenario in this document, the following guidelines are intended to assist in making land use determinations:

6.1.1.1 Determine Current Land Use

Identification of the use of the site and nearby properties is used to define potential on-site and off-site receptors that might be exposed to the COCs. Current land use and associated activities must be identified. Current land use refers to land use as it exists today and can be readily determined by a site visit. Thus there should be no ambiguity about current land use.

A visual, on-site land use survey, which should typically include properties within a 500-foot radius of the tank system, shall be conducted. The survey shall clearly identify the following: schools, hospitals, residences (apartments, single-family homes), buildings with basements, day care centers, churches, nursing homes, and types of businesses.

6.1.1.2 Determine Reasonably Anticipated Future Land Use

"Reasonably anticipated future use" means future use of a site or facility that can be predicted with a reasonably high degree of certainty given historical use, current use, development or use plans, local government planning and zoning, regional trends and community acceptance. In situations where there is an actual plan for development or redevelopment of a property, it shall be the primary consideration in determining "reasonably anticipated future use" when there is a sufficiently high degree of certainty that the plan will be implemented.

Conclusions regarding reasonably anticipated future (RAFU) use may be different for various properties included in the site conceptual model. However, a conclusion as to whether the RAFU for each property is "residential" or "non-residential" must be clearly presented, and the basis for each conclusion must be documented. The MDNR will be the final decision-maker regarding what the appropriate RAFU is for each property.

Future land use is always uncertain and its determination should be based on available information and good professional judgment. In the absence of definitive long-term development plans, the following factors may be used to determine reasonably anticipated future use:

Local planning and zoning ,
City/County development plans,
Current use of adjacent property,
Known future use of adjacent property,
Type and size of streets/highways adjacent to the property,
Existing deed instruments or similar instruments affecting the site and/or adjacent properties,
Building permits,
Financing Plans/Restrictions,
Interviews with current property owners, and
Community acceptance of proposed site development plans.

If an undeveloped parcel is located in a predominantly commercial/industrial area, then consideration of the parcel's future use as non-residential might be appropriate. However, if the setting is more rural or the land use is mixed, absent reliable evidence to the contrary, the undeveloped land should be considered residential.

6.1.1.3 On-site and Off-site Receptors

MRBCA evaluations must consider the impact of COCs to both on-site and off-site receptors. A plume moving off-site might impact multiple land uses and multiple receptors. For example, a plume may have migrated off-site below a residential and a non-residential area. In this case, both land uses have to be considered when developing the EM. For simplification, the following definitions should be used:

- **On-site**: The property located within the legal property boundaries within which the source of the release is located. This includes soil, groundwater, surface water, and air within those boundaries.

- **Off-site**: Property (ies) located outside the boundaries of the onsite property and on to which COCs associated with the release have or are likely to migrate. This includes soil, groundwater, surface water, and air located off-site.

6.1.2 Receptors

The MRBCA process requires consideration of both human and ecological receptors as discussed below:

6.1.2.1 Human Receptors

All current and future human receptors should be considered. At a minimum, the following human receptors are considered:

- Residential – Child, adult, and age-adjusted individual
- Non-residential Worker – Adult
- Construction Worker – Adult

The age-adjusted individual is one who lives at a site continuously from birth to age 30 (also refer to equations presented in Appendix B).

For residential land use, the lowest of the three target levels for child, age-adjusted, and adult are applicable.

Other human receptors such as visitors or maintenance workers will generally have less exposure than those listed above (due to lower exposure frequency and duration) and, therefore, their exposure and risk need not be quantified. However, if these or other such receptors will be or are known to be on the site for periods exceeding those considered for resident, non-resident worker, or construction worker, such receptors must be evaluated.

Because petroleum equipment companies are subject to other regulatory requirements regarding worker exposure, it is not necessary to evaluate the soil ingestion, inhalation, and dermal contact exposure pathway nor the dermal contact with groundwater exposure pathway for the construction worker receptor in the area in which an active underground storage tank (i.e., the tank pit) is located.

6.1.2.2 Ecological Receptors

All sites evaluated under MRBCA must be screened for the presence of ecological receptors and/or their habitats, except for those sites where initial sampling data indicates that COC concentrations are below the default target levels (DTLs) and the site poses no

obvious threat to ecological receptors. At certain sites where exposure to wetlands, sensitive environments, wildlife, threatened and/or endangered species, or other ecological receptors is complete, a quantitative ecological risk evaluation may have to be completed. The level of cleanup at such sites should be based on the lower of the target levels for human and ecological receptors. The MRBCA tiered ecological risk evaluation process is further discussed in Section 6.6.

As appropriate, surface water bodies should be evaluated to determine potential impacts of discharging groundwater or surface runoff from the release site. Such an evaluation might require information on the location, flow rates, depth, flow direction, and designated beneficial uses of specific surface water bodies. Refer to Section 5.10 and 6.4 for further information.

6.1.2.3 Utilities

On-site and off-site underground utilities and, specifically, their ability to serve as petroleum contamination conduits, must be evaluated. Adverse impacts to utilities might include degradation of water and sewer lines; vapors in storm and sanitary sewers; damage to outer coatings of gas lines; damage to plastic lines, and damage to buried phone and electrical lines due to contact with chemicals. Utility evaluations are of particular importance at sites where utilities may come in contact with free product for an extended period of time. Refer to Section 5.4.3 for further information regarding the evaluation of utilities.

6.1.3 Human Exposure Pathways and Routes of Exposure

A receptor comes in contact with COCs if a complete exposure pathway exists under current or future land use conditions. For a pathway to be complete, there must be a (i) chemical source, (ii) mechanism by which the chemical is released, (iii) medium through which the chemical travels from the point of release to the receptor location, and (iv) a route of exposure by which the chemical enters the receptor's body and potentially causes adverse health effects.

Commonly encountered exposure pathways that must be considered are discussed below. For each complete pathway, the MRBCA process requires (i) collection of sufficient data to estimate the representative concentrations of COCs for each pathway (except for surficial soil in a residential setting where the maximum COC concentrations are used), and (ii) the comparison of representative (or maximum) concentrations with target levels for the corresponding pathway.

6.1.3.1 Pathways for Inhalation

For the inhalation pathway, chemical intake occurs indoors and outdoors at a site via the inhalation of vapors. Depending on the toxicity of the chemical, unacceptable exposures via the inhalation pathway might occur at concentrations below the odor threshold levels (i.e., receptors might be unaware of their exposure). If the source of

these vapors is volatile chemicals in soil and/or groundwater, their migration through the capillary fringe, unsaturated zone, and cracks in the floor/foundation to indoor or outdoor air must be evaluated. As discussed in Section 5.4.3, the potential for utilities to act as a conduit for vapors must also be evaluated. Relative to outdoor inhalation, indoor inhalation is the "risk driver," hence outdoor inhalation is not quantitatively evaluated except when there is or could be direct contact with soil (e.g., construction worker).

To quantitatively evaluate the indoor inhalation pathway, use the following approach (also refer to Appendix C, Figure C-1):

- **Tier 1 risk assessment:** Compare representative soil and groundwater concentrations to the applicable soil and groundwater target levels in Tables 7-1 through 7-6. Soil vapor sampling may be conducted at Tier 1.[1] When conducted, the sampling results shall be compared to the Tier 1 soil vapor RBTLs found in Tables 7-1 (residential land use) or 7-2 (non-residential land use), whichever is applicable. NOTE: If soil vapor sampling is done, the measured soil vapor concentrations *must* be used to evaluate the indoor inhalation risk in lieu of using soil and groundwater data to analyze this risk.

  Tier 2 risk assessment: Calculate Tier 2 SSTLs for residential and/or non-residential use, as appropriate for each impacted property.

  If soil vapor sampling was not conducted as part of Tier 1, determine whether to do it as part of the Tier 2 risk assessment.[1]

  How one assesses indoor inhalation risk at Tier 2 depends on whether soil vapor sampling is done. If soil vapor sampling is *not* done, compare representative concentrations of COCs in soil and groundwater to the calculated Tier 2 inhalation target levels to determine whether there is an indoor inhalation risk. If soil vapor sampling *is* done, the measured soil vapor concentrations *must* be used to evaluate the indoor inhalation risk in lieu of using soil and groundwater data to analyze this risk; use appropriate representative concentrations of measured soil vapor samples.

- **Tier 3 risk assessment:** Several options are available, each of which requires the development of a work plan and its approval by MDNR prior to implementation. Two examples are presented below:

  - Option 1: Use of measured soil, groundwater, or soil vapor concentrations with alternative models to estimate target risk due to indoor inhalation,
  - Option 2: Indoor air concentrations may be measured and compared with indoor air target levels. However, due to several difficulties associated with accurately determining whether and to what extent COCs detected in indoor air are attributable to soil and/or groundwater impacts, direct measurement of indoor air is seldom conducted.

[1] Refer to Appendix C for a discussion of soil vapor monitoring and development of SSTLs for soil vapor.

The exposure model for an active tank facility may assume that no building will be constructed over the tank pit.

6.1.3.2 Pathways for Surficial Soils (0 - 3 feet bgs)

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

- Leaching to groundwater and potential use of groundwater,
- Leaching to groundwater and subsequent migration to a surface water body, and
- Ingestion of soil, dermal contact with soil, and outdoor inhalation of vapors and particulates emitted by surficial soils.

6.1.3.3 Pathways for Subsurface Soils (>3 feet bgs to the water table)

Subsurface soils are defined as soils from three feet below ground surface to the water table or to bedrock, whichever occurs first. Exposure pathways associated with subsurface soils include:

- Indoor inhalation of vapor emissions,
- Leaching to groundwater and potential use of groundwater, and
- Leaching to groundwater and subsequent migration to a surface water body.

It is important to note that no distinction is made between the surface and subsurface soil for the construction worker. Instead, dermal contact, accidental ingestion, and outdoor inhalation of soil vapors and particulates from soils are considered complete pathways up to the typical depth of construction.

6.1.3.4 Pathways for Groundwater

Potentially complete exposure pathways for impacted groundwater include:

- Volatilization and upward migration of vapors from groundwater and potential indoor inhalation of vapor emissions,
- Ingestion of water if the groundwater is a current or future source of drinking water,
- Dermal contact with groundwater, and
- Migration to a surface water body and potential impacts to surface waters.

6.1.3.5 Pathways for Surface Water and Sediments

Depending on the use designation of the surface waters, potentially complete routes of exposure for surface water include:

- Ingestion of surface water,
- Contact with surface water during recreational activities (ingestion, inhalation of

vapors, and dermal contact),
- Ingestion of fish, and
- Contact with (accidental ingestion and dermal contact with) sediments.

In addition, ecological effects must be considered if surface water impacts are present.

Each of the above routes of exposure for surface water and sediments must be considered as part of the exposure assessment. If all of these routes of exposure are considered incomplete, no quantitative evaluation is necessary. Refer to Section 6.4 for information regarding the quantitative evaluation of these pathways.

6.1.3.6 Other Pathways

At some sites, other routes of exposure might be significant. These include, but are not limited to, exposure due to (i) ingestion of produce grown in impacted soils, (ii) exposures associated with use of groundwater for irrigation purposes, or (iii) use of groundwater for industrial purposes.

At UST/AST sites, these routes of exposure are likely to be significant only in rare cases and will be evaluated at Tier 3.

6.1.4 Exposure Domain

A key part in the development of an EM is the determination of the size and location of the exposure domain for each pathway, route of exposure, and receptor. The exposure domain is the portion of the total impacted area that contributes to the receptor's exposure via a specific pathway and route of exposure. The exposure domain can vary with the receptor and the route of exposure.
The following three examples may help clarify the concept of the exposure domain:

Example 1: For exposures within an existing building by indoor inhalation of vapors from subsurface soil, the exposure domain would be the volume of soil within the footprint of the building that contributes vapors to the indoor air.

Example 2: For direct contact with surficial soil, the exposure domain would be the area of impacted surficial soil that the receptor might come in contact with.

Example 3: For the protection of groundwater, the domain would be the volume of soil that could contribute chemicals to the groundwater plume via leaching and infiltration.

For each receptor and each complete route of exposure, the exposure domain must be determined. Concentrations measured within each exposure domain must be used to estimate the representative concentrations for each complete pathway, as discussed in Section 6.5 (except, as noted above, maximum COC concentrations are used for the evaluation of surficial soil in a residential setting).

6.2 CALCULATION OF RISK-BASED TARGET LEVELS

Within the MRBCA process, risk-based target levels include:

- Default target levels (DTLs),
- Tier 1 risk-based target levels (RBTLs),
- Tier 2 site-specific target levels (SSTLs), and
- Tier 3 SSTLs.

Note that the DTLs are the lowest of the Tier 1 RBTLs for soil and groundwater.

Also refer to Appendix B (Sections B.8 and B.9) for a discussion of the target levels for lead and target levels when LNAPL is present on groundwater.

Calculation of the above target levels requires quantitative values of (i) target risk, (ii) chemical-specific toxicological factors, (iii) receptor-specific exposure factors, (iv) fate and transport parameters, (v) physical and chemical properties of the COCs, and (vi) mathematical models. Each of these is discussed below (also refer to Appendix B):

6.2.1 Target Risk Level

For carcinogenic effects, risk is quantified using **individual excess lifetime cancer risk (IELCR),** a value that represents an increase in the probability of an individual developing cancer due to exposure to a chemical via a specific route of exposure. For petroleum tank sites, the target IELCR for each COC and route of exposure is 1×10^{-5}.

For non-carcinogenic effects, risk is quantified using a **hazard quotient (HQ)** that represents the ratio of the estimated dose for a chemical via a specific route of exposure to the reference or allowable dose. At petroleum UST/AST sites, the target HQ for each COC and each route of exposure is 1.0.

Due to the limited number of COCs at typical petroleum UST/AST sites, the additivity of risk due to multiple chemicals and multiple routes of exposure is not considered.

6.2.2 Quantitative Toxicity Factors

The toxicity of chemicals is quantified using slope factors for chemicals with carcinogenic adverse health effects and reference doses for chemicals that cause non-carcinogenic adverse health effects. Toxicity values may differ for the inhalation, dermal and ingestion pathways.

Toxicity values for the COCs are presented in Appendix B. MDNR requires that the most recent toxicity values recommended by the US EPA be used. For a Tier 3 risk assessment, values other than those presented in Appendix B may be used if their use can be adequately justified and the values are approved by MDNR.

6.2.3 Exposure Factors

Exposure factors describe the physiological and behavioral characteristics of the receptor and are typically estimated based on literature rather than site-specific measurements. Default exposure factors for calculating Tier 1 and Tier 2 target levels are presented in Appendix B. For a Tier 3 risk assessment, a combination of site-specific and default exposure values may be used if their use can be adequately justified and the values are approved by MDNR.

6.2.4 Fate and Transport Parameters

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties (such as depth to groundwater, soil porosity, and infiltration rate) and building characteristics (such as the height of a building and the air exchange rate). For calculating DTLs and Tier 1 RBTLs, MDNR has selected the conservative default fate and transport values presented in Appendix B. For Tier 2, a combination of site-specific and default values may be used. However, all the values used must be justified based on site-specific considerations.

6.2.5 Physical and Chemical Properties

The development of target levels requires the physical and chemical properties of the COCs that are listed in Appendix B. Several of the physical and chemical properties are experimentally determined; hence their values are not exact and include a certain amount of variability. MDNR requires the use of values presented in Appendix B for all tiers, unless there are justifiable reasons to modify these values. The use of different values would be allowed only under a Tier 3 risk assessment and upon MDNR's approval of a work plan.

6.2.6 Mathematical Models

Two types of models, or equations, namely the (i) uptake equations, and (ii) fate and transport models, are required to calculate the target levels. For the calculation of DTLs, Tier 1, and Tier 2 target levels, MDNR has selected the following fate and transport models:

Indoor Inhalation of Volatile Emissions from Soil and Water: This pathway requires (i) an emission model and (ii) an indoor air mixing model. These models are combined together and included in the Johnson and Ettinger Model (US EPA, 2001) and are used in the MRBCA process. Note that the model used in the MRBCA process does not include advective transport of vapors.

Surficial Soil Outdoor Inhalation (construction worker only): This pathway requires (i) an emission model for vapors, (ii) an emission model for particulates, and (iii) an outdoor air mixing model. The vapor emission model used is based on the volatilization model developed by Jury et al. (1984) for an infinite source. The particulate emissions

model is based on Cowherd's model, and the outdoor air mixing model is a simplified form of the Gaussian Dispersion model. These models are presented in the Soil Screening Guidance Document (US EPA, 1996).

Leaching to Groundwater: This pathway requires (i) equilibrium conversion to convert soil concentrations to leachate concentration, and (ii) mix the leachate with the regional groundwater. The equilibrium conversion model is that found in EPA's Soil Screening Guidance Document (US EPA, 1996). Summer's model is used for mixing of the leachate with the groundwater.

Horizontal Migration in Groundwater: Domenico's steady-state infinite source model is used to quantify the downgradient migration of chemicals. For Tier 2 risk assessments, a biodegradation rate may be used if it can be justified based on site-specific conditions and has the prior approval of MDNR.

Unsaturated Zone Transport: For the calculation of Tier 2 values, the following dilution attenuation factors (DAF) will be used:

Depth to groundwater of less than 20 feet, DAF = 1
Depth to groundwater 20-50 feet, DAF = 2
Depth to groundwater > 50 feet, DAF = 4

DAF represents the reduction in the concentration, due to the combined influence of natural attenuation processes, of the leachate as it migrates from the "source" to the bottom of the unsaturated zone (typically the water table). A DAF of 1 indicates that there is no reduction in concentration. A DAF of 2 implies that the concentration of the leachate reduces by a factor of 2 as the leachate migrates from the "point of generation" to the water table. The DAF factors presented above are empirical. For a Tier 3 risk assessment, unsaturated zone fate and transport models may be used to estimate the unsaturated DAF, with the approval of MDNR.

6.3 EVALUATION OF GROUNDWATER USE

Within the MRBCA process, all current and reasonably anticipated future use of groundwater must be protected. Impacts to groundwater and potential exposures via the groundwater ingestion pathway are of significant concern in Missouri since several areas of the state obtain their drinking water from groundwater sources. The evaluation process and groundwater protection measures are intended to be used in cases where groundwater has been impacted or is likely to be impacted by a site-specific petroleum release. This process has the following objectives:

- To protect all current and reasonably likely future domestic use of groundwater,
- To provide a rational basis for incorporating site-specific characteristics into the determination of groundwater target levels, and
- To facilitate the development of properties based on reasonable expectations for groundwater cleanup.

A key consideration in developing risk-based groundwater target levels is whether the groundwater use pathway is complete under current or future conditions. The process used to make this determination is shown in Figure 6-1 and discussed below. Note that this determination is required for all groundwater zones at and in the vicinity of a site.

Figure 6-1 focuses on the domestic use of groundwater. As a part of this step, other groundwater uses (e.g., cooling water, industrial process water, etc.) must also be identified.

Evaluations of groundwater use must be in strict accordance with Figure 6-1 and each applicable element of Figure 6-1 must be clearly addressed in a risk assessment report. MDNR recommends these conclusions be presented in the same order as the evaluation criteria in Figure 6-1.

At some sites, the zone of groundwater contamination and the zone utilized for domestic use might not be the same. Therefore, as shown in Figure 6-1, the first step in determining whether the groundwater use pathway is complete is to identify all groundwater zones beneath a site and whether they are interconnected.

6.3.1 Current Conditions

The current groundwater use pathway is considered complete if (i) there are existing wells near the site, and (ii) the wells are reasonably likely to be impacted by COCs.

The existence of wells near the site is determined based on a water well search that might range, at a minimum, from a search of the State of Missouri well database to a door-to-door survey. The level of effort will depend on site-specific considerations. For example, in urban areas having a municipal water supply, a door-to-door survey might not be necessary whereas in rural areas where groundwater is the primary source of water, a door-to-door survey might be necessary. The survey shall identify all private water wells within a one-quarter (¼) mile radius and all public water supply wells within a one-mile radius of the tank system.

Whether the wells have a reasonable probability of impact depends on the distribution and migration potential of COCs relative to the groundwater zone or zones of interest. Whether COCs will reach a groundwater zone of interest depends on the volume of the release and the properties of the subsurface soil and bedrock. Once COCs impact groundwater, whether they have a reasonable probability of reaching a point of exposure, (such as an existing well), depends on hydrogeological conditions including, but not limited to: (i) groundwater flow direction, (ii) distance to well, (iii) the zone where the wells are screened, (iv) casing of the well, and (v) biodegradability and other physical/chemical properties of the COCs. Depending on site-specific conditions, a fate and transport model may be used to evaluate the potential impacts (generally, such modeling would be a Tier 3 activity).

6.3.2 Future Conditions

All groundwater zones beneath and/or in the vicinity of the site that could potentially be targeted in the future for the installation of domestic water wells must be identified. For the purposes of this analysis, the saturated zone can be divided into multiple "layers", but all layers within the saturated zone must be considered[2].
For each zone, determining whether the future groundwater use pathway is complete or likely to be complete is based on consideration of the following factors:

Determination of Sufficient Activity and Use Limitations (AUL): If there is an AUL in place that essentially eliminates any reasonable probability that a groundwater zone under consideration will ever serve as a future source of domestic water, no further evaluation of the groundwater use (domestic consumption) pathway is required for that groundwater zone.

Suitability for Use Determination: For groundwater to be considered a viable water supply source, total dissolved solids (TDS) and yield criteria must be met. Groundwater containing less than 10,000 mg/L total dissolved solids shall be considered as having sufficient natural quality to serve as a potential source of domestic water.

Groundwater zones capable of producing a minimum of 1/4 gallon per minute or 360 gallons per day on a sustained basis shall be considered as having sufficient yield to serve as a potential source of domestic water. 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-ft diameter augered 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 D for further guidance on determining whether a particular zone should be considered as a potential domestic water source.

Groundwater zones meeting both TDS and yield criteria shall be considered as suitable for domestic use.

Sole Source Determination: If the groundwater zone being considered is the only viable source of water at or in the vicinity of the site (groundwater or surface water), then one must assume that future domestic use is reasonable (irrespective of TDS or yield considerations), and evaluate whether the zone is likely to be impacted by COCs from the site. Determining the availability of alternative water supplies must include consideration of other groundwater zones, municipal water supply systems, and surface water sources. Note, however, in accordance with Figure 6-1, if the groundwater zone being evaluated is determined to be suitable for use, the sole source determination step of the evaluation is not relevant.

[2] It must be assumed that all zones currently utilized will be utilized in the future as well.

Probability of Future Use Determination: The probability that a groundwater zone could be used as a future source of water for domestic consumption shall be evaluated based on consideration of the following factors:

- Current groundwater use patterns in the vicinity of the site under evaluation,
- Suitability of use (e.g., TDS, yield),
- Availability of alternative water supplies,
- AULs,
- Urban development considerations for sites in areas:
  - of intensive historic industrial/commercial activity,
  - located within metropolitan areas that had a population of at least 70,000 in 1970, and
  - having groundwater zones in hydraulic communication with such industrial/commercial surface activity.
- Aquifer capacity limitations (ability to support a given density of production wells).

The above factors will be evaluated on a "weight of evidence" basis: the weight that a single factor will be given in determining the probability of future use will vary based on site-specific considerations, including the durability of the AUL.

The degree to which AULs will affect the determination will depend on the attributes of the specific AUL. If the attributes of the AUL are not appropriate, the groundwater zone might remain a reasonably likely future domestic water source, despite the existence of the AUL. If the AUL does not explicitly apply to a specific water bearing zone that meets each of the following criteria, that groundwater zone will generally be determined as having a reasonable probability of future use:

(i) The zone is the highest quality groundwater resource (considering both yield and natural quality) in the hydrostratigraphic column.
(ii) The zone has sufficient quantity and yield to serve as a primary component of the regional water supply.
(iii) The zone has no widespread groundwater impacts associated with historic human activity in the vicinity of the site (excluding groundwater impacts associated with the specific site).

The above is only one set of circumstances that would result in a determination that the groundwater zone has a reasonable probability of future use as a domestic water supply. Other circumstances might result in the same determination.

Each groundwater zone that has a reasonable probability of future use as a domestic water supply shall be carried forward to the "probability of impact" determination discussed below.

Probability of Impact Determination: The probability that the site could impact the water quality in a groundwater zone having a reasonable probability of serving as a future source of domestic water shall be evaluated. The evaluation shall 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. For the purpose of evaluating potential site impacts to groundwater zones that could serve as future water supply sources, the potential impact shall 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.

6.3.3 Evaluation of Complete Pathway

If the groundwater use pathway is deemed to be complete under current or future conditions, it must be quantitatively evaluated as follows:

Step 1: Identification of the critical POE. The POE shall be the nearest down-gradient three-dimensional location that could reasonably be considered for installation of a groundwater supply well. Note that the POE need not necessarily be an actual existing well; the POE could be a hypothetical well.

Step 2: Determination of target levels at the POE. For chemicals that have maximum contaminant levels (MCLs), the target level at the POE will be the MCLs. For chemicals that do not have MCLs, the target levels will be the risk-based calculated value that assumes groundwater ingestion and indoor inhalation of vapors based on water use. Note that the indoor inhalation of vapors based on water use pathway will be considered only for volatile COCs (refer to Figure 6-2).

Step 3: Identification of point of demonstration (POD) wells and calculation of target levels at the POD. POD wells are found between the source and the POE for the purpose of monitoring COC concentrations in groundwater as a means of protecting against exceedances at the POE. Risk-based target concentrations will be developed for the POD using appropriate fate and transport models and site-specific parameters as explained in Appendix B. If the POE is within an area where COCs in groundwater currently exceed applicable target levels, a POD is not relevant. A POD is relevant only if the POE is outside the area where COCs in groundwater exceed applicable target levels.

Step 4: Calculation of soil COC concentrations in the area of release. Risk-based target levels for soil and groundwater source areas are calculated as indicated in Appendix B.

Thus the quantitative evaluation of this pathway requires the calculation of target levels at the (i) POE, (ii) POD, and (iii) soil point and area of release. The soil point and area of release concentrations must be compared with representative concentrations at the site while the POE and POD are to be compared to COC concentrations at those points. If the POE is within the groundwater COC plume, target levels for the POD and groundwater source are not applicable.

6.4 SURFACE WATER AND STREAM PROTECTION

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Sampling for COCs in surface water bodies will be necessary when COC migration is known or suspected to adversely affect a surface water body.

6.4.1 Protection of Streams

Protection of streams requires the determination of (i) stream classification, (ii) identification of the use designations of the stream, (iii) estimation of allowable COC concentrations in the stream, (iv) determination of stream 7Q10, and (v) calculation of allowable COC concentrations at various locations within the stream and the groundwater plume. The latter include:

- Instream COC concentrations at the downstream edge (and beyond) of a mixing zone (C_{sw}),
- Instream COC concentrations at the downstream edge (and beyond) of the zone of initial dilution, if applicable (C_{zid}),
- Groundwater COC concentrations at the point of discharge of the groundwater plume to the surface water body (C_{gw}),
- Groundwater COC concentrations at points of demonstration at different distances between the source and the point of discharge (C_{pod}), and
- Soil COC concentrations at the source area soils (C_{soil}).

The locations of these various points are schematically shown in Figure 6-3. Depending on site-specific conditions, sampling for COC concentrations at one or more of these locations may be necessary.

The procedure for protection of streams and surface waters is shown in Figure 6-4 and discussed below:

Step 1: Determine stream classification: As per 10 CSR 20-7.031(1)(F), streams in Missouri are classified as Class C, Class P, or P1 waters. Stream classification applies to specific reaches of a stream and not necessarily to the entire stream length. Classification of streams and the length of the classified segment can be found in Table H of 10 CSR 20-7.031. Streams not included in Table H are unclassified (Class U) and have no assigned designated uses.

Step 2: Determine the beneficial use designation(s) of the stream: As per 10 CSR 20-7.031(1)(C), beneficial uses of a stream include one or more of the following:

- Irrigation (IRR),
- Livestock & wildlife watering (LWW),
- Protection of warm water aquatic life/human health – fish consumption (AQL),
- Cool water fishery (CLF),

- Cold water fishery (CDF),
- Whole body contact recreation (WBC),
- Boating and canoeing (BTG),
- Drinking water supply (DWS), and
- Industrial (IND).

Beneficial use designations for classified streams are tabulated in Table H of 10 CSR 20-7.031. A stream may have multiple beneficial use designations, in which case all beneficial uses must be identified.

Step 3: Determine stream water quality criteria: Stream water quality criteria depend on the beneficial use designation(s) of the stream and can be found in Table A of 10 CSR 20-7.031. For the COCs relevant to petroleum storage tank sites, the criteria are also presented in Table 6-1. For streams 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. For specific water quality criteria values, refer to 10 CSR 20-7.031, Table A.

If chemicals for which water quality criteria are not available are present at a site, contact MDNR's Water Protection Program (WPP) for further guidance.

For Class C and Class P or P1 streams, water quality criteria must be met at the downstream edge of the mixing zone. For unclassified streams, applicable water quality criteria must be met at the point of groundwater discharge to the stream.

Step 4: 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 shall follow current industry practices as included in USGS and USEPA literature. 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 0.0 cfs. Also, 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. Specific equations are included in Appendix B. For flow-regulated streams, contact MDNR's WPP for the estimation of 7Q10.

Step 5: Estimate concentrations at the point of discharge: The concentrations at the point of discharge can be estimated using mass balance considerations. For streams with a 7Q10 of 0.1 cfs or greater, the stream flow to be used in the calculation is 0.25 of the 7Q10 flow calculated in Step 4. The specific equations are included in Appendix B.

Step 6: Estimate groundwater and soil concentrations: Applicable COC concentrations for soil and groundwater can be back-calculated using the concept of DAFs. The specific equations, a combination of the Summer's Model and the Domenico's model, are presented in Appendix B.

The soil and groundwater COC concentrations discussed above apply to the protection of surface water. Other routes of exposure from groundwater, such as inhalation of volatiles and ingestion of groundwater, must also be evaluated as part of the process. Cleanup criteria based on these routes of exposure may result in allowable COC concentrations lower than those protective of a surface water body.

Step 7: Other considerations: 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 discussed in 10 CSR 20-7.031(3).

In addition to meeting chronic water quality criteria at the downstream edge of the mixing zone, acute water quality criteria must be met as per the following:

- For Class C and unclassified streams, the acute criteria must be met at the point of discharge.
- 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.
- 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.

6.4.2 Protection of Lakes

For lakes the above considerations also apply. Note that the mixing zone shall not exceed one-quarter (¼) of the lake width at the discharge point or one hundred feet (100 ft) from the point of discharge, whichever is less. Also, a zone of initial dilution is not allowed in lakes.

6.5 ESTIMATION OF REPRESENTATIVE CONCENTRATIONS

Application of the MRBCA process results in target levels for each complete pathway identified in the EM and each associated COC. For site-specific risk management decisions, these target concentrations must be compared with appropriate representative concentrations. Note, however, that for the direct contact with surficial soil pathway at a residential site, the target levels are compared with the maximum surficial soil COC concentrations. In addition, representative concentrations are not determined when comparing COC concentrations to the DTLs. Rather, maximum COC concentrations are used in this comparison.

Note that representative concentrations must be calculated for each complete route of exposure. Since there may be several complete pathways at a site, several representative concentrations, one for each complete pathway, must be calculated. If the maximum media-specific concentration of a COC for a specific pathway does not exceed the target level for that pathway, a representative concentration need not be calculated for that pathway.

Calculation of representative concentrations is further discussed at Appendix E. A brief summary is presented in Table 6-2.

6.6 ECOLOGICAL RISK EVALUATION

A key objective of the MRBCA process is to manage sites so that they are protective of both human health and the environment, the latter including all non-human organisms and their habitat (i.e., ecological receptors). Exposures to ecological receptors must be evaluated to ensure such receptors are adequately protected.

A three tiered process has been developed to incorporate ecological protection into the MRBCA process. The ecological protection process includes the following:

Except at sites where initial investigations indicate that COC concentrations are below the DTLs and the site poses no obvious threat to ecological receptors, a Tier 1 ecological evaluation must be performed at every site to identify whether any ecological receptors or habitat exist at, adjacent to, or near the site. This evaluation is accomplished through completion of Ecological Risk Assessment Checklist #1 (Attachment A located at the end of Section 5), consisting of eight questions. MDNR intends for this checklist to be a qualitative evaluation that can be completed by an experienced environmental professional who is not necessarily a trained biologist or ecologist. The checklist is designed such that, if the answer to all the questions is negative, no further ecological evaluation is necessary and there are no ecological concerns at the site.

A positive answer to any one of the eight questions in the checklist implies that a receptor or a habitat exists on or near the site and, therefore, further evaluation is warranted. If any of the questions in checklist 1 are answered in the affirmative, a second checklist, Checklist #2 (Attachment B located at the end of Section 5), consisting of seven questions, must be completed. The intent of this checklist is to determine whether any complete pathways to the receptor(s) identified in Checklist #1 exist. If the answer to all the questions is negative, the implication 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. If the answer to one or more of the seven questions is positive, a Tier 2 risk assessment may be necessary to determine whether contamination at the site being evaluated poses an unacceptable risk to ecological receptors.

A Tier 2 ecological evaluation will include comparison of site-specific COC concentrations that might reach an environmental receptor to existing literature values. Examples of existing sources of these values include, but are not limited to, the following:

- Oklahoma's Water Quality Standards as presented in Title 785: Oklahoma Water Resources Board, Chapter 45. Oklahoma's Water Quality Standards. Subchapter 5. Surface Water Quality Standards. Part 3. Beneficial Uses and Criteria to Protect Uses. Acquired from the Oklahoma Water Resources website http://www.state.ok.us/~owrb/wq/StandardsNew_final.htm.

- Ecotox Thresholds (ETs) as presented in ECO Update, US EPA, Office of Solid Waste and Emergency Response. Publication 9354.0-12FSI, EPA 540/F-95/038, PB95-963324. January 1996. Officer of Emergency and Remedial Response Intermittent Bulletin Volume 3, Number 2.

- ORNL Values as presented in Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision. ES/R/Tm-96/R2. Suter II and C.L. Tsao. June.

If comparison of site-specific soil, groundwater, surface water, or sediment values indicates that applicable values are exceeded, available options include: (i) performance of a Tier 3 ecological evaluation or (ii) use of the applicable literature values as cleanup goals. If the latter option is chosen, a corrective action plan (CAP) must be submitted, approved by MDNR, and implemented in a timely manner.

A Tier 3 ecological evaluation will include a detailed site-specific evaluation as per the current U.S. EPA guidance on performing risk evaluation (for instance, EPA's April 1998, Guidelines for Ecological Risk Assessment, EPA/630/R-95/002F). A Tier 3 risk assessment will require the development of a site-specific, detailed work plan and approval of MDNR prior to its implementation.

6.7 CONSIDERATION OF NUISANCE CONDITIONS

In addition to the evaluation of human health and ecological risks, any nuisance conditions that exist, such as objectionable taste or odor in groundwater, aesthetic problems with resurfacing groundwater, and odor from soils remaining in place, must be documented and reported to MDNR.

6.8 EVALUATION OF LIGHT NON-AQUEOUS PHASE LIQUID (LNAPL)

Detection of the mobile phase of LNAPL, known as free product, must trigger a response sufficient to achieve the following objectives:

1. Free product must not be present at levels that would cause explosive conditions to occur at or near the site (see 10 CSR 26-2.075),
2. The extent of free product in the environment shall be fully delineated,
3. Dissolution of and volatilization from LNAPL must not generate dissolved phase or vapor phase concentrations that result in unacceptable human or ecological risk,
4. Free product must no longer be migrating, and
5. Free product shall be removed to the maximum extent practicable.

When data collected under the MRBCA process shows that these goals have been achieved, no further evaluation or removal of free product will be required. In some cases, provided all other requirements are met, MDNR may issue a NFA letter for a site even though free product remains.

A brief discussion of each of these objectives is presented below.

6.8.1 Protection against Explosive Risk

In certain circumstances, the presence of free product can pose a risk of explosion due to vapor migration and accumulation. At sites where free product is present, vapor monitoring must be conducted in the area immediately above and within 100 feet of the known extent of free product. Such monitoring must use monitoring equipment capable of detecting contaminants associated with the specific type of free product found at a site at concentrations equal to or less than 10 percent of the lower explosive limit (LEL) of each volatile component of the free product. Vapor concentrations must be monitored at all utilities, subsurface and surface structures, and any other enclosed spaces found immediately above and within 100 feet of the known extent of the free product plume. The detection of vapors at concentrations equal to or greater than 10 percent of the LEL of any one of the volatile components of the free product shall constitute a potential explosion hazard and shall require abatement. Refer to Table 6-3 for a listing of the LELs and 10% LELs of various volatile petroleum components.

6.8.2 Free Product Plume Shall be Fully Delineated

The occurrence of free product petroleum must be documented and investigations must be conducted to determine the extent of the free product and whether and to what extent it is migrating. This determination will require the installation of a number of borings and monitoring wells sufficient to fully define the free product and periodic measurement of free product in these wells. The resulting data must be sufficient to demonstrate spatial and temporal trends in free product thickness. Note that free product thickness is critically affected by water table fluctuations. Therefore, the collection of sufficient data, especially at sites where there are strong seasonal and long-term water table fluctuations, is very important to ensure accurate delineation and characterization.

6.8.3 Free Product Tiered Risk Assessment

Free product can pose a direct risk to human health via, for instance, vapor migration or direct contact. The risk free product poses to human health and the environment depends, in part, on the dissolved and vapor phase concentrations associated with the free product. These concentrations, in turn, depend on the composition of the free product. For a Tier 1 risk assessment, the default free product composition values shown in Table 5-2 are used to estimate the dissolved and vapor phase concentrations associated with free product at a site. To accurately evaluate free product at Tier 1 requires that the evaluator know the specific type of free product present at his or her site (e.g., gasoline, diesel fuel, etc.). If the free product is composed of more than one type of petroleum, all applicable values from Table 5-2 must be used. The specific equations used to calculate the values in Table 5-2 are presented in Appendix B.

For a Tier 2 risk assessment, a sample of the free product at the site can be used to determine the mole fraction of the various COCs comprising the free product and these site-specific values can be used to evaluate risk. In the absence of such site-specific

values, default values from Table 5-2 may be used at Tier 2 with adequate justification. At Tier 3, alternate technically defensible methods and models to evaluate free product, whether as to composition, fate and transport, or plume stability, may be proposed in the work plan and used upon approval by MDNR.

6.8.4 Free Product Plume Stability

The stability of the free product plume must be evaluated. The outcome of such an evaluation will, in part, dictate whether and to what extent continued free product recovery is required. Refer to Section 5.9.3 of this document for information regarding demonstrations of plume stability.

6.8.5 Practicability of Free Product Removal

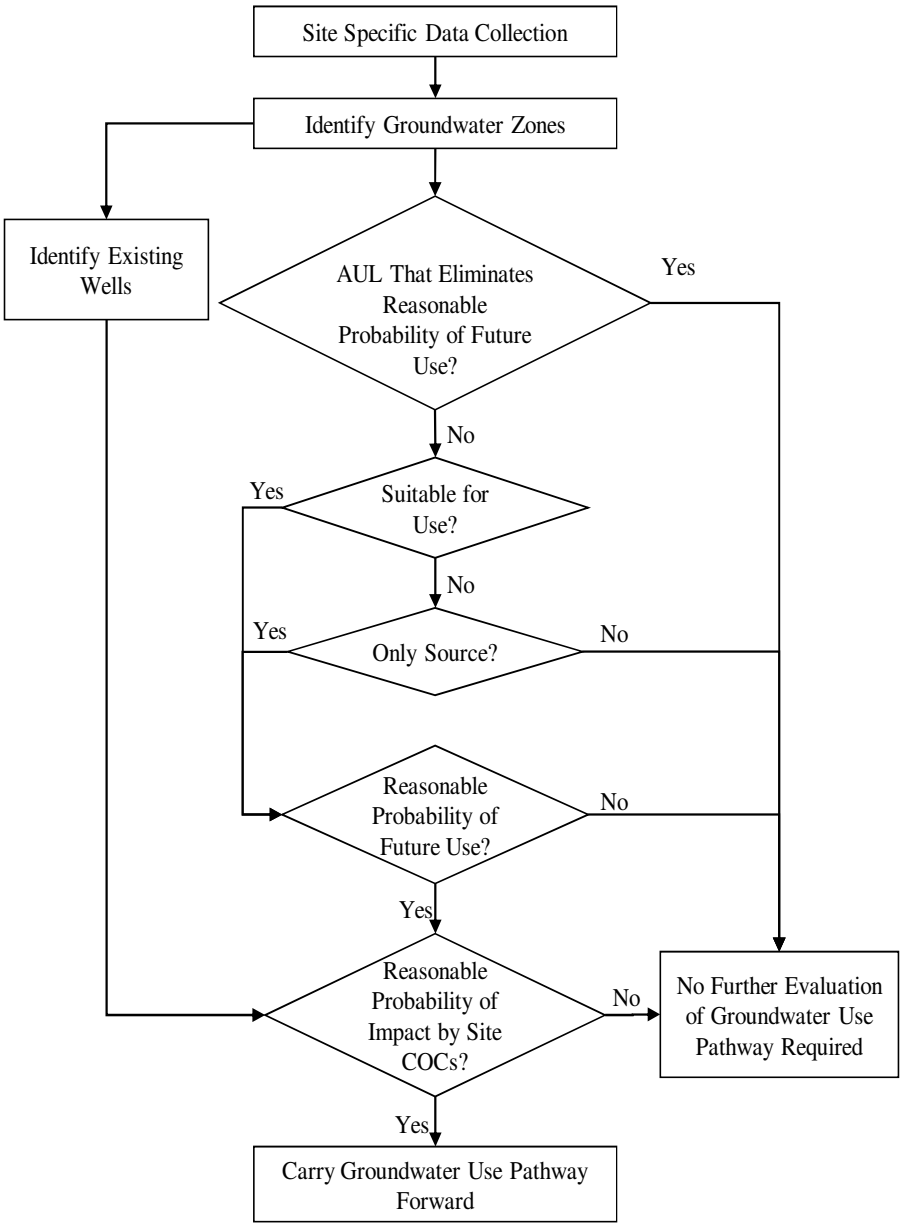
Free product must be removed from the environment to the maximum extent practicable. The degree of removal constituting the "maximum extent practicable" is a site-specific determination and does not equate to a generic "free product thickness in well" measurement that can be uniformly applied to all sites.

6.9 ACTIVITY AND USE LIMITATIONS

AULs can be used, when appropriate, in conjunction with, or instead of, active remediation methods in managing risk at UST/AST sites. AULs will generally be used when residual COCs will remain on a site following an evaluation of risk. AULs are applied for a variety of reasons that include (ASTM, 2000):

- To eliminate certain pathways of exposure, e.g. an AUL that prevents the construction of a structure on a portion of a site may eliminate the need to evaluate the indoor inhalation exposure pathway;
- To ensure that information about past corrective action activities and the presence of residual chemicals on the property is readily available to all current and future interested parties (e.g. owners, tenants, lenders, etc.);
- To identify, for the benefit of all current and future interested parties, any restrictions on the use of the property, e.g., if the property has been cleaned for non-residential use, AULs shall specify that residential development of the site be restricted;
- To identify for the benefit of current and future interested parties the types of activities that may be conducted without resulting in unacceptable risk,
- Identify any long term operation and maintenance obligations, e.g. if a vapor barrier or ventilation system has been constructed under a building, an AUL might identify periodic maintenance and operation requirements. In such cases, the AUL will identify the entity responsible for these obligations.
- AULs may provide a right of entry to MDNR or others to allow for, for instance, inspection of AUL provisions or the performance of any future on-site activities that may be necessary, e.g. access to monitoring wells and the ability to install additional wells, if necessary.

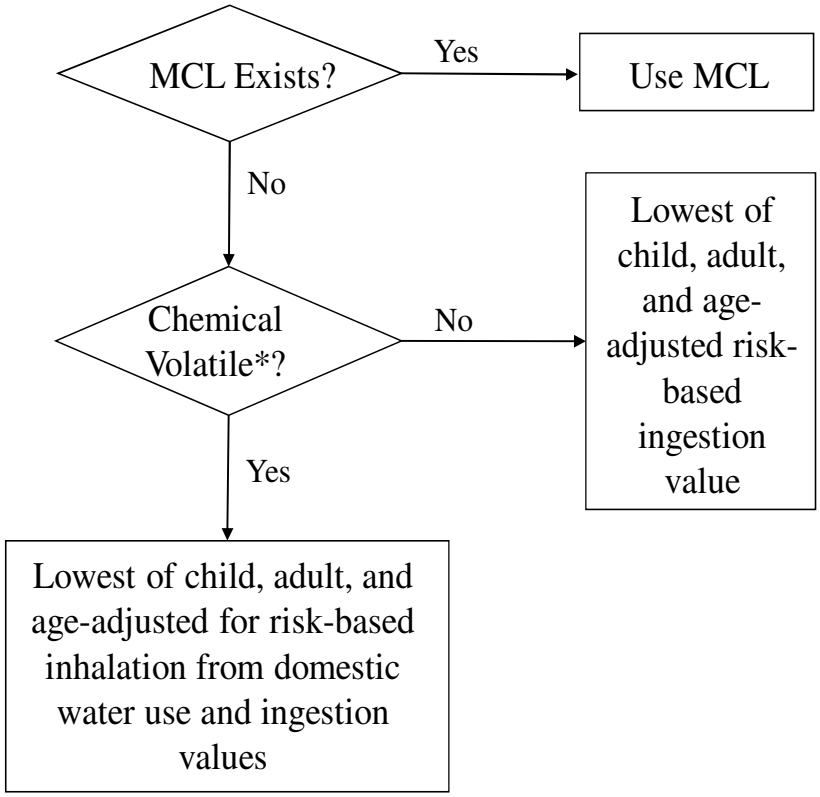
MDNR's AUL policy for the MRBCA process is found at Section 11 of this document.



NOTE:

1. In this chart, "use" refers to domestic consumption.
2. The analysis embodied in the chart is performed for each groundwater zone of interest. The conclusion of the analysis (the groundwater use pathway is either carried forward for additional consideration, or no further evaluation of the pathway is required) applies to the individual groundwater zone under analysis. Different conclusions may apply to different groundwater zones at a given site.
3. The attributes of an AUL must be sufficient to "eliminate reasonable probability of future use", and, by that, allow a conclusion that "no further evaluation of groundwater use pathway required."

Figure 6-1. Site Conceptual Model for Domestic Consumption of Groundwater Exposure Pathway Analysis



* Chemical is volatile if MW < 200 and H (dimensionless) > 2.2×10^{-7}.

Figure 6-2. Determination of Groundwater Target Concentration at POE

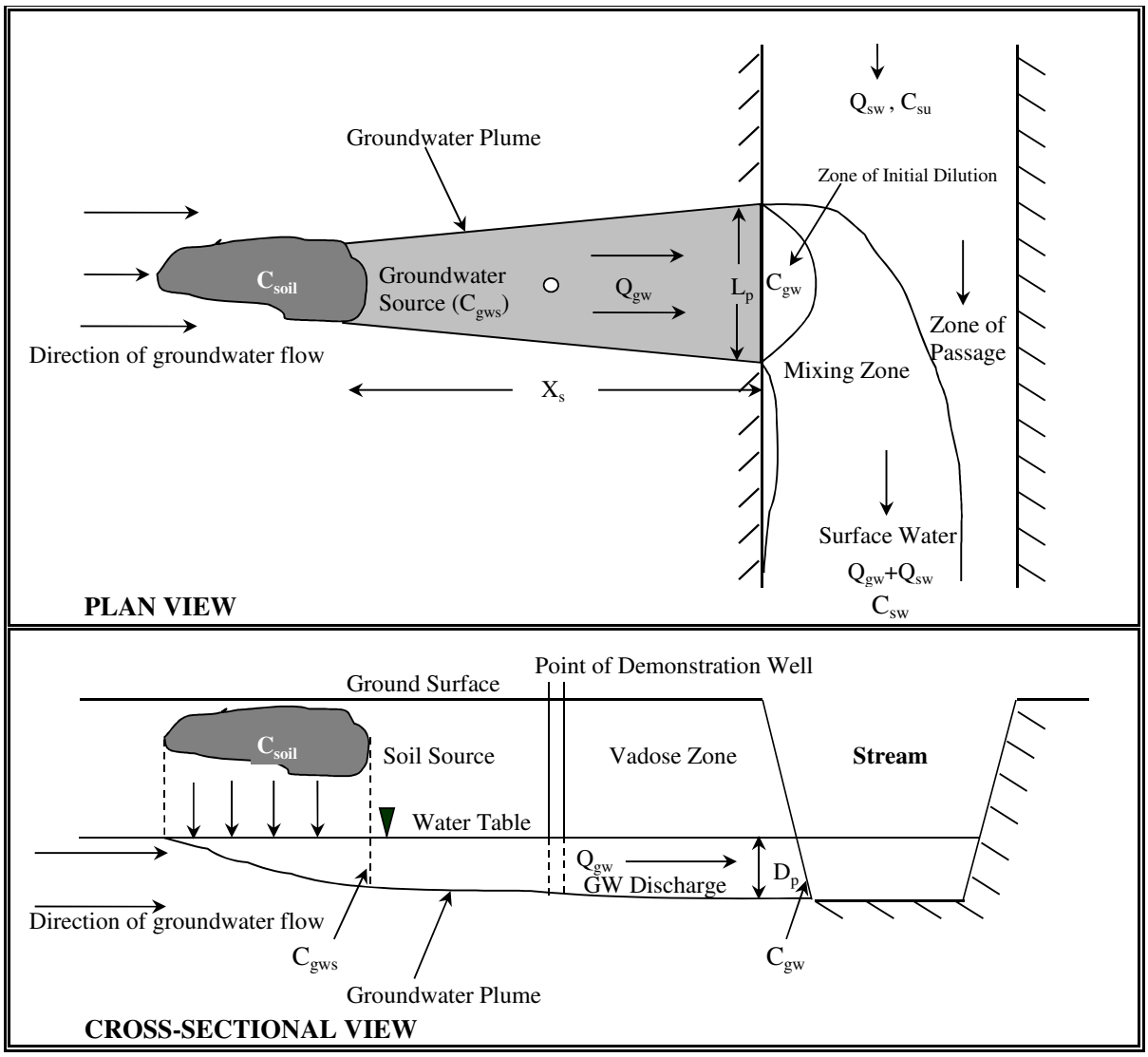


Figure 6-3. Schematic of Leachate Migration From the Soil to a Stream

Explanation of Symbols

Q_{sw} = Stream flow upstream of the point of groundwater discharge[ft^3/day]
C_{su} = Concentration upstream of the groundwater discharge [mg/L]
Q_{gw} = Impacted groundwater discharge into the stream [ft^3/day]
C_{sw} = Allowable downstream concentration, i.e., specific water quality criteria to be met beyond the mixing [mg/L]
C_{gw} = Allowable concentration in the groundwater discharge to the stream [mg/L]
C_{gws} = Allowable concentration in the groundwater at the edge of the soil source [mg/L]
C_{soil} = Allowable soil concentration at the source [mg/kg]
L_p = Width of groundwater plume discharging to the stream [ft]
D_p = Thickness of groundwater plume discharging to the stream [ft]
X_s = Distance from the downgradient edge of the groundwater source to the stream [ft]

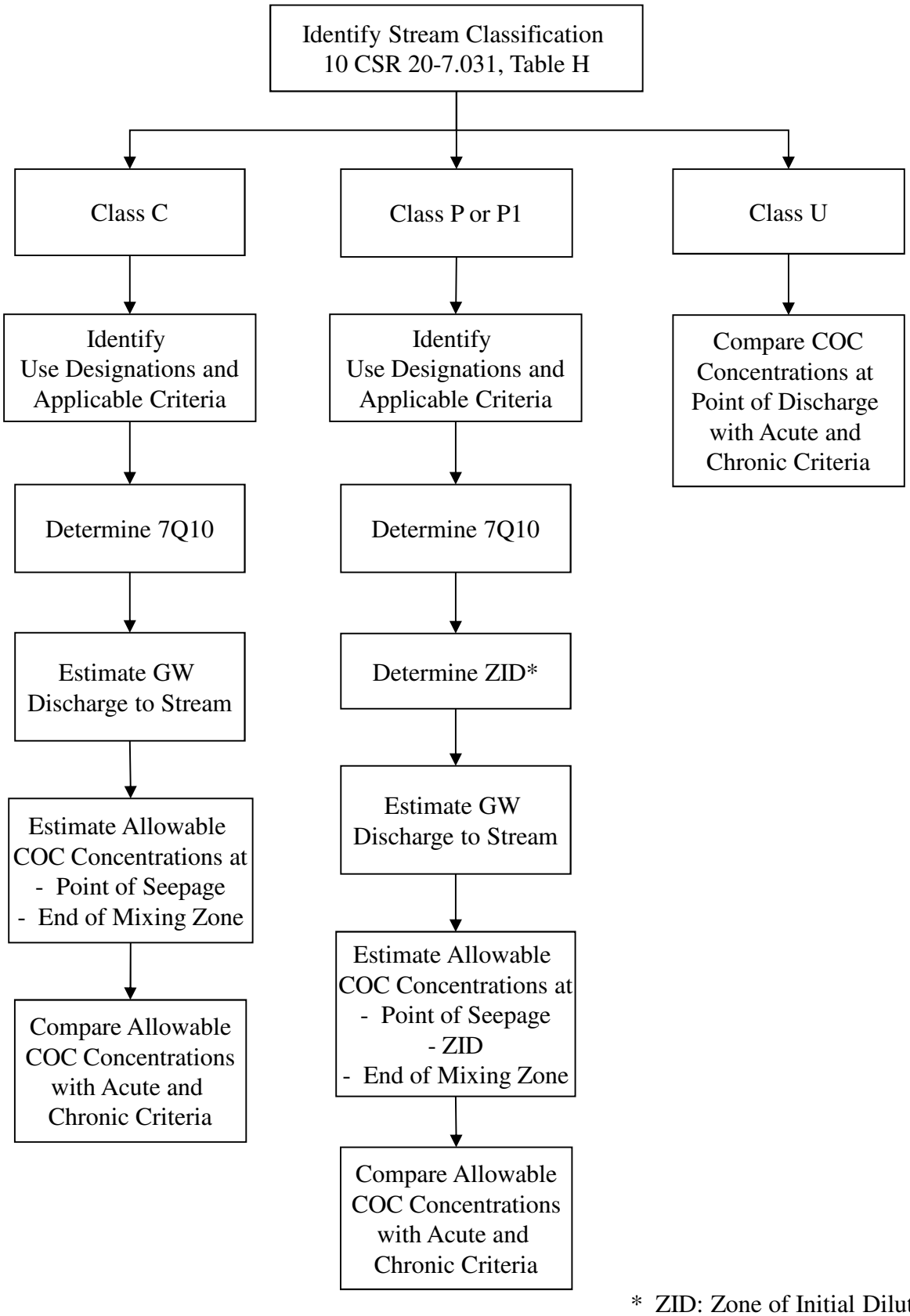


Figure 6-4. Procedure for Protection of Stream Body

Table 6-1
Allowable COC Concentrations in Surface Water

Chemical of Concerns	Target Concentrations in Surface Water (mg/L)					
	Protection of Aquatic Life	Human Health Protection – Fish Consumption	Drinking Water Supply	Irrigation	Livestock and Wildlife Watering	Whole-body Contact Recreation
Benzene	---	0.071	0.005	---	---	---
Toluene	---	200	1	---	---	---
Ethylbenzene	0.32	---	0.70	---	---	---
Xylenes (mixed)	---	---	10	---	---	---
Ethylene Dibromide (EDB)	---	---	0.00005	---	---	---
Ethylene Dichloride (EDC)	---	0.099	0.005	---	---	---
Methyl-tert-butyl-ether (MTBE)	---	---	---	---	---	---
Acenaphthene	---	2.7	1.2	---	---	---
Anthracene	---	110	9.6	---	---	---
Benzo(a)anthracene	---	0.000049	0.0000044	---	---	---
Benzo(a)pyrene	---	0.000049	0.0002	---	---	---
Benzo(b)fluoranthene	---	0.000049	0.0000044	---	---	---
Benzo(k)fluoranthene	---	0.000049	0.0000044	---	---	---
Chrysene	---	0.000049	0.0000044	---	---	---
Dibenzo(a,h)anthracene	---	0.000049	0.0000044	---	---	---
Fluoranthene	---	0.37	0.30	---	---	---
Fluorene	---	14	1.3	---	---	---
Naphthalene	---	---	0.02	---	---	---
Pyrene	---	11	0.96	---	---	---
TPH-GRO	---	---	---	---	---	---
TPH-DRO	---	---	---	---	---	---
TPH-ORO	---	---	---	---	---	---
Tertiary-amyl-methyl-ether (TAME)	---	---	---	---	---	---
Tertiary-butyl- alcohol (TBA)	---	---	---	---	---	---
Ethyl-tert-butyl-ether (ETBE)	---	---	---	---	---	---
Diisopropyl ether (DIPE)	---	---	---	---	---	---
Ethanol	---	---	---	---	---	---
Methanol	---	---	---	---	---	---

---: Not available
Note that target concentrations for metals are hardness dependent; refer to 10 CSR 20-7, Table A for allowable concentrations.

Table 6-2
Calculation of Representative Concentrations

Route of Exposure	Calculation of Representative Concentration
Surficial Soil (0-3 ft bgs)	
Soil concentration protective of leaching to groundwater or surface water body	Average of the surface soil concentrations collected within the area of release.
Direct contact with soil including ingestion of soil, dermal contact with soil, and the outdoor inhalation of vapors and particulates emitted by surficial soils	Average of the surface soil concentrations within exposure domain for non-residential receptor. Maximum concentration for residential receptor.
Subsurface Soil (> 3 ft bgs)	
Indoor inhalation of vapor emissions	Average of the subsurface soil concentrations collected below or within 10 ft of the real or hypothetical footprint of the building (Excluding concentrations below water table and capillary fringe).
Soil concentration protective of leaching to groundwater	Average of the subsurface soil concentration within the area of release (Excluding concentrations below water table and capillary fringe).
Groundwater	
Indoor inhalation of vapor emissions	Average of the groundwater concentrations around the footprint of the real or hypothetical building
Dermal contact with groundwater	Average of the groundwater concentrations that a receptor may come in contact with
Groundwater domestic use pathway • Concentration at POE • Concentration at POD	 Average of the groundwater concentrations* Average of the groundwater concentrations*

- If the measured concentrations are stable, the representative concentration is the arithmetic average of the most recent eight consecutive measurements, of which no two shall be less than three months apart. If the measured concentrations are decreasing, the representative concentration is the arithmetic average of the most recent six consecutive measurements, of which no two shall be less than three months apart.

Table 6-3
Vapor Concentrations Protective of Explosive Hazards

Compound	LEL (%)	UEL (%)	Action Levels (%)*
Gasoline	1.2	7.6	0.12 (1,200 ppm)
JP-4	1.3	8.0	0.13 (1,300 ppm)
Diesel Fuel	1.3	7.5	0.13 (1,300 ppm)
Fuel Oils	0.6	7.5	0.06 (600 ppm)
Kerosene	0.7	5.0	0.07 (700 ppm)
Benzene	1.3	7.9	0.13 (1,300 ppm)
Ethylbenzene	1.0	6.7	0.10 (1,000 ppm)
Toluene	1.2	7.1	0.12 (1,200 ppm)
Xylenes	1.0	7.0	0.10 (1,000 ppm)

* Action levels are equal to 10 % of the LEL.

7.0
TIER 1 RISK ASSESSMENT

A Tier 1 risk assessment requires the following steps:

Step 1: Compilation of data and identification of data gaps,
Step 2: Development of exposure model (EM),
Step 3: Collection of data to fill data gaps,
Step 4: Calculation of exposure pathway-specific representative concentrations of chemicals of concern (COCs) in affected media,
Step 5: Comparison of Tier 1 risk-based target levels (RBTLs) with site-specific representative concentrations,
Step 6: Recommendations for the next course of action, and
Step 7: Documentation of Tier 1 risk assessment.

Details of each of these steps are presented below.

7.1 STEP 1: COMPILATION OF DATA AND IDENTIFICATION OF DATA GAPS

The objective of this step is to compile available relevant data, evaluate the data, and identify any data gaps. This is best accomplished by collecting all available data for the site and comparing the data with the data needs discussed in Section 5.0. It is recommended that this step and Step 2 (develop EM) be completed simultaneously since the development of an EM may also help in the identification of data gaps.

Examples of Tier 1 data gaps include:

- Lack of an updated/current land use map,
- Lack of soil or groundwater COC concentrations representative of current conditions (e.g. soil or groundwater COC data might be too old or not representative of recent releases),
- Lack of a water well search,
- Contamination on the site insufficiently delineated, and
- Lack of soil, soil vapor, and/or groundwater data for certain COCs.

Once all the data gaps have been identified, the evaluator may have to develop a work plan that includes a (i) scope of work to fill in the data gaps, (ii) schedule, and (iii) cost proposal[1]. To ensure that all data gaps have been identified, refer to Section 5.0 of this document.

[1] Cost proposals need not be submitted to MDNR, but may be required by the Petroleum Storage Tank Insurance Fund.

7.2 STEP 2: DEVELOPMENT OF EXPOSURE MODEL

This step is necessary to identify exposure pathways at a site that are currently complete or that are reasonably likely to become complete in the future. The presence of exposure pathways and the types of pathways that might be present are dependent on current and anticipated future use of the site. If contamination has migrated off-site, use of the affected off-site property or properties must be considered independent of the use of the site on which the contamination originated. Pathways should be determined through consideration of the locations of the point and area of release in soil and the extent of contamination in groundwater relative to the exposure pathways identified at Section 6.1 that might exist on-site and off-site. Clearly, prior to determining exposure pathways, sufficient site assessment will have had to be conducted such that the horizontal and vertical extents of COCs in soil and groundwater have been determined. Otherwise, pathways that are of concern might be excluded or pathways not of concern (due to their location relative to the location of soil and/or groundwater contamination) might be erroneously included in the evaluation.

This step includes the development of an EM to identify (i) all complete routes of exposure for current and reasonably anticipated future land use, (ii) the exposure domain for each complete route of exposure, and (iii) the point of exposure for each route of exposure (refer to Section 6.1).

7.3 STEP 3: COLLECTION OF DATA TO FILL DATA GAPS

This step will be necessary only if data gaps are identified in Step 1. Depending on the specifics, this may require approval of a work plan by MDNR[2]. Upon completion of this step in a timely manner and with appropriate documentation of the fieldwork, the evaluator shall proceed with Step 4 below.

7.4 STEP 4: CALCULATION OF EXPOSURE PATHWAY-SPECIFIC REPRESENTATIVE CONCENTRATIONS

Using the data compiled in Steps 1 and 3, the evaluator shall calculate representative chemical concentrations for affected soil, groundwater, and, as applicable, soil vapor, as discussed in Section 6.5 and Appendix E. The need to calculate representative concentrations may be avoided by initially comparing the historical maximum media-specific concentrations for each pathway with the Tier 1 RBTLs (Step 5). If the historical maximum concentrations do not exceed the target levels, calculation of representative concentrations is not necessary.

[2] No work plan is required for soil vapor sampling conducted in accordance with the *Soil Gas Sampling Protocol* in Appendix C of this guidance. A cost estimate may be required by the Petroleum Storage Tank Insurance Fund.

Depending on site conditions (and as discussed in Section 6.5), multiple representative concentrations may have to be developed for a site. For example, at a site where a groundwater plume exists below an onsite commercial building and has migrated off-site under a residential building, representative groundwater concentrations beneath the on-site building would be different from those beneath the off-site building (in this example, the occupants of the buildings are the receptors and the volatilization from groundwater to indoor air is the exposure pathway).

7.5 STEP 5: COMPARISON OF TIER 1 RBTLs WITH SITE-SPECIFIC REPRESENTATIVE CONCENTRATIONS

In this step, the Tier 1 RBTLs for the complete routes of exposure identified in Step 2 are compared with the representative COC concentrations calculated in Step 4 (note that, for surficial soil in a residential setting, the maximum COC concentrations are used for comparison). The Tier 1 target levels are presented in Tables 7-1 to 7-6(c). Note that Tables 7-4(a) to 7-4(c) present soil concentrations protective of groundwater where the domestic use of groundwater pathway is complete.

The target levels in Tables 7-4(a) to 7-6(c) were developed based on the point of exposure (e.g., a groundwater well or a building or other enclosed space) being within a set distance of (i.e., 25', 50', 75', etc.) the area of contamination (and groundwater at a set depth). If one or more points of exposure for a particular site are not within the area of contamination, the equations in Appendix B or the MRBCA computational software (which uses the same equations as found in Appendix B) shall be used to calculate soil concentrations protective of such distant points of exposure.

To evaluate COCs leaching from soil to groundwater, the user must select the nearest distance where a domestic water use well is or could be located under current and reasonably anticipated future conditions. Depending on this distance and the depth to groundwater, as discussed above, soil concentrations protective of groundwater will be selected from Tables 7-4(a), 7-4(b), or 7-4(c).

When the domestic groundwater use pathway is complete, the evaluator must identify the distance from the outer edges of the plume to the nearest point at which a domestic water use well (i.e., the point of exposure) is or could be located under current and reasonably anticipated future conditions. This point of exposure might be on the site itself and within the existing plume, in which case the distance would be zero (0).

When the vapors from groundwater to indoor air pathway is complete, the evaluator must identify the distance from the outer edges of the plume to the nearest point at which a structure (i.e., the point of exposure) currently exists or could be built. This point of exposure might be on the site itself and within the current extent of contamination, in which case the distance would be zero (0).

As mentioned in Step 4, the evaluator is encouraged to initially compare maximum COC concentrations to the RBTLs. If the maximum concentrations do not exceed the target levels, calculating representative concentrations is not necessary. Based on the results of this step, the evaluator shall recommend the path forward as discussed in Step 6.

7.6 STEP 6: RECOMMENDATIONS FOR THE NEXT COURSE OF ACTION

Depending on the result of the comparison, one of the following alternatives is available.

Alternative 1: If the analyses at Steps 4 and 5 indicate that all current and potential future exposure pathways are incomplete (both on and off-site) or that maximum or representative concentrations of COCs do not exceed applicable target levels for complete exposure pathways, and provided the following conditions are met, the tank owner or operator may request that MDNR issue a NFA letter for the release.

Condition 1: Confirmation that the plume is stable or decreasing (see definition at Section 5.9.3). If this condition is not satisfied, the entity conducting the cleanup shall recommend that compliance monitoring be continued until the plume is demonstrably stable and/or take actions to hasten plume stability.

Condition 2: The maximum concentration of any COC does not exceed 10 times the representative concentration of that COC, for any exposure pathway. This condition should be documented and MDNR will determine what actions, if any, will be necessary to address the situation.

Condition 3: Assurance that the land use assumptions used in the MRBCA evaluation are not violated in the future. The need for such assurance may require that an activity and use limitation (AUL) apply to the site prior to issuance of a no further action (NFA) letter.

Condition 4: Absence of ecological concerns at the site. If this condition is not met, the entity conducting the cleanup shall provide recommendations to MDNR to address the condition.

Alternative 2: If one or more representative concentrations exceed the RBTLs, the evaluator shall determine whether to conduct corrective action to achieve the Tier 1 RBTLs or otherwise mitigate risks to acceptable levels, conduct soil vapor sampling if warranted[3], or perform a Tier 2 risk assessment. If the evaluator chooses to conduct corrective action, the tank owner or operator must submit a Corrective Action Plan (CAP)

[3] If the soil or groundwater vapor intrusion pathway is complete and COCs exceed the associated Tier 1 RBTLs.

to MDNR for review and approval before corrective action activities are implemented. If the tank owner or operator intends to conduct soil vapor sampling, the soil vapor sampling shall be conducted in accordance with the Soil Vapor Sampling Protocol in Appendix C of this guidance or under a different methodology as presented in a work plan submitted to MDNR for approval.

7.7 STEP 7: DOCUMENTATION OF TIER 1 RISK ASSESSMENT

To facilitate documentation and review of the Tier 1 risk assessment, the contents of the various MRBCA reports are discussed in Section 12 of this document. The Tier 1 risk assessment shall be appropriately documented and submitted to MDNR. If a Tier 2 risk assessment is conducted, both the Tier 1 and Tier 2 risk assessments may be submitted simultaneously. Refer to Section 2.5 and Section 12 for further information regarding reporting.

Table 7-1
Tier 1 Risk-Based Target Levels for Residential Land Use

Chemicals of Concern	Air	Surficial Soil	Subsurface Soil	Soil Vapor	Groundwater		
	Indoor	Ingestion, Inhalation (Vapors and Particulates), and Dermal Contact	Indoor Inhalation of Vapor Emissions	Indoor Inhalation of Vapor Emissions	Indoor Inhalation of Vapor Emissions	Dermal Contact	Domestic Water Use
	[mg/m^3-air]	[mg/kg]	[mg/kg]	[mg/m^3-air]	[mg/L]		
Benzene	4.98E-03	1.77E+02 *	3.78E-01	1.90E+02	1.00E+00	2.92E-01	5.00E-03 m
Toluene	2.92E+00	6.21E+03 *	4.99E+02 *	1.13E+05 +	5.08E+02 #	8.58E+00	1.00E+00 m
Ethylbenzene	6.06E-01	7.45E+03 *	1.93E+02 *	2.72E+04 +	1.03E+02 #	6.34E+00 #	7.00E-01 m
Xylenes (total)	6.06E-02	7.83E+03 *	2.47E+01	2.91E+03	1.18E+01	2.13E+01 #	1.00E+01 m
Ethylene dibromide (EDB)	4.27E-05	3.02E+00	8.61E-02	6.62E+00	2.30E-01	1.41E-02	5.00E-05 m
Ethylene dichloride (EDC)	9.86E-04	6.65E+01	1.32E-01	3.19E+01	8.62E-01	3.53E-01	5.00E-03 m
Methyl tertiary butyl ether (MTBE)	9.86E-02	3.45E+03	2.16E+01	4.14E+03	1.81E+02	2.35E+01	1.28E-01
Acenaphthene	1.25E-01	3.13E+03 *	6.69E+04 *	1.00E+04 +	1.61E+03 #	1.35E+00	1.65E-01
Anthracene	6.27E-01	1.57E+04 *	3.90E+05 *	6.50E+04 +	2.29E+03 #	3.17E+00 #	6.96E-01 #
Benzo(a)anthracene	2.30E-04	6.20E+00	2.60E+05 *	1.49E+01 +	1.10E+02 #	1.74E-04	1.03E-04
Benzo(a)pyrene	2.30E-05	6.20E-01	2.25E+05 *	1.70E+00 +	3.73E+01 #	1.02E-05	2.00E-04 m
Benzo(b)fluoranthene	2.30E-04	6.19E+00	5.55E+04 *	3.42E+01 +	7.65E+00 #	1.01E-04	6.27E-05
Benzo(k)fluoranthene	2.30E-04	6.20E+01 *	6.83E+06 *	3.14E+01 +	9.37E+02 #	1.04E-03 #	6.46E-04
Chrysene	2.30E-03	5.99E+02 *	1.92E+05 *	3.12E+02 +	8.17E+01 #	1.74E-02 #	1.03E-02 #
Dibenzo(a,h)anthracene	2.19E-05	6.20E-01	2.22E+07 *	5.86E-01 +	9.85E+02 #	6.60E-06	4.21E-06
Fluoranthene	8.36E-02	2.28E+03 *	9.01E+06 *	9.27E+03 +	1.42E+04 #	3.00E-01 #	1.64E-01
Fluorene	8.36E-02	2.20E+03 *	2.46E+05 *	7.73E+03 +	3.01E+03 #	6.27E-01	1.03E-01
Naphthalene	7.48E-04	3.63E+01 *	2.59E+01 *	4.26E+01 +	2.25E+00 #	2.06E-02	1.09E-03
Pyrene	6.27E-02	1.71E+03 *	1.07E+07 *	7.69E+03 +	1.73E+04 #	1.64E-01 #	9.61E-02
TPH-GRO	1.18E+01	3.54E+05 *	3.85E+02	3.97E+05 +	2.08E+01	NA	1.81E+01
TPH-DRO	1.45E+00	1.40E+05 *	4.15E+03 *	4.87E+04 +	1.17E+02 #	NA	3.43E+01 #
TPH-ORO	NA	1.24E+05 *	NA	NA	NA	NA	3.18E+01 #
Aliphatics - > C6-C8	1.11E+01	3.44E+05 *	2.53E+02 *	3.72E+05 +	9.94E+00 #	NA	1.73E+01 #
Aliphatics - > C8-C10	6.06E-01	7.45E+03 *	5.24E+01	2.04E+04	3.40E-01	NA	6.83E-01 #
Aliphatics - >C10-C12	6.06E-01	5.88E+03 *	2.60E+02 *	2.04E+04 +	2.27E-01 #	NA	6.83E-01 #

Aliphatics - >C12-C16	6.06E-01	5.88E+03	*	1.18E+03	*	2.04E+04	+	5.23E-02	#	NA	1.56E+00	#
Aliphatics - >C16-C21	NA	1.22E+05	*	NA		NA		NA		NA	3.13E+01	#
Aliphatics - >C21-C35	NA	1.22E+05	*	NA		NA		NA		NA	3.13E+01	#
Aromatics - >C8-C10	1.19E-01	2.84E+03	*	8.03E+01		4.00E+03		1.05E+01		NA	1.72E-01	
Aromatics - >C10-C12	1.19E-01	2.26E+03	*	4.33E+02	*	4.00E+03	+	3.34E+01	#	NA	1.72E-01	
Aromatics - >C12-C16	1.19E-01	2.26E+03	*	2.28E+03	*	4.00E+03	+	8.29E+01	#	NA	1.72E-01	
Aromatics - >C16-C21	NA	1.72E+03	*	NA		NA		NA		NA	4.69E-01	
Aromatics - >C21-C35	NA	1.72E+03	*	NA		NA		NA		NA	4.69E-01	#
Tertiary-amyl-methyl-ether (TAME)	4.80E-02	2.50E+03	*	5.86E+00		2.31E+03		2.06E+01		1.86E+01	8.28E-02	
Tertiary-butyl-alcohol (TBA)	1.80E-01	6.11E+03		1.03E+03		7.07E+03		1.32E+04		1.52E+02	2.86E-01	
Ethyl-tert-butyl-ether (ETBE)	1.80E-01	7.81E+01		2.58E+01		8.69E+03		9.90E+01		5.00E-01	1.44E-02	
Diisopropyl ether (DIPE)	2.30E-01	6.91E+03	*	3.30E+01		1.13E+04		8.19E+01		3.48E+01	3.51E-01	
Ethanol	1.13E+00	2.62E+05	*	7.17E+03		3.28E+04		1.20E+05		2.48E+05	5.15E+02	
Methanol	2.30E+00	3.67E+04		2.94E+04		5.11E+04		2.77E+05		6.63E+03	7.81E+00	
Arsenic	5.98E-06	3.89E+00		N/A		N/A		N/A		1.58E-01	1.00E-02	m
Barium	2.92E-04	1.50E+04		N/A		N/A		N/A		1.12E+03	2.00E+00	m
Cadmium	1.42E-05	1.68E+01		N/A		N/A		N/A		6.25E-01	5.00E-03	m
Chromium (III) total chromium	6.06E-05	7.46E+04		N/A		N/A		N/A		8.38E+03	1.00E-01	m
Chromium (VI)	2.14E-06	1.47E-01		N/A		N/A		N/A		2.83E-03	3.37E-06	
Lead	NA	2.60E+02		2.60E+02		N/A		N/A		NA	1.50E-02	m
Selenium	1.19E-04	3.80E+02		N/A		N/A		N/A		2.79E+01	5.00E-02	m

Notes:

NA: Not available N/A: Not applicable m: Target level is MCL. Soil concentrations are presented on a dry weight basis.

***:** Calculated target level exceeds effective/saturated soil concentration for gasoline. Calculated value is shown.

#: Calculated target level exceeds effective/solubility for gasoline. Calculated value is shown.

+: Calculated target level exceeds effective/saturated vapor concentration for gasoline. Calculated value is shown.

Table 7-2
Tier 1 Risk-Based Target Levels for Non-Residential Land Use

Chemicals of Concern	Air	Surficial Soil	Subsurface Soil	Soil Vapor	Groundwater	
	Indoor	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact	Indoor Inhalation of Vapor Emissions	Indoor Inhalation of Vapor Emissions	Indoor Inhalation of Vapor Emissions	Dermal Contact
	[mg/m^3-air]	[mg/kg]	[mg/kg]	[mg/m^3-air]	[mg/L]	
Benzene	1.06E-02	7.63E+02 *	1.98E+00	9.98E+02	5.25E+00	1.06E+00
Toluene	9.54E+00	8.11E+04 *	4.01E+03 *	9.09E+05 +	4.08E+03 #	4.76E+01
Ethylbenzene	1.98E+00	9.75E+04 *	1.55E+03 *	2.18E+05 +	8.32E+02 #	3.51E+01 #
Xylenes (total)	1.98E-01	1.04E+05 *	1.99E+02 *	2.34E+04 +	9.49E+01 #	1.18E+02 #
Ethylene dibromide (EDB)	9.09E-05	1.25E+01	4.52E-01	3.47E+01	1.21E+00	5.15E-02
Ethylene dichloride (EDC)	2.10E-03	2.76E+02	6.91E-01	1.67E+02	4.52E+00	1.29E+00
Methyl tertiary butyl ether (MTBE)	2.10E-01	1.49E+04 *	1.13E+02	2.17E+04	9.46E+02	8.58E+01
Acenaphthene	4.09E-01	3.07E+04 *	5.38E+05 *	8.05E+04 +	1.29E+04 #	7.50E+00 #
Anthracene	2.04E+00	1.54E+05 *	3.14E+06 *	5.23E+05 +	1.84E+04 #	1.76E+01 #
Benzo(a)anthracene	4.89E-04	2.11E+01	1.36E+06 *	7.83E+01 +	5.79E+02 #	6.37E-04
Benzo(a)pyrene	4.89E-05	2.11E+00	1.18E+06 *	8.93E+00 +	1.95E+02 #	3.74E-05
Benzo(b)fluoranthene	4.89E-04	2.10E+01 *	2.91E+05 *	1.79E+02 +	4.01E+01 #	3.68E-04
Benzo(k)fluoranthene	4.89E-04	2.11E+02 *	3.58E+07 *	1.65E+02 +	4.91E+03 #	3.80E-03 #
Chrysene	4.89E-03	1.99E+03 *	1.01E+06 *	1.63E+03 +	4.28E+02 #	6.37E-02 #
Dibenzo(a,h)anthracene	4.65E-05	2.11E+00	1.16E+08 *	3.07E+00 +	5.16E+03 #	2.41E-05
Fluoranthene	2.73E-01	2.18E+04 *	7.25E+07 *	7.45E+04 +	1.14E+05 #	1.66E+00 #
Fluorene	2.73E-01	2.07E+04 *	1.98E+06 *	6.22E+04 +	2.42E+04 #	3.48E+00 #
Naphthalene	1.59E-03	1.19E+02 *	1.36E+02 *	2.23E+02 +	1.18E+01 #	7.51E-02 #
Pyrene	2.04E-01	1.64E+04 *	8.64E+07 *	6.18E+04 +	1.39E+05 #	9.07E-01 #
TPH-GRO	3.85E+01	4.65E+06 *	3.10E+03 *	3.19E+06 +	1.67E+02 #	NA
TPH-DRO	4.73E+00	1.41E+06 *	3.34E+04 *	3.92E+05 +	9.38E+02 #	NA

TPH-ORO	NA	1.25E+06	*	NA		NA		NA		NA		
Aliphatics - > C6-C8	3.61E+01	4.52E+06	*	2.03E+03	*	2.99E+06	+	7.99E+01	#	NA		
Aliphatics - > C8-C10	1.98E+00	9.75E+04	*	4.21E+02	*	1.64E+05	+	2.73E+00	#	NA		
Aliphatics - >C10-C12	1.98E+00	5.98E+04	*	2.09E+03	*	1.64E+05	+	1.82E+00	#	NA		
Aliphatics - >C12-C16	1.98E+00	5.98E+04	*	9.50E+03	*	1.64E+05	+	4.21E-01	#	NA		
Aliphatics - >C16-C21	NA	1.23E+06	*	NA		NA		NA		NA		
Aliphatics - >C21-C35	NA	1.23E+06	*	NA		NA		NA		NA		
Aromatics - >C8-C10	3.89E-01	3.72E+04	*	6.46E+02	*	3.22E+04	+	8.44E+01	#	NA		
Aromatics - >C10-C12	3.89E-01	2.33E+04	*	3.48E+03	*	3.22E+04	+	2.69E+02	#	NA		
Aromatics - >C12-C16	3.89E-01	2.33E+04	*	1.83E+04	*	3.22E+04	+	6.67E+02	#	NA		
Aromatics - >C16-C21	NA	1.65E+04	*	NA		NA		NA		NA		
Aromatics - >C21-C35	NA	1.65E+04	*	NA		NA		NA		NA		
Tertiary-amyl-methyl-ether (TAME)	1.57E-01	3.29E+04	*	4.71E+01		1.86E+04		1.66E+02		1.03E+02		
Tertiary-butyl-alcohol (TBA)	5.86E-01	8.03E+04	*	8.26E+03		5.69E+04		1.06E+05		8.44E+02		
Ethyl-tert-butyl-ether (ETBE)	5.86E-01	1.02E+03		2.07E+02		6.99E+04		7.96E+02		2.77E+00		
Diisopropyl ether (DIPE)	7.50E-01	9.07E+04	*	2.65E+02		9.12E+04		6.59E+02		1.93E+02		
Ethanol	3.68E+00	3.55E+06	*	5.77E+04	*	2.64E+05	+	9.66E+05	#	1.37E+06	#	
Methanol	7.50E+00	4.81E+05	*	2.36E+05	*	4.11E+05	+	2.23E+06	#	3.68E+04		
Arsenic	1.27E-05	1.59E+01		N/A		N/A		N/A		5.78E-01		
Barium	9.54E-04	1.81E+05		N/A		N/A		N/A		6.19E+03		
Cadmium	3.03E-05	7.48E+01		N/A		N/A		N/A		2.28E+00		
Chromium (III) total chromium	1.98E-04	4.72E+05		N/A		N/A		N/A		4.65E+04		
Chromium (VI)	4.54E-06	6.39E-01		N/A		N/A		N/A		1.03E-02		
Lead	NA	6.60E+02		6.60E+02		N/A		N/A		NA		
Selenium	3.89E-04	4.78E+03		N/A		N/A		N/A		1.55E+02		

Notes:

NA: Not available N/A: Not applicable Soil concentrations are presented on a dry weight basis.

***:** Calculated target level exceeds effective/saturated soil concentration for gasoline. Calculated value is shown.

#: Calculated target level exceeds effective/solubility for gasoline. Calculated value is shown.

+: Calculated target level exceeds effective/saturated vapor concentration for gasoline. Calculated value is shown.

Table 7-3
Tier 1 Risk-Based Target Levels for Construction Worker

Chemicals of Concern	Air	Soil		Groundwater			
	Outdoor	Ingestion, Inhalation (Vapor Emissions and Particulates), and Dermal Contact		Outdoor Inhalation of Vapor Emissions		Dermal Contact	
	[mg/m^3-air]	[mg/kg]		[mg/L]			
Benzene	1.51E-01	1.82E+03	*	1.16E+04	#	1.48E+01	
Toluene	2.45E+01	1.38E+05	*	1.77E+06	#	1.32E+02	#
Ethylbenzene	5.08E+00	5.81E+04	*	3.73E+05	#	9.76E+01	#
Xylenes (total)	5.08E-01	7.21E+03	*	4.10E+04	#	3.28E+02	#
Ethylene dibromide (EDB)	5.84E-03	7.74E+01		1.83E+03		3.58E+00	
Ethylene dichloride (EDC)	2.45E-02	3.51E+02		3.98E+03		8.95E+01	
Methyl tertiary butyl ether (MTBE)	1.35E+01	1.65E+05	*	2.95E+06	#	5.96E+03	
Acenaphthene	1.05E+00	2.57E+04	*	7.91E+05	#	2.08E+01	#
Anthracene	5.26E+00	1.35E+05	*	1.82E+06	#	4.89E+01	#
Benzo(a)anthracene	3.15E-02	1.19E+03	*	6.56E+05	#	4.42E-02	#
Benzo(a)pyrene	3.15E-03	1.19E+02	*	2.20E+05	#	2.59E-03	#
Benzo(b)fluoranthene	3.15E-02	1.14E+03	*	5.39E+04	#	2.55E-02	#
Benzo(k)fluoranthene	3.15E-02	1.19E+04	*	5.53E+06	#	2.64E-01	#
Chrysene	3.15E-01	6.57E+04	*	5.60E+05	#	4.42E+00	#
Dibenzo(a,h)anthracene	2.99E-03	1.19E+02	*	5.80E+06	#	1.67E-03	
Fluoranthene	7.01E-01	4.38E+04	*	5.32E+06	#	4.62E+00	#
Fluorene	7.01E-01	2.75E+04	*	1.23E+06	#	9.66E+00	#
Naphthalene	1.51E-02	2.15E+02	*	4.82E+03	#	5.21E+00	#
Pyrene	5.26E-01	3.37E+04	*	6.36E+06	#	2.52E+00	#
TPH-GRO	9.90E+01	1.29E+06	*	9.06E+04	#	NA	
TPH-DRO	1.22E+01	3.01E+06	*	2.42E+05	#	NA	

TPH-ORO	NA	2.89E+06	*	NA		NA	
Aliphatics - > C6-C8	9.29E+01	1.22E+06	*	4.76E+04	#	NA	
Aliphatics - > C8-C10	5.08E+00	5.81E+04	*	1.63E+03	#	NA	
Aliphatics - >C10-C12	5.08E+00	4.83E+04	*	1.09E+03	#	NA	
Aliphatics - >C12-C16	5.08E+00	4.83E+04	*	2.51E+02	#	NA	
Aliphatics - >C16-C21	NA	2.85E+06	*	NA		NA	
Aliphatics - >C21-C35	NA	2.85E+06	*	NA		NA	
Aromatics - >C8-C10	9.99E-01	1.27E+04	*	4.14E+04	#	NA	
Aromatics - >C10-C12	9.99E-01	1.15E+04	*	9.37E+04	#	NA	
Aromatics - >C12-C16	9.99E-01	1.15E+04	*	1.46E+05	#	NA	
Aromatics - >C16-C21	NA	3.72E+04	*	NA		NA	
Aromatics - >C21-C35	NA	3.72E+04	*	NA		NA	
Tertiary-amyl-methyl-ether (TAME)	4.03E-01	5.51E+03	*	5.49E+04	#	2.86E+02	
Tertiary-butyl-alcohol (TBA)	1.51E+00	2.00E+04	*	5.04E+06	#	2.35E+03	
Ethyl-tert-butyl-ether (ETBE)	1.51E+00	2.51E+03	*	2.35E+05	#	7.70E+00	
Diisopropyl ether (DIPE)	1.93E+00	2.52E+04	*	2.39E+05	#	5.36E+02	
Ethanol	9.46E+00	1.36E+05	*	4.46E+07	#	3.81E+06	#
Methanol	1.93E+01	2.32E+05	*	1.02E+08	#	1.02E+05	
Arsenic	1.51E-04	6.54E+02		N/A		2.58E+01	
Barium	2.45E-03	4.39E+05		N/A		1.72E+04	
Cadmium	1.95E-03	2.81E+03		N/A		8.60E+01	
Chromium (III) total chromium	5.08E-04	5.21E+05		N/A		1.29E+05	
Chromium (VI)	4.03E-05	4.30E+01		N/A		7.17E-01	
Lead	NA	NA		N/A		NA	
Selenium	9.99E-04	1.28E+04		N/A		4.30E+02	

Notes:

NA: Not available N/A: Not applicable Soil concentrations are presented on a dry weight basis.

***:** Calculated target level exceeds effective/saturated soil concentration for gasoline. Calculated value is shown.

#: Calculated target level exceeds effective/solubility for gasoline. Calculated value is shown.

+: Calculated target level exceeds effective/saturated vapor concentration for gasoline. Calculated value is shown.

Table 7-4(a): Soil Concentration Protective of Groundwater Domestic Use for Different Distances to POE

Depth to Groundwater <20' (DAF=1)

Chemicals of Concern	Distance to POE (ft)																					
	0		25		50		75		100		150		200		250	
Benzene	5.61E-02		5.66E-02		7.34E-02		1.14E-01		1.74E-01		3.49E-01		5.96E-01		9.13E-01	
Toluene	2.98E+01		3.00E+01		3.89E+01		6.05E+01	*	9.24E+01	*	1.85E+02	*	3.16E+02	*	4.84E+02	*
Ethylbenzene	3.99E+01	*	4.02E+01	*	5.21E+01	*	8.10E+01	*	1.24E+02	*	2.48E+02	*	4.23E+02	*	6.49E+02	*
Xylenes (mixed)	6.34E+02	*	6.40E+02	*	8.29E+02	*	1.29E+03	*	1.97E+03	*	3.95E+03	*	6.73E+03	*	1.03E+04	*
Ethylene Dibromide (EDB)	4.73E-04		4.77E-04		6.19E-04		9.61E-04		1.47E-03		2.95E-03		5.02E-03		7.70E-03	
Ethylene Dichloride (EDC)	2.06E-02		2.07E-02		2.69E-02		4.18E-02		6.39E-02		1.28E-01		2.18E-01		3.34E-01	
Methyl-tert-butyl-ether (MTBE)	3.98E-01		4.02E-01		5.21E-01		8.09E-01		1.24E+00		2.48E+00		4.23E+00		6.48E+00	
Acenaphthene	1.74E+02		1.76E+02		2.28E+02	*	3.54E+02	*	5.41E+02	*	1.09E+03	*	1.85E+03	*	2.83E+03	*
Anthracene	3.06E+03	*	3.08E+03	*	4.00E+03	*	6.21E+03	*	9.49E+03	*	1.90E+04	*	3.24E+04	*	4.97E+04	*
Benzo(a)anthracene	6.12E+00		6.18E+00		8.01E+00		1.24E+01		1.90E+01		3.81E+01	*	6.50E+01	*	9.96E+01	*
Benzo(a)pyrene	3.04E+01	*	3.06E+01	*	3.97E+01	*	6.17E+01	*	9.43E+01	*	1.89E+02	*	3.22E+02	*	4.94E+02	*
Benzo(b)fluoranthene	1.15E+01	*	1.16E+01	*	1.50E+01	*	2.33E+01	*	3.56E+01	*	7.15E+01	*	1.22E+02	*	1.87E+02	*
Benzo(k)fluoranthene	1.18E+02	*	1.19E+02	*	1.55E+02	*	2.40E+02	*	3.67E+02	*	7.36E+02	*	1.26E+03	*	1.92E+03	*
Chrysene	6.12E+02	*	6.18E+02	*	8.01E+02	*	1.24E+03	*	1.90E+03	*	3.81E+03	*	6.50E+03	*	9.96E+03	*
Dibenzo(a,h)anthracene	2.38E+00		2.40E+00		3.11E+00		4.83E+00		7.39E+00		1.48E+01		2.53E+01		3.87E+01	
Fluoranthene	2.61E+03	*	2.63E+03	*	3.41E+03	*	5.29E+03	*	8.10E+03	*	1.62E+04	*	2.77E+04	*	4.24E+04	*
Fluorene	2.11E+02	*	2.13E+02	*	2.76E+02	*	4.29E+02	*	6.55E+02	*	1.31E+03	*	2.24E+03	*	3.43E+03	*
Napthalene	3.25E-01		3.28E-01		4.25E-01		6.60E-01		1.01E+00	*	2.02E+00	*	3.45E+00	*	5.29E+00	*
Pyrene	1.50E+03	*	1.52E+03	*	1.96E+03	*	3.05E+03	*	4.67E+03	*	9.36E+03	*	1.60E+04	*	2.44E+04	*
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA	
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
Tertiary-amyl-methyl-ether (TAME)	6.77E-01		6.83E-01		8.85E-01		1.37E+00		2.10E+00		4.22E+00		7.19E+00		1.10E+01	
Tertiary-butyl- alcohol (TBA)	5.58E-01		5.63E-01		7.30E-01		1.13E+00		1.73E+00		3.47E+00		5.92E+00		9.07E+00	
Ethyl-tert-butyl-ether (ETBE)	1.06E-01		1.07E-01		1.39E-01		2.15E-01		3.29E-01		6.60E-01		1.13E+00		1.72E+00	
Diisopropyl ether (DIPE)	4.12E+00		4.15E+00		5.38E+00		8.36E+00		1.28E+01		2.56E+01		4.37E+01		6.69E+01	
Ethanol	7.74E+02		7.80E+02		1.01E+03		1.57E+03		2.40E+03		4.82E+03		8.21E+03		1.26E+04	
Methanol	2.08E+01		2.10E+01		2.72E+01		4.23E+01		6.46E+01		1.30E+02		2.21E+02		3.38E+02	
Arsenic	7.21E+00		7.27E+00		9.43E+00		1.46E+01		2.24E+01		4.49E+01		7.65E+01		1.17E+02	
Barium	2.04E+03		2.06E+03		2.66E+03		4.14E+03		6.33E+03		1.27E+04		2.16E+04		3.31E+04	
Cadmium	9.31E+00		9.39E+00		1.22E+01		1.89E+01		2.89E+01		5.80E+01		9.88E+01		1.51E+02	
Chromium III	4.47E+06		4.51E+06		5.84E+06		9.07E+06		1.39E+07		2.78E+07		4.74E+07		7.26E+07	
Chromium VI	7.53E-03		7.60E-03		9.85E-03		1.53E-02		2.34E-02		4.69E-02		8.00E-02		1.23E-01	
Lead	NA		NA		NA		NA		NA		NA		NA		NA	
Selenium	6.27E+00		6.32E+00		8.20E+00		1.27E+01		1.95E+01		3.90E+01		6.66E+01		1.02E+02	

Notes:

NA : Not Available

Target levels are based on distance to groundwater < 20 ft for which default vadose zone DAF is 1.

All concentrations in mg/kg.

* Value exceeds effective /saturated soil concentration

17-Oct-13

Table 7-4(b): Soil Concentration Protective of Groundwater Domestic Use for Different Distances to POE

Depth to Groundwater 20-50' (DAF=2)

Chemicals of Concern	Distance to POE (ft)																					
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00	
Benzene	1.12E-01		1.13E-01		1.47E-01		2.28E-01		3.49E-01		6.99E-01		1.19E+00		1.83E+00	
Toluene	5.95E+01	*	6.01E+01	*	7.78E+01	*	1.21E+02	*	1.85E+02	*	3.71E+02	*	6.32E+02	*	9.68E+02	*
Ethylbenzene	7.97E+01	*	8.05E+01	*	1.04E+02	*	1.62E+02	*	2.48E+02	*	4.97E+02	*	8.47E+02	*	1.30E+03	*
Xylenes (mixed)	1.27E+03	*	1.28E+03	*	1.66E+03	*	2.58E+03	*	3.94E+03	*	7.90E+03	*	1.35E+04	*	2.06E+04	*
Ethylene Dibromide (EDB)	9.46E-04		9.55E-04		1.24E-03		1.92E-03		2.94E-03		5.89E-03		1.00E-02		1.54E-02	
Ethylene Dichloride (EDC)	4.11E-02		4.15E-02		5.38E-02		8.35E-02		1.28E-01		2.56E-01		4.37E-01		6.69E-01	
Methyl-tert-butyl-ether (MTBE)	7.96E-01		8.04E-01		1.04E+00		1.62E+00		2.47E+00		4.96E+00		8.46E+00		1.30E+01	
Acenaphthene	3.49E+02	*	3.52E+02	*	4.56E+02	*	7.08E+02	*	1.08E+03	*	2.17E+03	*	3.70E+03	*	5.67E+03	*
Anthracene	6.11E+03	*	6.17E+03	*	7.99E+03	*	1.24E+04	*	1.90E+04	*	3.81E+04	*	6.49E+04	*	9.94E+04	*
Benzo(a)anthracene	1.22E+01		1.24E+01		1.60E+01		2.49E+01	*	3.80E+01	*	7.63E+01	*	1.30E+02	*	1.99E+02	*
Benzo(a)pyrene	6.07E+01	*	6.13E+01	*	7.94E+01	*	1.23E+02	*	1.89E+02	*	3.78E+02	*	6.45E+02	*	9.88E+02	*
Benzo(b)fluoranthene	2.30E+01	*	2.32E+01	*	3.00E+01	*	4.66E+01	*	7.13E+01	*	1.43E+02	*	2.44E+02	*	3.73E+02	*
Benzo(k)fluoranthene	2.36E+02	*	2.39E+02	*	3.09E+02	*	4.80E+02	*	7.34E+02	*	1.47E+03	*	2.51E+03	*	3.85E+03	*
Chrysene	1.22E+03	*	1.24E+03	*	1.60E+03	*	2.49E+03	*	3.80E+03	*	7.63E+03	*	1.30E+04	*	1.99E+04	*
Dibenzo(a,h)anthracene	4.76E+00		4.80E+00		6.23E+00		9.67E+00		1.48E+01		2.96E+01		5.05E+01		7.74E+01	*
Fluoranthene	5.21E+03	*	5.26E+03	*	6.82E+03	*	1.06E+04	*	1.62E+04	*	3.25E+04	*	5.54E+04	*	8.48E+04	*
Fluorene	4.22E+02	*	4.26E+02	*	5.52E+02	*	8.57E+02	*	1.31E+03	*	2.63E+03	*	4.48E+03	*	6.87E+03	*
Napthalene	6.50E-01		6.56E-01		8.50E-01	*	1.32E+00	*	2.02E+00	*	4.05E+00	*	6.90E+00	*	1.06E+01	*
Pyrene	3.01E+03	*	3.03E+03	*	3.93E+03	*	6.10E+03	*	9.33E+03	*	1.87E+04	*	3.19E+04	*	4.89E+04	*
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA	
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
Tertiary-amyl-methyl-ether (TAME)	1.35E+00		1.37E+00		1.77E+00		2.75E+00		4.20E+00		8.43E+00		1.44E+01		2.20E+01	
Tertiary-butyl- alcohol (TBA)	1.12E+00		1.13E+00		1.46E+00		2.27E+00		3.47E+00		6.95E+00		1.18E+01		1.81E+01	
Ethyl-tert-butyl-ether (ETBE)	2.12E-01		2.14E-01		2.77E-01		4.31E-01		6.58E-01		1.32E+00		2.25E+00		3.45E+00	
Diisopropyl ether (DIPE)	8.23E+00		8.31E+00		1.08E+01		1.67E+01		2.56E+01		5.13E+01		8.74E+01		1.34E+02	
Ethanol	1.55E+03		1.56E+03		2.02E+03		3.14E+03		4.80E+03		9.63E+03		1.64E+04		2.52E+04	*
Methanol	4.16E+01		4.20E+01		5.44E+01		8.45E+01		1.29E+02		2.59E+02		4.42E+02		6.77E+02	
Arsenic	1.44E+01		1.45E+01		1.89E+01		2.93E+01		4.48E+01		8.98E+01		1.53E+02		2.34E+02	
Barium	4.07E+03		4.11E+03		5.33E+03		8.28E+03		1.27E+04		2.54E+04		4.33E+04		6.63E+04	
Cadmium	1.86E+01		1.88E+01		2.44E+01		3.78E+01		5.78E+01		1.16E+02		1.98E+02		3.03E+02	
Chromium III	8.93E+06		9.01E+06		1.17E+07		1.81E+07		2.77E+07		5.56E+07		9.48E+07		1.45E+08	
Chromium VI	1.51E-02		1.52E-02		1.97E-02		3.06E-02		4.68E-02		9.38E-02		1.60E-01		2.45E-01	
Lead	NA		NA		NA		NA		NA		NA		NA		NA	
Selenium	1.25E+01		1.26E+01		1.64E+01		2.55E+01		3.89E+01		7.81E+01		1.33E+02		2.04E+02	

Notes:

NA : Not Available

Target levels are based on distance to groundwater between 20 and 50 ft for which default vadose zone DAF is 2.

All concentrations in mg/kg.

* Value exceeds effective /saturated soil concentration

Table 7-4(c): Soil Concentration Protective of Groundwater Domestic Use for Different Distances to POE

Depth to Groundwater >50' (DAF=4)

Chemicals of Concern	Distance to POE (ft)																	
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00			
Benzene	2.24E-01		2.26E-01		2.94E-01		4.56E-01		6.97E-01		1.40E+00		2.38E+00		3.65E+00			
Toluene	1.19E+02	*	1.20E+02	*	1.56E+02	*	2.42E+02	*	3.70E+02	*	7.41E+02	*	1.26E+03	*	1.94E+03	*		
Ethylbenzene	1.59E+02	*	1.61E+02	*	2.09E+02	*	3.24E+02	*	4.95E+02	*	9.93E+02	*	1.69E+03	*	2.59E+03	*		
Xylenes (mixed)	2.54E+03	*	2.56E+03	*	3.32E+03	*	5.15E+03	*	7.88E+03	*	1.58E+04	*	2.69E+04	*	4.13E+04	*		
Ethylene Dibromide (EDB)	1.89E-03		1.91E-03		2.47E-03		3.84E-03		5.88E-03		1.18E-02		2.01E-02		3.08E-02			
Ethylene Dichloride (EDC)	8.22E-02		8.30E-02		1.08E-01		1.67E-01		2.55E-01		5.12E-01		8.73E-01		1.34E+00			
Methyl-tert-butyl-ether (MTBE)	1.59E+00		1.61E+00		2.08E+00		3.24E+00		4.95E+00		9.92E+00		1.69E+01		2.59E+01			
Acenaphthene	6.97E+02	*	7.03E+02	*	9.12E+02	*	1.42E+03	*	2.16E+03	*	4.34E+03	*	7.40E+03	*	1.13E+04	*		
Anthracene	1.22E+04	*	1.23E+04	*	1.60E+04	*	2.48E+04	*	3.80E+04	*	7.61E+04	*	1.30E+05	*	1.99E+05	*		
Benzo(a)anthracene	2.45E+01	*	2.47E+01	*	3.20E+01	*	4.98E+01	*	7.61E+01	*	1.53E+02	*	2.60E+02	*	3.98E+02	*		
Benzo(a)pyrene	1.21E+02	*	1.23E+02	*	1.59E+02	*	2.47E+02	*	3.77E+02	*	7.56E+02	*	1.29E+03	*	1.98E+03	*		
Benzo(b)fluoranthene	4.59E+01	*	4.63E+01	*	6.00E+01	*	9.32E+01	*	1.43E+02	*	2.86E+02	*	4.87E+02	*	7.47E+02	*		
Benzo(k)fluoranthene	4.73E+02	*	4.77E+02	*	6.18E+02	*	9.61E+02	*	1.47E+03	*	2.95E+03	*	5.02E+03	*	7.69E+03	*		
Chrysene	2.45E+03	*	2.47E+03	*	3.20E+03	*	4.98E+03	*	7.61E+03	*	1.53E+04	*	2.60E+04	*	3.98E+04	*		
Dibenzo(a,h)anthracene	9.52E+00		9.60E+00		1.25E+01		1.93E+01		2.96E+01		5.93E+01	*	1.01E+02	*	1.55E+02	*		
Fluoranthene	1.04E+04	*	1.05E+04	*	1.36E+04	*	2.12E+04	*	3.24E+04	*	6.49E+04	*	1.11E+05	*	1.70E+05	*		
Fluorene	8.44E+02	*	8.52E+02	*	1.10E+03	*	1.71E+03	*	2.62E+03	*	5.26E+03	*	8.96E+03	*	1.37E+04	*		
Napthalene	1.30E+00	*	1.31E+00	*	1.70E+00	*	2.64E+00	*	4.04E+00	*	8.10E+00	*	1.38E+01	*	2.12E+01	*		
Pyrene	6.01E+03	*	6.06E+03	*	7.86E+03	*	1.22E+04	*	1.87E+04	*	3.74E+04	*	6.38E+04	*	9.78E+04	*		
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA			
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
Tertiary-amyl-methyl-ether (TAME)	2.71E+00		2.73E+00		3.54E+00		5.50E+00		8.41E+00		1.69E+01		2.87E+01		4.40E+01			
Tertiary-butyl- alcohol (TBA)	2.23E+00		2.25E+00		2.92E+00		4.53E+00		6.93E+00		1.39E+01		2.37E+01		3.63E+01			
Ethyl-tert-butyl-ether (ETBE)	4.24E-01		4.28E-01		5.54E-01		8.61E-01		1.32E+00		2.64E+00		4.50E+00		6.90E+00			
Diisopropyl ether (DIPE)	1.65E+01		1.66E+01		2.15E+01		3.34E+01		5.11E+01		1.03E+02		1.75E+02		2.68E+02			
Ethanol	3.09E+03		3.12E+03		4.05E+03		6.28E+03		9.61E+03		1.93E+04	*	3.29E+04	*	5.03E+04	*		
Methanol	8.32E+01		8.40E+01		1.09E+02		1.69E+02		2.58E+02		5.18E+02		8.84E+02		1.35E+03			
Arsenic	2.88E+01		2.91E+01		3.77E+01		5.86E+01		8.95E+01		1.80E+02		3.06E+02		4.69E+02			
Barium	8.15E+03		8.22E+03		1.07E+04		1.66E+04		2.53E+04		5.07E+04		8.65E+04		1.33E+05			
Cadmium	3.72E+01		3.76E+01		4.87E+01		7.56E+01		1.16E+02		2.32E+02		3.95E+02		6.06E+02			
Chromium III	1.79E+07		1.80E+07		2.34E+07		3.63E+07		5.55E+07		1.11E+08		1.90E+08		2.91E+08			
Chromium VI	3.01E-02		3.04E-02		3.94E-02		6.12E-02		9.36E-02		1.88E-01		3.20E-01		4.90E-01			
Lead	NA		NA		NA		NA		NA		NA		NA		NA			
Selenium	2.51E+01		2.53E+01		3.28E+01		5.09E+01		7.79E+01		1.56E+02		2.66E+02		4.08E+02			

Notes:

NA : Not Available

Target levels are based on distance to groundwater >50 ft for which default vadose zone DAF is 4.

All concentrations in mg/kg.

* Value exceeds effective /saturated soil concentration

Table 7-5(a): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Resident

Depth to Groundwater <20' (DAF=1)

Chemicals of Concern	Distance to POE (ft)																	
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00			
Benzene	1.12E+01		1.13E+01		1.47E+01		2.28E+01	*	3.49E+01	*	7.00E+01	*	1.19E+02	*	1.83E+02	*		
Toluene	1.51E+04	*	1.52E+04	*	1.98E+04	*	3.07E+04	*	4.69E+04	*	9.41E+04	*	1.60E+05	*	2.46E+05	*		
Ethylbenzene	5.89E+03	*	5.95E+03	*	7.71E+03	*	1.20E+04	*	1.83E+04	*	3.67E+04	*	6.26E+04	*	9.59E+04	*		
Xylenes (mixed)	7.48E+02	*	7.55E+02	*	9.79E+02	*	1.52E+03	*	2.32E+03	*	4.66E+03	*	7.94E+03	*	1.22E+04	*		
Ethylene Dibromide (EDB)	2.18E+00		2.20E+00		2.85E+00		4.43E+00		6.77E+00		1.36E+01		2.32E+01		3.55E+01			
Ethylene Dichloride (EDC)	3.68E+00		3.71E+00		4.81E+00		7.47E+00		1.14E+01		2.29E+01		3.90E+01		5.98E+01			
Methyl-tert-butyl-ether (MTBE)	5.62E+02		5.67E+02		7.35E+02		1.14E+03		1.75E+03		3.50E+03		5.97E+03		9.15E+03	*		
Acenaphthene	1.70E+06	*	1.71E+06	*	2.22E+06	*	3.45E+06	*	5.27E+06	*	1.06E+07	*	1.80E+07	*	2.76E+07	*		
Anthracene	1.00E+07	*	1.01E+07	*	1.31E+07	*	2.04E+07	*	3.12E+07	*	6.26E+07	*	1.07E+08	*	1.63E+08	*		
Benzo(a)anthracene	6.55E+06	*	6.60E+06	*	8.56E+06	*	1.33E+07	*	2.03E+07	*	4.08E+07	*	6.95E+07	*	1.06E+08	*		
Benzo(a)pyrene	5.67E+06	*	5.72E+06	*	7.41E+06	*	1.15E+07	*	1.76E+07	*	3.53E+07	*	6.01E+07	*	9.22E+07	*		
Benzo(b)fluoranthene	1.40E+06	*	1.41E+06	*	1.83E+06	*	2.84E+06	*	4.35E+06	*	8.72E+06	*	1.49E+07	*	2.28E+07	*		
Benzo(k)fluoranthene	1.72E+08	*	1.73E+08	*	2.24E+08	*	3.49E+08	*	5.33E+08	*	1.07E+09	*	1.82E+09	*	2.79E+09	*		
Chrysene	4.84E+06	*	4.88E+06	*	6.33E+06	*	9.83E+06	*	1.50E+07	*	3.01E+07	*	5.14E+07	*	7.87E+07	*		
Dibenzo(a,h)anthracene	5.57E+08	*	5.62E+08	*	7.29E+08	*	1.13E+09	*	1.73E+09	*	3.47E+09	*	5.92E+09	*	9.07E+09	*		
Fluoranthene	2.27E+08	*	2.29E+08	*	2.97E+08	*	4.61E+08	*	7.05E+08	*	1.41E+09	*	2.41E+09	*	3.69E+09	*		
Fluorene	6.19E+06	*	6.25E+06	*	8.10E+06	*	1.26E+07	*	1.92E+07	*	3.86E+07	*	6.57E+07	*	1.01E+08	*		
Napthalene	6.72E+02	*	6.78E+02	*	8.79E+02	*	1.36E+03	*	2.09E+03	*	4.18E+03	*	7.13E+03	*	1.09E+04	*		
Pyrene	2.70E+08	*	2.73E+08	*	3.53E+08	*	5.49E+08	*	8.39E+08	*	1.68E+09	*	2.87E+09	*	4.40E+09	*		
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA			
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
Tertiary-amyl-methyl-ether (TAME)	1.68E+02		1.70E+02		2.20E+02		3.42E+02		5.23E+02		1.05E+03		1.79E+03	*	2.74E+03	*		
Tertiary-butyl- alcohol (TBA)	2.59E+04	*	2.61E+04	*	3.38E+04	*	5.25E+04	*	8.03E+04	*	1.61E+05	*	2.75E+05	*	4.21E+05	*		
Ethyl-tert-butyl-ether (ETBE)	7.28E+02		7.34E+02		9.52E+02		1.48E+03		2.26E+03	*	4.53E+03	*	7.72E+03	*	1.18E+04	*		
Diisopropyl ether (DIPE)	9.62E+02		9.71E+02		1.26E+03	*	1.95E+03	*	2.99E+03	*	5.99E+03	*	1.02E+04	*	1.57E+04	*		
Ethanol	1.81E+05	*	1.82E+05	*	2.36E+05	*	3.67E+05	*	5.61E+05	*	1.12E+06	*	1.92E+06	*	2.94E+06	*		
Methanol	7.39E+05	*	7.45E+05	*	9.66E+05	*	1.50E+06	*	2.29E+06	*	4.60E+06	*	7.84E+06	*	1.20E+07	*		
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA			
Barium	NA		NA		NA		NA		NA		NA		NA		NA			
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA			
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA			
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA			
Lead	NA		NA		NA		NA		NA		NA		NA		NA			
Selenium	NA		NA		NA		NA		NA		NA		NA		NA			

Notes:

NA : Not Available

Target levels are based on distance to groundwater < 20 ft for which default vadose zone DAF is 1.

All concentrations in mg/kg.

* Value exceeds effective/saturated soil concentration

Table 7-5(b): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Resident

Depth to Groundwater 20' – 50' (DAF=2)

Chemicals of Concern	Distance to POE (ft)																	
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00			
Benzene	2.25E+01	*	2.27E+01	*	2.94E+01	*	4.57E+01	*	6.98E+01	*	1.40E+02	*	2.39E+02	*	3.66E+02	*		
Toluene	3.02E+04	*	3.05E+04	*	3.95E+04	*	6.14E+04	*	9.39E+04	*	1.88E+05	*	3.21E+05	*	4.92E+05	*		
Ethylbenzene	1.18E+04	*	1.19E+04	*	1.54E+04	*	2.39E+04	*	3.66E+04	*	7.34E+04	*	1.25E+05	*	1.92E+05	*		
Xylenes (mixed)	1.50E+03	*	1.51E+03	*	1.96E+03	*	3.04E+03	*	4.65E+03	*	9.32E+03	*	1.59E+04	*	2.43E+04	*		
Ethylene Dibromide (EDB)	4.36E+00		4.40E+00		5.70E+00		8.86E+00		1.35E+01		2.72E+01		4.63E+01		7.10E+01			
Ethylene Dichloride (EDC)	7.36E+00		7.42E+00		9.62E+00		1.49E+01		2.28E+01		4.58E+01		7.81E+01		1.20E+02			
Methyl-tert-butyl-ether (MTBE)	1.12E+03		1.13E+03		1.47E+03		2.28E+03		3.49E+03		7.00E+03	*	1.19E+04	*	1.83E+04	*		
Acenaphthene	3.39E+06	*	3.42E+06	*	4.44E+06	*	6.89E+06	*	1.05E+07	*	2.11E+07	*	3.60E+07	*	5.52E+07	*		
Anthracene	2.01E+07	*	2.03E+07	*	2.63E+07	*	4.08E+07	*	6.24E+07	*	1.25E+08	*	2.13E+08	*	3.27E+08	*		
Benzo(a)anthracene	1.31E+07	*	1.32E+07	*	1.71E+07	*	2.66E+07	*	4.07E+07	*	8.15E+07	*	1.39E+08	*	2.13E+08	*		
Benzo(a)pyrene	1.13E+07	*	1.14E+07	*	1.48E+07	*	2.30E+07	*	3.52E+07	*	7.06E+07	*	1.20E+08	*	1.84E+08	*		
Benzo(b)fluoranthene	2.80E+06	*	2.83E+06	*	3.66E+06	*	5.69E+06	*	8.70E+06	*	1.74E+07	*	2.97E+07	*	4.56E+07	*		
Benzo(k)fluoranthene	3.43E+08	*	3.46E+08	*	4.49E+08	*	6.97E+08	*	1.07E+09	*	2.14E+09	*	3.64E+09	*	5.58E+09	*		
Chrysene	9.68E+06	*	9.76E+06	*	1.27E+07	*	1.97E+07	*	3.01E+07	*	6.03E+07	*	1.03E+08	*	1.57E+08	*		
Dibenzo(a,h)anthracene	1.11E+09	*	1.12E+09	*	1.46E+09	*	2.26E+09	*	3.46E+09	*	6.94E+09	*	1.18E+10	*	1.81E+10	*		
Fluoranthene	4.54E+08	*	4.58E+08	*	5.93E+08	*	9.22E+08	*	1.41E+09	*	2.83E+09	*	4.82E+09	*	7.38E+09	*		
Fluorene	1.24E+07	*	1.25E+07	*	1.62E+07	*	2.52E+07	*	3.85E+07	*	7.71E+07	*	1.31E+08	*	2.01E+08	*		
Napthalene	1.34E+03	*	1.36E+03	*	1.76E+03	*	2.73E+03	*	4.17E+03	*	8.37E+03	*	1.43E+04	*	2.19E+04	*		
Pyrene	5.41E+08	*	5.45E+08	*	7.07E+08	*	1.10E+09	*	1.68E+09	*	3.37E+09	*	5.74E+09	*	8.79E+09	*		
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA			
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA			
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA			
Tertiary-amyl-methyl-ether (TAME)	3.37E+02		3.40E+02		4.40E+02		6.84E+02		1.05E+03		2.10E+03	*	3.58E+03	*	5.48E+03	*		
Tertiary-butyl- alcohol (TBA)	5.17E+04	*	5.22E+04	*	6.77E+04	*	1.05E+05	*	1.61E+05	*	3.22E+05	*	5.49E+05	*	8.41E+05	*		
Ethyl-tert-butyl-ether (ETBE)	1.46E+03		1.47E+03		1.90E+03	*	2.96E+03	*	4.52E+03	*	9.06E+03	*	1.54E+04	*	2.37E+04	*		
Diisopropyl ether (DIPE)	1.92E+03	*	1.94E+03	*	2.52E+03	*	3.91E+03	*	5.98E+03	*	1.20E+04	*	2.04E+04	*	3.13E+04	*		
Ethanol	3.61E+05	*	3.64E+05	*	4.72E+05	*	7.33E+05	*	1.12E+06	*	2.25E+06	*	3.83E+06	*	5.87E+06	*		
Methanol	1.48E+06	*	1.49E+06	*	1.93E+06	*	3.00E+06	*	4.59E+06	*	9.20E+06	*	1.57E+07	*	2.40E+07	*		
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA			
Barium	NA		NA		NA		NA		NA		NA		NA		NA			
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA			
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA			
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA			
Selenium	NA		NA		NA		NA		NA		NA		NA		NA			

Notes:

NA : Not Available

Target levels are based on distance to groundwater between 20 and 50 ft for which default vadose zone DAF is 2.

All concentrations in mg/kg.

* Value exceeds effective/saturated soil concentration

Table 7-5(c): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Resident

Depth to Groundwater > 50' (DAF=4)

Chemicals of Concern	Distance to POE (ft)																			
	0		25		50		75		100		150		200		250	
Benzene	4.50E+01	*	4.54E+01	*	5.88E+01	*	9.13E+01	*	1.40E+02	*	2.80E+02	*	4.77E+02	*	7.31E+02	*
Toluene	6.05E+04	*	6.10E+04	*	7.91E+04	*	1.23E+05	*	1.88E+05	*	3.76E+05	*	6.42E+05	*	9.83E+05	*
Ethylbenzene	2.36E+04	*	2.38E+04	*	3.08E+04	*	4.79E+04	*	7.32E+04	*	1.47E+05	*	2.50E+05	*	3.83E+05	*
Xylenes (mixed)	2.99E+03	*	3.02E+03	*	3.91E+03	*	6.08E+03	*	9.30E+03	*	1.86E+04	*	3.18E+04	*	4.87E+04	*
Ethylene Dibromide (EDB)	8.72E+00		8.80E+00		1.14E+01		1.77E+01		2.71E+01		5.43E+01		9.26E+01		1.42E+02	
Ethylene Dichloride (EDC)	1.47E+01		1.48E+01		1.92E+01		2.99E+01		4.57E+01		9.16E+01		1.56E+02		2.39E+02	
Methyl-tert-butyl-ether (MTBE)	2.25E+03		2.27E+03		2.94E+03		4.57E+03		6.98E+03	*	1.40E+04	*	2.39E+04	*	3.66E+04	*
Acenaphthene	6.78E+06	*	6.85E+06	*	8.87E+06	*	1.38E+07	*	2.11E+07	*	4.23E+07	*	7.20E+07	*	1.10E+08	*
Anthracene	4.02E+07	*	4.05E+07	*	5.25E+07	*	8.16E+07	*	1.25E+08	*	2.50E+08	*	4.27E+08	*	6.54E+08	*
Benzo(a)anthracene	2.62E+07	*	2.64E+07	*	3.42E+07	*	5.32E+07	*	8.13E+07	*	1.63E+08	*	2.78E+08	*	4.26E+08	*
Benzo(a)pyrene	2.27E+07	*	2.29E+07	*	2.96E+07	*	4.60E+07	*	7.04E+07	*	1.41E+08	*	2.41E+08	*	3.69E+08	*
Benzo(b)fluoranthene	5.60E+06	*	5.65E+06	*	7.33E+06	*	1.14E+07	*	1.74E+07	*	3.49E+07	*	5.95E+07	*	9.11E+07	*
Benzo(k)fluoranthene	6.86E+08	*	6.92E+08	*	8.98E+08	*	1.39E+09	*	2.13E+09	*	4.27E+09	*	7.29E+09	*	1.12E+10	*
Chrysene	1.94E+07	*	1.95E+07	*	2.53E+07	*	3.93E+07	*	6.01E+07	*	1.21E+08	*	2.05E+08	*	3.15E+08	*
Dibenzo(a,h)anthracene	2.23E+09	*	2.25E+09	*	2.92E+09	*	4.53E+09	*	6.92E+09	*	1.39E+10	*	2.37E+10	*	3.63E+10	*
Fluoranthene	9.07E+08	*	9.15E+08	*	1.19E+09	*	1.84E+09	*	2.82E+09	*	5.65E+09	*	9.63E+09	*	1.48E+10	*
Fluorene	2.48E+07	*	2.50E+07	*	3.24E+07	*	5.03E+07	*	7.69E+07	*	1.54E+08	*	2.63E+08	*	4.03E+08	*
Napthalene	2.69E+03	*	2.71E+03	*	3.51E+03	*	5.46E+03	*	8.35E+03	*	1.67E+04	*	2.85E+04	*	4.37E+04	*
Pyrene	1.08E+09	*	1.09E+09	*	1.41E+09	*	2.20E+09	*	3.36E+09	*	6.73E+09	*	1.15E+10	*	1.76E+10	*
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA	
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
Tertiary-amyl-methyl-ether (TAME)	6.73E+02		6.79E+02		8.81E+02		1.37E+03		2.09E+03	*	4.19E+03	*	7.15E+03	*	1.10E+04	*
Tertiary-butyl- alcohol (TBA)	1.03E+05	*	1.04E+05	*	1.35E+05	*	2.10E+05	*	3.21E+05	*	6.44E+05	*	1.10E+06	*	1.68E+06	*
Ethyl-tert-butyl-ether (ETBE)	2.91E+03	*	2.94E+03	*	3.81E+03	*	5.91E+03	*	9.04E+03	*	1.81E+04	*	3.09E+04	*	4.73E+04	*
Diisopropyl ether (DIPE)	3.85E+03	*	3.88E+03	*	5.03E+03	*	7.82E+03	*	1.20E+04	*	2.40E+04	*	4.09E+04	*	6.26E+04	*
Ethanol	7.22E+05	*	7.29E+05	*	9.44E+05	*	1.47E+06	*	2.24E+06	*	4.50E+06	*	7.67E+06	*	1.17E+07	*
Methanol	2.95E+06	*	2.98E+06	*	3.86E+06	*	6.00E+06	*	9.18E+06	*	1.84E+07	*	3.14E+07	*	4.81E+07	*
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA	
Barium	NA		NA		NA		NA		NA		NA		NA		NA	
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA	
Selenium	NA		NA		NA		NA		NA		NA		NA		NA	

Notes:

NA : Not Available

Target levels are based on distance to groundwater >50 ft for which default vadose zone DAF is 4.

All concentrations in mg/kg.

* Value exceeds effective/saturated soil concentration

Table 7-6(a): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Non-Resident

Depth to Groundwater <20' (DAF=1)

Chemicals of Concern	Distance to POE (ft)																					
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00	
Benzene	5.89E+01	*	5.95E+01	*	7.71E+01	*	1.20E+02	*	1.83E+02	*	3.67E+02	*	6.26E+02	*	9.59E+02	*
Toluene	1.22E+05	*	1.23E+05	*	1.59E+05	*	2.47E+05	*	3.77E+05	*	7.57E+05	*	1.29E+06	*	1.98E+06	*
Ethylbenzene	4.74E+04	*	4.78E+04	*	6.20E+04	*	9.62E+04	*	1.47E+05	*	2.95E+05	*	5.03E+05	*	7.71E+05	*
Xylenes (mixed)	6.02E+03	*	6.07E+03	*	7.87E+03	*	1.22E+04	*	1.87E+04	*	3.75E+04	*	6.39E+04	*	9.79E+04	*
Ethylene Dibromide (EDB)	1.14E+01		1.15E+01		1.50E+01		2.32E+01		3.55E+01		7.12E+01		1.21E+02		1.86E+02	
Ethylene Dichloride (EDC)	1.93E+01		1.94E+01		2.52E+01		3.92E+01		5.99E+01		1.20E+02		2.05E+02		3.14E+02	
Methyl-tert-butyl-ether (MTBE)	2.95E+03		2.97E+03		3.85E+03		5.99E+03		9.15E+03	*	1.84E+04	*	3.13E+04	*	4.79E+04	*
Acenaphthene	1.36E+07	*	1.38E+07	*	1.78E+07	*	2.77E+07	*	4.24E+07	*	8.49E+07	*	1.45E+08	*	2.22E+08	*
Anthracene	8.08E+07	*	8.15E+07	*	1.06E+08	*	1.64E+08	*	2.51E+08	*	5.03E+08	*	8.57E+08	*	1.31E+09	*
Benzo(a)anthracene	3.43E+07	*	3.46E+07	*	4.49E+07	*	6.97E+07	*	1.07E+08	*	2.14E+08	*	3.64E+08	*	5.58E+08	*
Benzo(a)pyrene	2.97E+07	*	3.00E+07	*	3.88E+07	*	6.03E+07	*	9.22E+07	*	1.85E+08	*	3.15E+08	*	4.83E+08	*
Benzo(b)fluoranthene	7.34E+06	*	7.41E+06	*	9.60E+06	*	1.49E+07	*	2.28E+07	*	4.57E+07	*	7.79E+07	*	1.19E+08	*
Benzo(k)fluoranthene	8.99E+08	*	9.07E+08	*	1.18E+09	*	1.83E+09	*	2.79E+09	*	5.60E+09	*	9.55E+09	*	1.46E+10	*
Chrysene	2.54E+07	*	2.56E+07	*	3.32E+07	*	5.15E+07	*	7.88E+07	*	1.58E+08	*	2.69E+08	*	4.13E+08	*
Dibenzo(a,h)anthracene	2.92E+09	*	2.95E+09	*	3.82E+09	*	5.93E+09	*	9.07E+09	*	1.82E+10	*	3.10E+10	*	4.75E+10	*
Fluoranthene	1.82E+09	*	1.84E+09	*	2.39E+09	*	3.70E+09	*	5.66E+09	*	1.14E+10	*	1.94E+10	*	2.97E+10	*
Fluorene	4.98E+07	*	5.02E+07	*	6.51E+07	*	1.01E+08	*	1.55E+08	*	3.10E+08	*	5.29E+08	*	8.10E+08	*
Napthalene	3.52E+03	*	3.55E+03	*	4.60E+03	*	7.15E+03	*	1.09E+04	*	2.19E+04	*	3.74E+04	*	5.73E+04	*
Pyrene	2.17E+09	*	2.19E+09	*	2.84E+09	*	4.41E+09	*	6.75E+09	*	1.35E+10	*	2.31E+10	*	3.53E+10	*
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA	
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
Tertiary-amyl-methyl-ether (TAME)	1.35E+03		1.37E+03		1.77E+03	*	2.75E+03	*	4.20E+03	*	8.43E+03	*	1.44E+04	*	2.20E+04	*
Tertiary-butyl- alcohol (TBA)	2.08E+05	*	2.10E+05	*	2.72E+05	*	4.22E+05	*	6.46E+05	*	1.30E+06	*	2.21E+06	*	3.38E+06	*
Ethyl-tert-butyl-ether (ETBE)	5.85E+03	*	5.90E+03	*	7.65E+03	*	1.19E+04	*	1.82E+04	*	3.64E+04	*	6.21E+04	*	9.52E+04	*
Diisopropyl ether (DIPE)	7.74E+03	*	7.81E+03	*	1.01E+04	*	1.57E+04	*	2.40E+04	*	4.82E+04	*	8.21E+04	*	1.26E+05	*
Ethanol	1.45E+06	*	1.46E+06	*	1.90E+06	*	2.95E+06	*	4.51E+06	*	9.04E+06	*	1.54E+07	*	2.36E+07	*
Methanol	5.94E+06	*	5.99E+06	*	7.77E+06	*	1.21E+07	*	1.84E+07	*	3.70E+07	*	6.31E+07	*	9.66E+07	*
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA	
Barium	NA		NA		NA		NA		NA		NA		NA		NA	
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA	
Selenium	NA		NA		NA		NA		NA		NA		NA		NA	

Notes:

NA : Not Available

Target levels are based on distance to groundwater <20 ft for which default vadose zone DAF is 1.

All concentrations in mg/kg.

*Value exceeds effective/saturated soil concentration

Table 7-6(b): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Non-Resident

Depth to Groundwater 20-50' (DAF=2)

Chemicals of Concern	Distance to POE (ft)																			
	0.00		25.00		50.00		75.00		100.00		150.00		200.00		250.00					
Benzene	1.18E+02	*	1.19E+02	*	1.54E+02	*	2.39E+02	*	3.66E+02	*	7.34E+02	*	1.25E+03	*	1.92E+03	*				
Toluene	2.43E+05	*	2.45E+05	*	3.18E+05	*	4.94E+05	*	7.55E+05	*	1.51E+06	*	2.58E+06	*	3.95E+06	*				
Ethylbenzene	9.48E+04	*	9.56E+04	*	1.24E+05	*	1.92E+05	*	2.94E+05	*	5.90E+05	*	1.01E+06	*	1.54E+06	*				
Xylenes (mixed)	1.20E+04	*	1.21E+04	*	1.57E+04	*	2.44E+04	*	3.74E+04	*	7.49E+04	*	1.28E+05	*	1.96E+05	*				
Ethylene Dibromide (EDB)	2.29E+01		2.31E+01		2.99E+01		4.64E+01		7.10E+01		1.42E+02		2.43E+02		3.72E+02					
Ethylene Dichloride (EDC)	3.86E+01		3.89E+01		5.04E+01		7.83E+01		1.20E+02		2.40E+02		4.09E+02		6.27E+02					
Methyl-tert-butyl-ether (MTBE)	5.89E+03		5.95E+03		7.71E+03	*	1.20E+04	*	1.83E+04	*	3.67E+04	*	6.26E+04	*	9.59E+04	*				
Acenaphthene	2.73E+07	*	2.75E+07	*	3.57E+07	*	5.54E+07	*	8.47E+07	*	1.70E+08	*	2.90E+08	*	4.44E+08	*				
Anthracene	1.62E+08	*	1.63E+08	*	2.11E+08	*	3.28E+08	*	5.02E+08	*	1.01E+09	*	1.71E+09	*	2.63E+09	*				
Benzo(a)anthracene	6.86E+07	*	6.92E+07	*	8.97E+07	*	1.39E+08	*	2.13E+08	*	4.27E+08	*	7.29E+08	*	1.12E+09	*				
Benzo(a)pyrene	5.94E+07	*	5.99E+07	*	7.77E+07	*	1.21E+08	*	1.84E+08	*	3.70E+08	*	6.31E+08	*	9.66E+08	*				
Benzo(b)fluoranthene	1.47E+07	*	1.48E+07	*	1.92E+07	*	2.98E+07	*	4.56E+07	*	9.14E+07	*	1.56E+08	*	2.39E+08	*				
Benzo(k)fluoranthene	1.80E+09	*	1.81E+09	*	2.35E+09	*	3.65E+09	*	5.59E+09	*	1.12E+10	*	1.91E+10	*	2.93E+10	*				
Chrysene	5.07E+07	*	5.12E+07	*	6.63E+07	*	1.03E+08	*	1.58E+08	*	3.16E+08	*	5.39E+08	*	8.25E+08	*				
Dibenzo(a,h)anthracene	5.84E+09	*	5.89E+09	*	7.64E+09	*	1.19E+10	*	1.81E+10	*	3.64E+10	*	6.20E+10	*	9.50E+10	*				
Fluoranthene	3.65E+09	*	3.68E+09	*	4.77E+09	*	7.41E+09	*	1.13E+10	*	2.27E+10	*	3.87E+10	*	5.93E+10	*				
Fluorene	9.96E+07	*	1.00E+08	*	1.30E+08	*	2.02E+08	*	3.09E+08	*	6.20E+08	*	1.06E+09	*	1.62E+09	*				
Napthalene	7.04E+03	*	7.10E+03	*	9.21E+03	*	1.43E+04	*	2.19E+04	*	4.39E+04	*	7.48E+04	*	1.15E+05	*				
Pyrene	4.35E+09	*	4.38E+09	*	5.68E+09	*	8.83E+09	*	1.35E+10	*	2.71E+10	*	4.61E+10	*	7.07E+10	*				
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA					
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA					
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA					
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA					
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA					
Tertiary-amyl-methyl-ether (TAME)	2.71E+03	*	2.73E+03	*	3.54E+03	*	5.50E+03	*	8.41E+03	*	1.69E+04	*	2.87E+04	*	4.40E+04	*				
Tertiary-butyl- alcohol (TBA)	4.16E+05	*	4.20E+05	*	5.44E+05	*	8.45E+05	*	1.29E+06	*	2.59E+06	*	4.42E+06	*	6.77E+06	*				
Ethyl-tert-butyl-ether (ETBE)	1.17E+04	*	1.18E+04	*	1.53E+04	*	2.38E+04	*	3.63E+04	*	7.29E+04	*	1.24E+05	*	1.90E+05	*				
Diisopropyl ether (DIPE)	1.55E+04	*	1.56E+04	*	2.02E+04	*	3.14E+04	*	4.81E+04	*	9.64E+04	*	1.64E+05	*	2.52E+05	*				
Ethanol	2.90E+06	*	2.93E+06	*	3.80E+06	*	5.90E+06	*	9.02E+06	*	1.81E+07	*	3.08E+07	*	4.72E+07	*				
Methanol	1.19E+07	*	1.20E+07	*	1.55E+07	*	2.41E+07	*	3.69E+07	*	7.40E+07	*	1.26E+08	*	1.93E+08	*				
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA					
Barium	NA		NA		NA		NA		NA		NA		NA		NA					
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA					
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA					
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA					
Lead	NA		NA		NA		NA		NA		NA		NA		NA					
Selenium	NA		NA		NA		NA		NA		NA		NA		NA					

Notes:

NA : Not Available

Target levels are based on distance to groundwater 20-50 ft for which default vadose zone DAF is 2.

All concentrations in mg/kg.

* Value exceeds effective/saturated soil concentration

17-Oct-13

Table 7-6(c): Soil Concentration Protective of Indoor Inhalation for Groundwater for Different Distances to On/Off-Site Building for Non-Resident

Depth to Groundwater >50' (DAF=4)

Chemicals of Concern	Distance to POE (ft)																					
	0		25		50		75		100		150		200		250	
Benzene	2.36E+02	*	2.38E+02	*	3.08E+02	*	4.79E+02	*	7.32E+02	*	1.47E+03	*	2.50E+03	*	3.83E+03	*
Toluene	4.86E+05	*	4.90E+05	*	6.36E+05	*	9.87E+05	*	1.51E+06	*	3.03E+06	*	5.16E+06	*	7.91E+06	*
Ethylbenzene	1.90E+05	*	1.91E+05	*	2.48E+05	*	3.85E+05	*	5.89E+05	*	1.18E+06	*	2.01E+06	*	3.08E+06	*
Xylenes (mixed)	2.41E+04	*	2.43E+04	*	3.15E+04	*	4.89E+04	*	7.47E+04	*	1.50E+05	*	2.55E+05	*	3.91E+05	*
Ethylene Dibromide (EDB)	4.57E+01		4.61E+01		5.98E+01		9.29E+01		1.42E+02		2.85E+02		4.85E+02		7.44E+02	
Ethylene Dichloride (EDC)	7.71E+01		7.78E+01		1.01E+02		1.57E+02		2.40E+02		4.80E+02		8.19E+02		1.25E+03	
Methyl-tert-butyl-ether (MTBE)	1.18E+04	*	1.19E+04	*	1.54E+04	*	2.39E+04	*	3.66E+04	*	7.34E+04	*	1.25E+05	*	1.92E+05	*
Acenaphthene	5.46E+07	*	5.50E+07	*	7.13E+07	*	1.11E+08	*	1.69E+08	*	3.40E+08	*	5.79E+08	*	8.87E+08	*
Anthracene	3.23E+08	*	3.26E+08	*	4.22E+08	*	6.56E+08	*	1.00E+09	*	2.01E+09	*	3.43E+09	*	5.25E+09	*
Benzo(a)anthracene	1.37E+08	*	1.38E+08	*	1.79E+08	*	2.79E+08	*	4.26E+08	*	8.55E+08	*	1.46E+09	*	2.23E+09	*
Benzo(a)pyrene	1.19E+08	*	1.20E+08	*	1.55E+08	*	2.41E+08	*	3.69E+08	*	7.40E+08	*	1.26E+09	*	1.93E+09	*
Benzo(b)fluoranthene	2.94E+07	*	2.96E+07	*	3.84E+07	*	5.96E+07	*	9.12E+07	*	1.83E+08	*	3.12E+08	*	4.78E+08	*
Benzo(k)fluoranthene	3.60E+09	*	3.63E+09	*	4.70E+09	*	7.31E+09	*	1.12E+10	*	2.24E+10	*	3.82E+10	*	5.85E+10	*
Chrysene	1.01E+08	*	1.02E+08	*	1.33E+08	*	2.06E+08	*	3.15E+08	*	6.32E+08	*	1.08E+09	*	1.65E+09	*
Dibenzo(a,h)anthracene	1.17E+10	*	1.18E+10	*	1.53E+10	*	2.37E+10	*	3.63E+10	*	7.28E+10	*	1.24E+11	*	1.90E+11	*
Fluoranthene	7.30E+09	*	7.36E+09	*	9.54E+09	*	1.48E+10	*	2.27E+10	*	4.54E+10	*	7.75E+10	*	1.19E+11	*
Fluorene	1.99E+08	*	2.01E+08	*	2.60E+08	*	4.05E+08	*	6.19E+08	*	1.24E+09	*	2.11E+09	*	3.24E+09	*
Napthalene	1.41E+04	*	1.42E+04	*	1.84E+04	*	2.86E+04	*	4.37E+04	*	8.77E+04	*	1.50E+05	*	2.29E+05	*
Pyrene	8.69E+09	*	8.77E+09	*	1.14E+10	*	1.77E+10	*	2.70E+10	*	5.41E+10	*	9.23E+10	*	1.41E+11	*
TPH-GRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-DRO	NA		NA		NA		NA		NA		NA		NA		NA	
TPH-ORO	NA		NA		NA		NA		NA		NA		NA		NA	
>C6 - C8 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C35 (Aliphatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C8 - C10 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C10 - C12 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C12 - C16 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C16 - C21 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
>C21 - C35 (Aromatics)	NA		NA		NA		NA		NA		NA		NA		NA	
Tertiary-amyl-methyl-ether (TAME)	5.42E+03	*	5.46E+03	*	7.08E+03	*	1.10E+04	*	1.68E+04	*	3.37E+04	*	5.75E+04	*	8.81E+04	*
Tertiary-butyl- alcohol (TBA)	8.32E+05	*	8.39E+05	*	1.09E+06	*	1.69E+06	*	2.58E+06	*	5.18E+06	*	8.83E+06	*	1.35E+07	*
Ethyl-tert-butyl-ether (ETBE)	2.34E+04	*	2.36E+04	*	3.06E+04	*	4.75E+04	*	7.27E+04	*	1.46E+05	*	2.48E+05	*	3.81E+05	*
Diisopropyl ether (DIPE)	3.09E+04	*	3.12E+04	*	4.05E+04	*	6.29E+04	*	9.61E+04	*	1.93E+05	*	3.29E+05	*	5.03E+05	*
Ethanol	5.81E+06	*	5.86E+06	*	7.59E+06	*	1.18E+07	*	1.80E+07	*	3.62E+07	*	6.16E+07	*	9.44E+07	*
Methanol	2.38E+07	*	2.40E+07	*	3.11E+07	*	4.83E+07	*	7.38E+07	*	1.48E+08	*	2.52E+08	*	3.86E+08	*
Arsenic	NA		NA		NA		NA		NA		NA		NA		NA	
Barium	NA		NA		NA		NA		NA		NA		NA		NA	
Cadmium	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium III	NA		NA		NA		NA		NA		NA		NA		NA	
Chromium VI	NA		NA		NA		NA		NA		NA		NA		NA	
Lead	NA		NA		NA		NA		NA		NA		NA		NA	
Selenium	NA		NA		NA		NA		NA		NA		NA		NA	

Notes:

NA : Not Available

Target levels are based on distance to groundwater >50 ft for which default vadose zone DAF is 4.

All concentrations in mg/kg.

* Value exceeds effective/saturated soil concentration

When conducted, a Tier 2 risk assessment follows a Tier 1 risk assessment and includes:

Step 1: Compilation of site-specific fate and transport parameters,
Step 2: Development of Tier 2 site-specific target levels (SSTLs); this step will typically be done with the computational software available through MDNR,
Step 3: Comparison of the Tier 2 SSTLs with exposure pathway-specific representative concentrations,
Step 4: Recommend a course of action, and
Step 5: Documentation of the Tier 2 risk assessment.

When doing a Tier 2 risk assessment, SSTLs must be calculated for all of the complete and potentially complete routes of exposure identified in the exposure model (EM) and all applicable chemicals of concern (COCs). As indicated in section 2.3, any Tier 2 SSTLs which are lower than the Tier 1 RBTLs for that site must be used as the applicable corrective action standards.

Details of each of these steps are presented below.

8.1 STEP 1: COMPILATION OF SITE-SPECIFIC FATE AND TRANSPORT PARAMETERS

The objective of this step is to select fate and transport parameters to be used for the development of Tier 2 SSTLs. Values will be considered site-specific if (i) correctly measured on site, (ii) literature values are representative of site conditions, or (iii) use of default values can be justified or shown to be conservative based on site conditions. Note that a work plan for the collection of site-specific fate and transport data need not be submitted to MDNR for approval.

The fate and transport parameters that may be modified for a Tier 2 risk assessment are presented below. The evaluator shall review the site information and select values for each of these parameters, providing justification for the selection of each specific value. For a few of the fate and transport parameters (e.g., the thickness of the capillary fringe), literature values consistent with the site stratigraphy may be used in lieu of field measurements. Note that the use of any default parameters will also require justification.

8.1.1 Soil Parameters

Length of Area of Release Parallel to Wind (W_a) (Tier 1 default value = 1500 cm)

Since the wind direction is variable, and the exact dimensions of the area of release are generally not known, W_a should represent the longest dimension of the area of release (e.g. diagonal if the soil source is roughly rectangular, diameter if the area of release is roughly circular.)

Depth to Subsurface Soil Sources (d_{ts}) (Tier 1 default value = 91.44 cm)

Tier 2 allows for the actual measured depth of contaminated soils to be used in developing Tier 2 SSTLs. Conservatively, the measured depth to subsurface soil may be the shallowest detected contamination or an average depth of the shallowest detected contamination from several borings. Either way, the measurements should reflect the distance from the surface to the top of the first zone of contaminated soil.

Thickness of Capillary Fringe (h_c) (Tier 1 default value = 5 cm)

The value used at Tier 2 to represent the capillary fringe thickness must be representative of the site soils/sediments and is dependent on soil grain size. Typically, the thickness of the capillary fringe should be based on literature values since direct measurement will be generally impractical. Note that the sum of the thickness of the capillary fringe and the thickness of the vadose zone should equal the depth to groundwater (i.e., $h_c + h_v = L_{gw}$). A site-specific capillary fringe thickness value may be used only if the evaluator adequately demonstrates that the capillary fringe is uncontaminated. Otherwise, the default value of 5 cm must be used.

Thickness of Vadose Zone (h_v) (Tier 1 default value = 295 cm)

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

Vadose Zone Dry Soil Bulk Density (ρ_s) (Tier 1 default value = 1.5 g/cm^3)

See Section 5.6.2 for a discussion related to the determination of soil bulk density. If multiple measurements from the vadose zone are available or when multiple values are necessary to represent different soil types, use the average value.

Fractional Organic Carbon Content in Vadose Zone (f_{ocv}) (Tier 1 default value = 0.006)

See Section 5.6.5 for a discussion of sample collection and laboratory methods. If measurements of fractional organic matter (not the same as fractional organic carbon) are available, the value must be corrected as discussed in Section 5.6.5. If multiple values are available (as is recommended), the average value should be used. Where soil lithology is significantly heterogeneous, samples should be collected at each change in lithology and composited into one sample for fractional organic carbon content analysis.

Porosity in the Vadose Zone (θ_T) (Tier 1 default value = 0.434 cm^3/cm^3)

In both Tier 1 and Tier 2, the assumption is made that the porosity of vadose zone, capillary fringe, and soil that fills the foundation or wall cracks is identical. This assumption is necessary, as, generally, measuring porosity in the capillary fringe and in foundation and wall cracks is not practical. See Section 5.6.3 for a discussion of

laboratory methods. 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.

Volumetric Water Content in Vadose Zone (θ_{ws}) (Tier 1 default value = 0.15 cm^3/cm^3)

The Tier 2 value is typically measured as discussed in Section 5.6.4. When using a site-specific value, the value is measured on a weight basis (gravimetric: grams of water/grams of dry soil) and must be converted to a volumetric value (cm^3 of water/cm^3 of soil) as discussed in Section 5.6.4. An average value based on multiple samples shall be used. Note that moisture content values may be obtained from soil samples to be analyzed for COCs (COCs must be reported by laboratories on a dry weight basis; therefore, the moisture content of each sample must be determined).

Volumetric Air Content in Vadose Zone (θ_{as}) (Tier 1 default value = 0.284 cm^3/cm^3)

This parameter is the difference between the total soil porosity in the vadose zone and the volumetric water content in the vadose zone (i.e., $\theta_T - \theta_{WS} = \theta_{as}$).

Volumetric Water Content in Capillary Fringe (θ_{wcap}) (Tier 1 default value = 0.39 cm^3/cm^3)

This value is typically estimated as 90% of the total vadose zone soil porosity (i.e., $0.9\theta_T$). Total soil porosity in the capillary fringe is typically assumed to be equal to the total vadose zone porosity.

Volumetric Air Content in Capillary Fringe (θ_{acap}) (Tier 1 default value = 0.0434 cm^3/cm^3)

Tier 2 assumes that the volumetric air content in the capillary fringe is 10% of the total porosity in the vadose zone (i.e., $0.1\theta_T$).

Volumetric Water Content in Foundation or Wall Cracks (θ_{wcrack}) (Tier 1 default value = 0.15 cm^3/cm^3)

Tier 2 assumes that the volumetric water content in soil that fills foundation or wall cracks is the same as the volumetric water content of the soil in the vadose zone.

Volumetric Air Content in Foundation or Wall Cracks (θ_{acrack}) (Tier 1 default value = 0.284 cm^3/cm^3)

The volumetric air content in foundation wall/cracks is assumed to be the same as the volumetric air content of the soil in the vadose zone. The latter is determined as mentioned above.

8.1.2 Groundwater Parameters

Depth to Groundwater (L_{gw}) (Tier 1 default value = 300 cm)

Since the depth to groundwater fluctuates, an average depth to groundwater using data no more than 2 years old should be used. However, calculating an average depth to groundwater using data collected from several monitoring events over an extended period of time (such as one year of quarterly measurements or six months of monthly measurements) is preferable. If such data are available, the average should be calculated using the average depth to groundwater for each quarter (the average for all wells for each event should be used to calculate an overall average depth to groundwater for the entire site).

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, the shallowest average depth to groundwater should be used (i.e., a single well average using data from the well showing the shallowest depth to groundwater).

Width of Groundwater Source Area Perpendicular to Groundwater Flow Direction (Y) (Tier 1 default value = 1500 cm)

Figure 8-1 shows a schematic of the groundwater source that is considered by Domenico's groundwater model. The model assumes that COCs migrate vertically downward from the area of release to groundwater. By projecting the area of release to the water table, Y can be estimated. Domenico's model is used to simulate migration in the saturated zone and will be necessary only in cases where the groundwater use pathway is complete.

Length of Groundwater Source Area Parallel to Groundwater Flow Direction (W_{ga}) (Tier 1 default value = 1500 cm)

Figure 8-1 shows a schematic of the groundwater source that is considered by Domenico's groundwater model. The model assumes that COCs migrate vertically downward from the area of release to groundwater. By projecting the area of release to the water table, W_{ga} can be estimated.

Porosity in Saturated Zone (θ_{TS}) (Tier 1 default value = 0.434 cm^3/cm^3)

An accurate estimate of the total soil porosity in the saturated zone is essential when biodecay is considered. 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 or an appropriate literature value used. Where total and effective porosity differ or are expected to differ, the effective porosity value must be used.

Saturated Zone Dry Soil Bulk Density (ρ_{ss}) (Tier 1 default value = 1.5 g/cm^3)

An accurate estimate of the total soil bulk density in the saturated zone is essential when biodecay is considered. If the unsaturated and saturated zone stratigraphies are similar, the saturated zone dry soil bulk density may be set equal to the vadose zone dry soil bulk density. If multiple values are available, an average should be used. If the vadose and saturated zone stratigraphies are significantly dissimilar, the dry soil bulk density of the saturated zone must be measured in the field or an appropriate literature value used.

Fractional Organic Carbon Content in Saturated Zone (f_{ocs}) (Tier 1 default value = 0.006)

An accurate estimate of the fractional organic carbon content in the saturated zone is essential when biodecay is considered. Refer to Section 5.6.5 for discussion of this parameter. 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 an appropriate, justifiable literature value.

Groundwater Mixing Zone Thickness (δ_{gw}) (Tier 1 default value = 200 cm)

The groundwater mixing zone thickness is a measure of the thickness over which COCs mix within the saturated zone, primarily due to water table fluctuations. While difficult to estimate accurately, the mixing zone thickness may be approximated based on photoionization detector (PID) readings or soil concentrations measured in borings. 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 utilized with the prior approval of MDNR.

Groundwater Darcy Velocity (U_{gw}) (Tier 1 default value = 2500 cm/yr)

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 might have to be estimated for more than one direction.

Infiltration Rate (I) (Tier 1 default value = 14 cm/yr)

The infiltration rate may be estimated as 10% of the average annual rainfall at the site. Annual rainfall values are based on a 30-year average and may be obtained from literature.

8.2 STEP 2: DEVELOPMENT OF TIER 2 SSTLs

The evaluator shall use the parameter values compiled in Step 1 of Section 8.1 to develop Tier 2 SSTLs. These levels can be developed by the use of the MRBCA software or by equivalent methods. The values compiled in Step 1 are entered on the Fate and Transport Parameters page of the software.

8.3 STEP 3: COMPARISON OF TIER 2 SSTLs WITH SITE-SPECIFIC REPRESENTATIVE CONCENTRATIONS

In this step, the Tier 2 SSTLs calculated in Step 2 are compared with the representative concentrations (or, for surficial soil in a residential setting, maximum COC concentrations) previously calculated for the Tier 1 risk assessment (unless there is reason to modify the calculation). Based on the results of this comparison, the entity doing the cleanup shall recommend the path forward as discussed in Step 4 below.

8.4 STEP 4: RECOMMENDATIONS FOR THE NEXT COURSE OF ACTION

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

Alternative 1: If the representative concentrations (or maximum COC concentrations for surficial soil in a residential setting) of the COCs do not exceed the Tier 2 SSTLs for any of the complete pathways and all the following conditions are met, the tank owner or operator may request that MDNR issue a no further action (NFA) letter for the release.

Condition 1: Confirmation that the plume is stable or decreasing (see Section 5.9.3 for definition). If this condition is not met, the evaluator shall recommend continued groundwater monitoring until the plume stabilizes and/or take actions to hasten stabilization.

Condition 2: The maximum concentration of any COC does not exceed 10 times the representative concentration of that COC, for each complete route of exposure. This condition should be documented and MDNR will stipulate what actions, if any, must be taken.

Condition 3: If current site use is non-residential and exposure pathways are incomplete because of non-residential use (i.e., residential use would result in a complete pathway), or non-residential Tier 2 SSTLs are met but residential risk-based target levels (RBTLs) or

SSTLs are not, future non-residential use of the site must be assured through an AUL (see Section 11) or other adequate documentation. If this condition is not met, the evaluator must report this to MDNR, and MDNR will specify what actions, if any, must be taken.

Condition 4: Absence of ecological concerns at the site. If this condition is not met, the entity conducting the cleanup shall provide recommendations to MDNR to address the condition.

Alternative 2: If one or more representative concentrations exceed the Tier 2 SSTLs, the tank owner or operator shall determine whether to perform corrective action to achieve Tier 2 SSTLs or perform a Tier 3 risk assessment. MDNR will review the Tier 2 Risk Assessment Report and the recommendations and provide comments to the tank owner or operator.

8.5 STEP 5: DOCUMENTATION OF TIER 2 RISK ASSESSMENT

The Tier 2 risk assessment shall be documented as described in Section 12, and submitted to MDNR.

9.0
TIER 3 RISK ASSESSMENT

A Tier 3 risk assessment is a detailed, site-specific evaluation that may be conducted when Tier 2 site-specific target levels (SSTLs) are exceeded and it is not cost-effective to remediate the site to Tier 2 SSTLs. A Tier 3 risk assessment may be performed only after receiving approval of a Tier 3 work plan from MDNR. The Tier 3 risk assessment provides the most flexibility in developing SSTLs and requires the following steps:

Step 1: Development of a Tier 3 work plan,
Step 2: Collection of additional data, if necessary,
Step 3: Development of Tier 3 SSTLs,
Step 4: Comparison of Tier 3 SSTLs with representative concentrations,
Step 5: Recommendations for the next course of action, and
Step 6: Documentation of the Tier 3 risk assessment.

A Tier 3 risk assessment should focus only on the complete and potentially complete routes of exposure for which COCs exceed the Tier 2 SSTLs. However, if the models used at Tier 3 result in Tier 3 SSTLs that are lower than the Tier 2 SSTLs, the Tier 2 risk assessment findings must be re-evaluated; any conclusions based on the higher Tier 2 standard must be included in the Tier 3 assessment and applicable Tier 3 SSTLs must be calculated and compared to representative concentrations, and the Tier 3 SSTLs will be the applicable corrective action standards for the site.

If light non-aqueous phase liquid (LNAPL) is present at a site evaluated under Tier 3, the evaluator shall determine concentrations of COCs associated with the LNAPL using values for the effective solubility and vapor pressure in Tables B-5 and B-2, respectively, or by another method or using other values approved by MDNR. The equilibrium dissolved and vapor phase concentrations of chemicals of concern in LNAPL shall be used to evaluate the risks posed by the LNAPL and to develop representative concentrations for use in the risk assessment.

9.1 STEP 1: DEVELOPMENT OF A TIER 3 WORK PLAN

Since a Tier 3 risk assessment provides considerable flexibility to the evaluator (i.e., it allows the use of methods and models other than those presented in this guidance), MDNR will require the development and submittal of a detailed technical work plan. The technical portion of the work plan shall, at a minimum, include the following:

- An explanation of the COCs and the complete and potentially complete routes of exposure to be evaluated at Tier 3. As mentioned above, only those routes of exposure where COCs exceeded the Tier 2 SSTLs, and the specific COCs that exceeded the Tier 2 SSTLs, need to be considered in a Tier 3 risk assessment. Thus the Tier 3 investigation will generally focus on a limited set of pathways, receptors, and COCs.

- An explanation of the fate and transport models to be used for the evaluation of the complete and potentially complete routes of exposure. The entity performing the work may propose use of a model(s) different than that used to develop Tier 1 risk-based target levels (RBTLs) and Tier 2 SSTLs. At a minimum, the proposed model must be (i) peer reviewed, (ii) publicly available, (iii) have a history of use on similar projects, and (iv) be technically defensible.

- An explanation of the input parameters required to compute the Tier 3 SSTLs. These would typically include (i) chemical-specific physical properties, (ii) chemical-specific toxicological properties, (iii) site-specific or other alternate exposure factors, and (iv) media and site-specific parameters required by the selected fate and transport models. For each of these parameters, the evaluator must provide justification for using the selected value.

- An explanation of data gaps that require additional fieldwork. At Tier 3, the evaluator must provide a detailed scope of work for the collection of this data to MDNR.

9.2 STEP 2: COLLECTION OF ADDITIONAL DATA, IF NECESSARY

Upon approval of the work plan, the evaluator shall implement the approved scope of work. Any changes in the work plan made subsequent to MDNR's approval shall be brought to the attention of MDNR. Such changes must be pre-approved by MDNR and the changes documented.

9.3 STEP 3: DEVELOPMENT OF TIER 3 TARGET LEVELS

The Tier 3 risk assessment may be performed in the forward or the backward mode as explained below.

9.3.1 Forward Mode

In the forward mode, the end result of the risk assessment will be (i) the site-specific risk values (individual excess lifetime cancer risk ($IELCR_{calculated}$) for carcinogens and hazard quotient ($HQ_{calculated}$) for non-carcinogens) and (ii) the estimated COC concentrations at the nearest current or reasonably anticipated future groundwater receptor (C_{POE}). In the forward mode, risk is first estimated based on representative COC concentrations. The estimated IELCR and HQ values are then compared with the target IELCR ($1x10^{-5}$) and HQ (1). In addition, the actual or projected concentrations in the nearest drinking water well shall be compared with the maximum contaminant levels (MCLs), health advisories, or other applicable groundwater protection levels. If the calculated risk is acceptable, the entity conducting the evaluation should request that MDNR issue a no further action (NFA) letter (assuming other conditions for NFA issuance have been met).

If the calculated risk exceeds the acceptable levels, Tier 3 SSTLs can be established by using the following relationship for each COC and each route of exposure:

$$C_{target} = C_{calculated} \times \frac{1 \times 10^{-5}}{IELCR_{calculated}} \quad (9\text{-}1)$$

$$C_{target} = C_{calculated} \times \frac{1.0}{HQ_{calculated}} \quad (9\text{-}2)$$

where,

C_{target}	=	Tier 3 SSTLs,
$C_{calculated}$	=	Representative COC concentration used to estimate site-specific risk (obtained from sampling data),
$IELCR_{calculated}$	=	Site-specific calculated risk,
$HQ_{calculated}$	=	Site-specific calculated hazard quotient.

9.3.2 Backward Mode

Alternatively, the evaluator may calculate Tier 3 SSTLs directly using the backward mode as explained in Appendix B.

9.4 STEP 4: COMPARISON OF TIER 3 TARGET LEVELS WITH REPRESENTATIVE CONCENTRATIONS

In this step the Tier 3 SSTLs are compared with the representative concentrations (or, for surficial soil at a residential setting, the maximum COC concentrations). Note that representative concentrations used at Tier 2 may be used at Tier 3 unless additional data requires that these be modified (i.e., a new average or representative concentration must be calculated). Based on the comparison, the evaluator shall recommend the next course of action.

9.5 STEP 5: RECOMMENDATIONS FOR THE NEXT COURSE OF ACTION

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

Alternative 1: If the representative (or, for surficial soil in a residential setting, the maximum) concentrations for the complete exposure pathways do not exceed the Tier 3 SSTLs, or the calculated risks do not exceed the target risk levels, and the following four conditions are met, the tank owner or operator may request that MDNR issue a NFA letter for the release. These conditions include:

Condition 1: Confirmation that the plume is stable or decreasing (see definition at Section 5.9.3). If this condition is not satisfied, the evaluator shall recommend additional monitoring and/or source removal, as appropriate, to MDNR to achieve plume stability.

Condition 2: The maximum concentration of a COC does not exceed 10 times the representative concentration of that COC. If the maximum

concentration for any COC exceeds 10 times the representative concentration, MDNR will stipulate what actions, if any, must be taken.

Condition 3: If current site use is non-residential and exposure pathways are incomplete because of the non-residential use (i.e., residential use would result in additional complete pathways), or non-residential Tier 3 SSTLs are met but residential SSTLs are exceeded, future non-residential use of the site must be assured through adequate documentation. If this condition is not met, MDNR may require that an activity and use limitation (AUL) apply to the site before a NFA letter is issued.

Condition 4: Absence of ecological concerns at the site. If this condition is not met, the evaluator shall provide recommendations to MDNR to address the condition.

Alternative 2: If one or more representative concentrations exceed the Tier 3 SSTLs, or the estimated risks exceed the target risk levels, the evaluator shall propose remedial actions to MDNR in a Corrective Action Plan (CAP).

9. 6 STEP 6: DOCUMENTATION OF TIER 3 RISK ASSESSMENT

A Tier 3 risk assessment is very site-specific. Therefore, the entity performing the work shall submit a report clearly describing the data used, the methodology and key assumptions, the results, and recommendations regarding the path forward. Any deviation from the approved scope of work and the rationale for the deviation shall be clearly documented in the report. Refer to Section 12 of this document for further information regarding the expected content of the Tier 3 Risk Assessment Report.

10.0
CORRECTIVE ACTION PLAN

A corrective action plan (CAP) encompasses all activities necessary to manage human health and environmental risk so that they do not exceed the acceptable risk levels under either current or reasonably anticipated future land use conditions. CAP activities may include, but are not limited to, (i) corrective action plans, (ii) activity use limitations (AULs), and (iii) monitoring to verify assumptions made in the risk assessment.

10.1 NEED FOR A CORRECTIVE ACTION PLAN

A site-specific CAP is required if either of the following two conditions is met:

- representative chemical of concern (COC) concentrations for one or more complete or potentially complete routes of exposure exceed the appropriate tier-specific risk-based target levels, or

- representative COC concentrations for each complete or potentially complete route of exposure do not exceed the appropriate tier-specific target levels, but the tiered risk assessment was based on certain site-specific assumptions that must be preserved via a CAP.

The overall objective of a CAP is to ensure that:

- Site conditions are protective of human health and the environment under current and reasonably anticipated future conditions,
- Assumptions made in the development of target levels are not violated and/or remain applicable in the future, and
- Mobile or immobile light non-aqueous phase liquids (LNAPL; mobile LNAPL is referred to as "free product") are not present in the soil or groundwater in volumes that will result in any of the following conditions: (i) an expanding free product plume in soil or groundwater, (ii) an expanding dissolved plume, (iii) unacceptable risk to human health or the environment, and (iv) explosive or fire hazard.

Note that adequate protection of human health and the environment is afforded by achieving any of the tiered target levels discussed in Section 2.3. Successful implementation of the CAP will result in the issuance of a no further action (NFA) letter by MDNR.

The following sections provide general information regarding the preparation of a CAP.

10.2 CONTENTS OF CORRECTIVE ACTION PLAN

Once it is determined that a CAP is necessary for a site, the evaluator should prepare and submit a CAP to MDNR. A CAP may include one or a combination of:

- Active remedial actions to reduce COC concentrations to meet applicable target levels. Examples include, but are not limited to, soil excavation and off-site treatment or disposal, groundwater pump and treat, soil or groundwater vapor extraction, and enhanced in-situ attenuation;

- Application of AULs to eliminate certain exposure pathways. Examples include, but are not limited to, conditions imposed on the property that prevent the installation of wells, thereby eliminating the groundwater use pathway; conditions imposed to prevent future residential land use, etc., or

- Use of monitored natural attenuation to reduce COC concentrations.

Prior to implementation of the CAP, the evaluator must submit the plan to MDNR for approval. A CAP has to be tailored to meet site-specific conditions. However, at a minimum, it should include:

- The reasons why a CAP is being prepared and the specific objectives of the plan. As mentioned above, reasons for preparing the plan include:

  - Exceedance of target levels. The CAP should very clearly indicate the pathway, COC, and media that exceed the target level.

  - Need for AULs. The CAP should very clearly identify the specific reasons why AULs are necessary and the area to which they apply.

  - Presence of recoverable free product. The CAP should very clearly indicate the wells where this condition exists and the extent of the free product.

- A description of the specific activities that will be conducted as a part of the CAP. Examples include soil vapor extraction until the representative soil concentrations achieve a specified numerical value, or semi-annual monitoring of specified wells until concentrations show a clear decreasing trend. For the latter, the CAP shall indicate the method used to confirm plume stability (plots, contour maps or statistical evaluation of data). Note that, for active remedial actions, a corrective action plan must be prepared for submittal to, and approval by, MDNR.

- The CAP shall include specific criteria that will be used to demonstrate that the CAP activities have been successfully completed. Generally, this demonstration will require the collection of samples from the medium or media of concern.

Note that a CAP Performance Monitoring Plan must be submitted to, and approved by, MDNR for such activities.

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

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

- If AULs are a part of the CAP, sufficient documentation must be provided to MDNR demonstrating the existence, execution, and long term viability of the AULs. Note that an AUL Work Plan is required when AULs are proposed to address a specific risk or risks.

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

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

MDNR will review the CAP and either approve the plan as submitted, approve the plan with comments, disapprove the plan, or disapprove the plan with comments. The person who prepared the plan shall then revise the CAP to include MDNR's comments and resubmit the plan for approval. Upon receipt of approval, the entity performing the CAP should begin implementing the plan as per the approved schedule.

Note that Section 12 of this document provides further information regarding the content of a CAP and related work plans. This section and Section 12 should be carefully reviewed prior to developing a CAP.

10.3 COMPLETION OF CORRECTIVE ACTION ACTIVITIES

Upon successful completion of the approved CAP, the entity performing the work will submit a CAP Completion and Performance Monitoring Report that will include (i) confirmation of the successful completion of all elements of the CAP, (ii) a request for site closure, and (iii) a request to plug and abandon monitoring wells related to the environmental activities at the site. Refer to Section 2.4 and Section 12 for further information regarding final reporting.

Upon review of the final report, MDNR will either issue a NFA letter for the site or provide comments to the tank owner/operator explaining why a NFA letter cannot be issued and what additional activities are necessary. CAP activities must continue until MDNR issues a NFA letter or provides written authorization to terminate CAP activities.

10.4 NO FURTHER ACTION PROCEDURE

When the MRBCA evaluation has been performed, the evaluation has been approved by MDNR, and the approved CAP has been successfully implemented, the tank owner or operator may submit a request for issuance of a NFA letter to MDNR**.** The NFA request should be a part of the CAP Completion and Performance Monitoring Report discussed above and in Section 12.

Typically, the CAP Completion and Performance Monitoring Report, including the NFA request, would be the last report submitted to the MDNR prior to receiving a NFA letter. MDNR will review the report and request and issue a NFA letter if all applicable requirements have been met.

11.1 APPLICATION OF POLICY

The activity and use limitation (AUL) policy presented below explains the circumstances under which one or more specific AULs may or must be used to manage risks associated with a site. The policy includes an explanation of the various AULs that may be used to manage risks.

Note that Section 6.9 of this document includes a discussion of the reasons why an AUL might be used.

11.2 ACTIVITY AND USE LIMITATION POLICY FOR PETROLEUM STORAGE TANK SITES

11.2.1 Introduction

This policy has been developed, in cooperation with interested stakeholders, as an integral component of Missouri's Risk Based Corrective Action (MRBCA) guidance document. This policy was developed to ensure adequate protection of human health and the environment and to facilitate safe, cost-effective, and sustainable future land use.

[Note that the applicability of the MRBCA process to environmental emergency response incidents and sites involving imminent threats to human health or the environment is addressed at Section 1.3 of the *MRBCA Process for Petroleum Storage Tanks Guidance Manual, January 2004*.]

11.2.2 Definitions

A. **Activity and Use Limitations** (AULs) are legal or physical restrictions or limitations on the use of, or access to, a site or facility to eliminate or minimize potential exposures to chemicals of concern or to prevent activities that could interfere with the effectiveness of a response action. AULs ensure maintenance of a condition of "acceptable risk" or "no significant risk" to human health and the environment.

B. For the purposes of this policy, "**reasonably anticipated future use**" means "future use of a site or facility that can be predicted with a reasonably high degree of certainty given historical use, current use, development or use plans, local government planning and zoning, regional trends and community acceptance." The actual plan shall be the primary consideration in determining "reasonably anticipated future use" when there is a sufficiently high degree of certainty that the plan will be implemented.

C. A **Deed Notice** is an informational document filed in public land records (pertaining to a specific property) that alerts anyone searching the records to important information about the property.[1]

A Deed Notice shall:

(1) Be recorded in the chain of title of the real property to which the deed notice pertains;
(2) Be written in language a lay person can understand;
(3) Be legally precise;
(4) Adequately inform interested persons of the type, concentration, and location of contamination left on the property;
(5) Adequately inform interested persons what exposure pathway is a concern;
(6) Provide information on where the environmental data about the site is located; and
(7) Contain a reference to, include, or describe the 'No Further Action Letter' issued by the Department and conditions contained therein.

D. A **Restrictive Covenant** shall be a legally enforceable agreement included in the chain of title to real property that subjects all future owners to the limitations of the future use of the property. Generally, a covenant is a promise by the holder of the possessory interest in property to use or refrain from using the property in a certain manner. This covenant will run with the land.[2]

E. A **tank facility** is a facility that has or had one or more petroleum storage tanks, as defined at Section 319.100 RSMo.

F. An **underground storage tank (UST) facility** is a facility that has or had one or more petroleum underground storage tanks, as defined at Section 319.100 RSMo.

G. A **Corrective Action Plan** (CAP) encompasses all activities necessary to manage human health and environmental risks so that they do not exceed acceptable risk levels under current and reasonably anticipated future land use conditions. CAPs might include, but not necessarily be limited to, corrective action (remediation of chemicals of concern via physical or chemical processes), activity and use limitations, and monitoring.[3]

[1] US EPA, September 2000. Institutional Controls: A Site Manager's Guide to Identifying, Evaluating and Selecting Institutional Controls at Superfund and RCRA Corrective Action Cleanups. OSWER. EPA 540-F-00-005.
[2] Ibid. Definition based on definition of "covenant."
[3] MDNR, 2004. Missouri Risk-Based Corrective Action (MRBCA) Process for Petroleum Storage Tanks Guidance Manual. Section 10, pg. 10-1.

11.2.3 Application of Policy at Operating Tank Facilities

A. No AUL is required at an operating UST facility where a petroleum release is cleaned up to non-residential standards.

B. Instead of removing or remediating the chemicals of concern at an operating tank facility, the owner/operator may, as part of a CAP approved by the department, use one or more AULs listed in 11.2.4.D to mitigate a risk.

11.2.4 Application of Policy at Sites That Are No Longer Operating Tank Facilities

A. One or more AULs may be proposed in the CAP to mitigate the risk of exposure to chemicals of concern. The AULs may be used to address current exposure pathways or exposure pathways arising from the reasonably anticipated future use of the property, as identified in the site conceptual model (SCM). The CAP is subject to the approval of the department.

B. If the current or reasonably anticipated future use of the property is residential, the SCM identifies one or more exposure pathways to be addressed to allow for residential land use, and the CAP does not include cleanup to residential standards, one or more AULs is required.

C. If the current or reasonably anticipated future use of the property is non-residential, the SCM identifies exposure pathways for a non-residential use, and the CAP does not include cleanup to non-residential or stricter standards, one or more AULs is required.

D. To address the groundwater ingestion pathway, one or more of the following must be used, upon department approval, as part of the CAP:

(1) a deed notice;

(2) a restrictive covenant;

(3) a viable local ordinance requiring all future developments, including residences, to utilize public water supplies, or similarly minimizing the likelihood of a future private well being installed into the impacted groundwater zone;

(4) a substantial and reasonably durable "engineering control," such as a highway, durable commercial building, etc., that is expected to remain in place and functional for at least as long as the residual contamination poses an elevated risk through the identified pathway(s). This option will generally require notice to current and future owners by means of the AUL mechanism at D. (1) or (2) above or other means acceptable to the department;

(5) a state regulation prohibiting installation of wells into the affected groundwater zone;

(6) a financial assurance mechanism that will fund additional cleanup if the land is converted to residential use or used for any other purpose that will or could result in a complete groundwater ingestion pathway. This option requires notice to current and future owners by means of the AUL mechanism at D. (1) or (2) above or other means acceptable to the department;

(7) any other method approved by the department (this assumes the owner of a specific site may propose another option as part of the CAP).

E. To address the vapor exposure pathway, one or more of the following must be used, upon department approval, as part of the CAP:

(1) a deed notice;

(2) a restrictive covenant;

(3) a substantial and reasonably durable "engineering control," such as a highway, durable commercial building, etc, that is expected to remain in place and functional for at least as long as the residual contamination poses an elevated risk through the identified pathway(s). This option will generally require notice to current and future owners by means of the AUL mechanism at D. (1) or (2) above or other means acceptable to the department;

(4) a financial assurance mechanism which will fund additional cleanup if the land is converted to residential use or used for any other purpose that will result in a complete vapor exposure pathway. This option requires notice to current and future owners by means of the AUL mechanism at D. (1) or (2) above or other means acceptable to the department;

(5) any other method approved by the department (this assumes the owner of a specific site may propose another option as part of the CAP).

F. To address any other complete or potentially complete exposure pathway that is identified as a result of current or reasonably anticipated future use in the SCM, methods similar to those listed above shall be used, subject to approval by the department during review of the CAP.

12.0 REPORTING

This section presents the reports that would typically be submitted to MDNR to document each of the MRBCA activities. In the following discussion, the term "narrative report" refers to conventional, written reports and can include text, figures, tables, and attachments. Please note that the narrative content descriptions below might not be inclusive of all elements needed to fully explain events and actions at a site. Therefore, the person preparing the report may include in the narrative sections any additional information they believe necessary.

Note that submitting information to MDNR more than once is not necessary, except as part of the Tier 1, 2, and 3 Risk Assessment Reports, as more fully discussed below. For instance, information submitted with the Tank Closure Report need not be resubmitted as part of a Site Characterization Report and information from the Initial Hazard Abatement Measures Report need not be submitted as part of the Corrective Action Plan. Many other examples exist; however, the point is that providing the same information to MDNR on more than one occasion, except as part of the Tier 1, 2, or 3 Risk Assessment Reports, is not necessary.

12.1 TANK CLOSURE

12.1.1 Closure Notice

- **Schedule**: Closure schedule as requested by the owner/operator; closure notice form must be submitted to MDNR no less than 30 days prior to closure
- **Intent of report**: To notify MDNR of tank closure
- **Contents**: Form MO 780-2121 (01-12) available on-line at http://dnr.mo.gov/env/hwp/tanks/ustclosure.htm

12.1.2 Closure Report

- **Schedule**: Within 60 days of closure
- **Intent of report**: To document tank closure.
- **Contents**: Form MO 780-2120 (10-12) available on-line at http://dnr.mo.gov/env/hwp/tanks/ustclosure.htm

12.2 SITE DISCOVERY

12.2.1 Release/Suspected Release Report

- **Schedule**: As soon as practical but no later than 24 hours of discovery
- **Intent of report**: The Release/Suspected Release report is intended to provide MDNR with sufficient information to identify the time, place, and source of the release and hazards and contamination resulting from the release.
- **Contents to include, but not necessarily be limited to, the following**

(unless previously submitted):

- Identification of site (name, location, owner, contact information, ST and R numbers, if applicable),
- Description of release and identification of source of release,
- Steps taken to confirm release and address immediate hazards,
- Site map with source of release and known extent of resulting impact identified,
- Laboratory analytical data sheets, Quality Assurance/Quality Control (QA/QC) data, and chain of custody forms (must be submitted as received from the laboratory),
- Documentation of release reporting,
- Explanation of need for further action, and
- Further actions planned and schedule for such actions.

12.2.2 Initial Hazard Abatement Measures Report

- **Schedule**: 20 days from release confirmation, subsequent reports as stipulated by MDNR
- **Intent of report**: The Initial Hazard Abatement Measures report shall document the release and the responsible party's response to the release.
- **Contents to include, but not necessarily be limited to, the following (unless previously submitted)**:
  - Site identification (location, site name, owner, contact information, ST and/or R numbers (if applicable),
  - Identification and description of tank systems and their status (i.e., closed, inactive, active),
  - An explanation of the release and actions taken to identify and abate hazards associated with the release,
  - If applicable, laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - An explanation of the need for future actions (investigative, monitoring, remedial, etc.),
  - Site map showing general location,
  - Site map showing specific site features (e.g., tanks, dispensers, piping, utilities, release points, etc.),
  - A discussion of planned actions and a schedule for such actions, and
  - Tables, figures, and other maps shall be included as warranted.

12.2.3 Site Check Report

- **Schedule**: to be performed within 7 days from suspected release, report within 60 days of completion of site check
- **Intent of report:** The Site Check Report is intended to document the responsible party's efforts to determine whether a release has occurred and, if so, the actions taken to define the general extent of contamination, in all media of concern, resulting from the release.

- **Contents to include, but not necessarily be limited to, the following**:
  - An explanation of the reason for, and the scope and purpose of, the Site Check,
  - A narrative chronology of events resulting in the Site Check,
  - A map showing general site location and specific sampling locations,
  - The rationale for sample locations chosen,
  - An explanation of the field and laboratory methods and procedures utilized,
  - As applicable, monitoring well construction diagrams as per the examples at 5-4(a) and (b) of Section 5.0 of this document,
  - Boring logs for all borings (a log must be submitted regardless of whether the boring was converted to a monitoring well) as per the examples at 5-3(a) and (b) of Section 5.0,
  - As appropriate, maps showing isoconcentration lines for benzene, TPH-GRO or DRO, MTBE, and any other COCs detected at high concentrations and/or over a broad area,
  - Laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - An analysis of the findings of the investigation,
  - A discussion of response or remedial actions taken, if applicable,
  - A discussion of the need for subsequent action (investigative, monitoring, remedial, etc.) and identification of planned action,
  - A schedule for future actions, and
  - Figures, tables, other maps, etc. shall be included as warranted

12.2.4 System Test Report

- **Schedule**: to be performed within 7 days from suspected release, report within 20 days of the test
- **Intent of report**: The System Test Report is intended to provide documentation of tests conducted on a tank system in response to a release or suspected release for the purpose of determining whether a leak exists in the tank(s) and/or any portion of the tank system.
- **Contents to include, but not necessarily be limited to, the following (unless previously submitted)**:
  - Identification of site (location, site name, owner, contact information, ST and/or R numbers (if applicable),
  - Identification and description of tank systems and their status (i.e., closed, inactive, active),
  - A chronology of events leading up to the system test,
  - The rationale for conducting the specific type of test used,
  - A description of how the test was conducted,
  - An explanation of the system test results and, as appropriate, an analysis of the results,
  - A discussion of the need for subsequent testing and/or other actions,
  - Identification of planned actions and a schedule for such actions,

- As appropriate, documentation of repairs made to the tank system based on the results of the system test, and
- Maps, figures, tables, etc. shall be included as warranted.

12.3 SITE CHARACTERIZATION

12.3.1 Work plans for Site Characterization & Monitoring

- **Schedule**: as requested by the entity conducting the work and approved by MDNR or at the request of MDNR; if requested by MDNR, a work plan must typically be submitted within 30 days of the request
- **Intent of work plan**: Work plans for site characterization shall explain in detail how full site characterization will occur. Work plans for monitoring shall explain why and how monitoring will be conducted.
- **Contents to include, but not necessarily be limited to, the following (unless previously submitted)**:
  - Site Characterization Work Plan
    - Identification of site (location, site name, owner, contact information, ST and/or R numbers (if applicable),
    - Identification and description of tank systems and their status (i.e., closed, inactive, active),
    - Brief history of the site and any previous investigations,
    - A brief explanation of the scope and intended purpose of the proposed work,
    - A description of the work planned, including field and laboratory methods and procedures to be utilized,
    - Site map showing general location of the site,
    - Site map showing specific site features (e.g., release points; tanks; dispensers; piping; utilities; existing and proposed borings, piezometers, monitoring wells, etc.),
    - Quality assurance/quality control provisions,
    - A schedule for implementation of the work plan and submittal of the investigation report, and
    - Tables, figures, and other maps as warranted shall be included.
  - Monitoring Work Plan
    - Identification of site (location, site name, owner, contact information, ST and/or R numbers (if applicable),
    - Brief history of site including releases and previous investigations and monitoring events,
    - Identification and description of tank systems and their status (i.e., closed, inactive, active),
    - A brief explanation of the scope and intended purpose of the monitoring,
    - Identification of monitoring points and rationale for their use,
    - A description of the work planned, including field and laboratory methods and procedures to be utilized,

- Site map showing general location of the site,
- Site map showing specific site features (e.g., release points; tanks; dispensers; piping; utilities; existing and proposed borings, piezometers, monitoring wells, etc.; ensure borings and monitoring wells are identified on each map),
- Quality assurance/quality control provisions,
- Tables, figures, and other maps shall be included as warranted.

12.3.2 Periodic Monitoring Reports

Characterization of a site with groundwater contamination frequently entails monitoring contaminant concentrations in groundwater on a regular basis (e.g., monthly, quarterly, etc.) over an extended period of time. Such monitoring is necessary to characterize the physical extent of the groundwater plume, identify potentially affected receptors, and evaluate the plume's stability. For sites where groundwater monitoring is occurring on a regular basis over an extended period of time, groundwater monitoring reports must be submitted subsequent to each monitoring event. Under the MRBCA process, MDNR requires that groundwater monitoring reports include, at a minimum, the information specified below.

Periodic Monitoring Reports

- **Schedule**: As proposed by the entity conducting monitoring and approved by MDNR or as stipulated by MDNR
- **Intent of report**: To provide recent monitoring data and, overall, to allow for the tracking of contaminant concentrations at a site.
- **Contents to include, but not necessarily be limited to, the following (unless previously submitted)**:
  - A brief history of the site,
  - An explanation of the reason for, and scope and intended purpose of, monitoring,
  - Identification of the monitoring points used and the rationale for their selection,
  - A site map showing the locations of the monitoring points (ensure each is appropriately identified),
  - A description of monitoring conducted, including field and laboratory methods and procedures utilized,
  - If not previously submitted, or if monitoring wells have been added subsequent to the previous groundwater monitoring report, monitoring well installation diagrams (as per the examples at Figures 5-4(a) and (b) of Section 5.0 of this document) and boring logs (as per the examples at Figures 5-3(a) and (b) of Section 5.0),
  - A site map visually depicting the direction of groundwater flow,
  - As appropriate, maps showing isoconcentration lines for benzene, total petroleum hydrocarbon-gasoline range organic (TPH-GRO) or diesel range organic (DRO), methyl tert-butyl ether (MTBE), and any other

chemicals of concern (COCs) detected at high concentrations and/or over a broad area,
  - As appropriate, graphs showing COC concentrations in groundwater at each well over time,
  - Laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - A discussion of the monitoring results and monitoring end point,
  - Recommendations or plans for future monitoring,
  - A schedule for future monitoring, and
  - Tables, figures, and other maps shall be included as warranted.

12.3.3 Site Characterization Report

- **Schedule**: As per the schedule in the work plan or as stipulated by MDNR
- **Intent of report**: Site Characterization Reports shall describe and present the results of actions taken to define the full extent of a release and document current and future land use.
- **Contents to include, but not necessarily be limited to, the following (unless previously submitted)**:
  - An explanation of the reason for, and the scope and purpose of, the Site Characterization,
  - A map showing general site location and specific sampling locations,
  - Brief discussion of the rationale for sample locations chosen,
  - An explanation of the field and laboratory methods and procedures utilized,
  - Monitoring well construction diagrams as per the examples at 5-4(a) and (b) of Section 5.0 of this document,
  - Boring logs for all borings (a log must be submitted regardless of whether the boring was converted to a monitoring well) as per the examples at 5-3(a) and (b) of Section 5.0,
  - As appropriate, maps showing isoconcentration lines for benzene, TPH-GRO or DRO, MTBE, and any other COCs detected at high concentrations and/or over a broad area,
  - Laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - An explanation of any deviations from the approved work plan,
  - An analysis of the findings of the investigation,
  - A discussion of response or remedial actions taken, if applicable,
  - A discussion of the need for subsequent action (investigative, monitoring, remedial, etc.) and identification of planned action,
  - A schedule for future actions, and
  - Figures, tables, other maps, etc. shall be included as warranted.

Soil Vapor Measurement Work Plan

- **Schedule**: As requested by the entity conducting monitoring and approved by MDNR or as stipulated by MDNR
- **Intent of work plan**: To present information pertaining to the purpose and methods of soil vapor sampling. A work plan is not required if soil gas sampling is in accordance with the *Soil Gas Sampling Protocol* found in Appendix C of this guidance.
- **Contents to include, but not necessarily be limited to, the following**:
  - Background information describing why soil vapor monitoring is being proposed, focusing on potentially affected structures,
  - An explanation of how the monitoring will be conducted, including an accounting of both field and laboratory methods and procedures,
  - An explanation of where the monitoring will be conducted, including justification for the proposed soil vapor monitoring points,
  - A map of the site specifically showing the soil vapor monitoring points and all relevant site features (i.e., potentially affected structures),
  - Schematics or other drawings showing the construction of the soil vapor monitoring points and associated sampling equipment,
  - A proposed schedule for monitoring; if more than one monitoring event is being proposed, specify schedule for all events, and
  - Relevant site maps.

12.3.4 Soil Vapor Monitoring Report

- **Schedule:** As proposed in the work plan and agreed to by MDNR or as stipulated by MDNR
- **Intent of report**: The Soil Vapor Monitoring Report shall fully document soil vapor monitoring activities and results.
- **Contents of report to include, but not necessarily be limited to, the following**:
  - A brief site description and history (focusing on potentially affected structures),
  - The purpose and scope of monitoring,
  - The location of monitoring,
  - Site maps showing monitoring points and all relevant site features,
  - If not submitted with work plan, schematics or other drawings illustrating the construction of the monitoring points and sampling equipment,
  - An explanation of any deviations from the approved work plan,
  - Field and laboratory methods and procedures utilized,
  - Laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - An explanation of the monitoring results, including, as appropriate, interpretation of the results,
  - Recommendations for future activities (e.g., additional monitoring, other investigation, remedial action, etc.),

- Schedule of future activities, and
- Other information, maps, tables, graphs, etc., as warranted.

12.4 TIERED RISK ASSESSMENT

12.4.1 Tier 1 Risk Assessment Report

- **Schedule**: As stipulated by MDNR
- **Intent of report**: The Tier 1 Risk Assessment Report is to be a stand alone, comprehensive document that presents all of the data necessary to characterize the site and contamination and to evaluate the risks posed by the contamination.

Note: A Tier 1 Risk Assessment Report by itself need not be submitted for a site evaluated under Tier 2. See discussion below at 12.4.2, Tier 2 Risk Assessment Report.

- **Contents to include, but not necessarily be limited to, the following**:
  - A brief site history,
  - Information pertaining to release discovery, hazard abatement, and initial response,
  - An explanation of investigations conducted,
  - An explanation of the distribution of COCs in all affected media,
  - All applicable boring logs and well construction sheets,
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - A discussion of how geologic and hydrogeologic conditions have affected COC distribution,
  - An exposure model and explanation of how the model was developed (include both on and off-site complete and potentially complete pathways),
  - A discussion of applicable Tier 1 standards corresponding to the exposure model,
  - A discussion of how representative COC concentrations were developed,
  - A discussion of the results of comparing site-specific representative COC concentrations to applicable target levels,
  - Completed ecological exposure checklists,
  - A discussion of ecological exposure concerns and the need, if applicable, for further evaluation of ecological exposure concerns
  - A discussion of actions, if any, needed to move site toward issuance of a No Further Action letter,
  - A schedule for proposed actions,
  - Site maps showing the site, site features, area(s) and extent of contamination, sampling and monitoring points, surrounding land use, COC isoconcentration lines, and other information as warranted, and
  - Other maps, figures, tables, graphs, diagrams, etc. as warranted.

12.4.2 Tier 2 Risk Assessment Report

A Tier 2 Risk Assessment Report includes all information collected for the Tier 1 risk assessment (and that would be submitted in a Tier 1 Risk Assessment Report if evaluations stopped at Tier 1), plus the additional data from Tier 2 risk assessments. Generally, if a site is evaluated under Tier 2, only one report, the Tier 2 Risk Assessment Report, will be submitted to cover both the Tier 1 and Tier 2 risk assessments.

Tier 2 Risk Assessment Report

- **Schedule**: As stipulated by MDNR
- **Intent of report**: The Tier 2 Risk Assessment Report is to be a stand-alone, comprehensive document that presents all of the data necessary to characterize the site and contamination and to evaluate the risks posed by the contamination in consideration of site-specific conditions. The report shall present the findings of both the Tier 1 and Tier 2 risk assessments but shall do so as to differentiate between the findings.
- **Content of report to include, but not necessarily be limited to**:
  - Identification of Tier 2 activities,
  - An explanation of the purpose and scope of Tier 2 activities,
  - An explanation of the field and laboratory methods and procedures utilized at Tier 2,
  - All boring logs and well construction sheets (if not previously submitted),
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - If revised or not previously submitted, an exposure model and explanation of how the model was developed (include both on and off-site complete and potentially complete pathways),
  - Discussion of applicable Tier 2 standards corresponding to exposure model,
  - A discussion of how the Tier 2 standards were developed (e.g., fate and transport parameters and their selection, rationale for selections, etc.),
  - A discussion of how representative COC concentrations were developed,
  - A discussion of the results of comparing site-specific COC concentrations to applicable Tier 2 target levels,
  - Completed ecological exposure checklists,
  - A discussion of ecological exposure concerns and the need, if applicable, for further evaluation of ecological exposure concerns,
  - A discussion of actions, if any, needed to move site toward issuance of a No Further Action letter,
  - A schedule for proposed actions,
  - Site maps showing the site, site features, area(s) and extent of contamination, sampling and monitoring points, surrounding land use, COC isoconcentration lines, and other information as warranted, and
  - Other maps, figures, tables, graphs, diagrams, etc. as warranted.

12.4.3 Tier 3 Work Plan

The content of a Tier 3 Work Plan is beyond the scope of this guidance document, though some guidance regarding the content is provided below.

Tier 3 Work Plan

- **Schedule**: As stipulated by MDNR
- **Intent of work plan**: The intent of a Tier 3 work plan is to clearly explain what specific activities are to be conducted at Tier 3, the purpose of such activities, how they will be conducted, and their intended scope. All alternative methods and models used at Tier 3 must be clearly identified and their use fully explained.
- **Contents of work plan to include, but not necessarily be limited to, the following:**
  - A brief discussion of the results of Tier 1 and 2 risk assessments,
  - Proposed activities to be conducted at Tier 3,
  - An explanation of the purpose, scope, and intent of the Tier 3 activities,
  - A detailed explanation of methods and models to be used at Tier 3,
  - A schedule for conducting the proposed Tier 3 activities, and
  - Site maps necessary to identify and characterize site and areas to which Tier 3 activities will apply.

12.4.4 Tier 3 Risk Assessment Report

- **Schedule**: As per the schedule in the approved work plan or as stipulated by MDNR
- **Intent of report**: The Tier 3 Risk Assessment Report must fully and clearly explain the purpose, scope, and intent of activities conducted at Tier 3 and present the results of such activities.
- **Contents to include, but not necessarily be limited to, the following**:
  -
  - An explanation of the Tier 3 activities, their purpose, scope, and intent,
  - The field, office, and laboratory methods and procedures used,
  - Identification and application of the methods and models used at Tier 3 to develop site-specific target levels,
  - A discussion of the exposure model and, in particular, any modifications made to the exposure model between Tiers 1, 2, and 3,
  - A presentation and discussion of the Tier 3 target levels that were developed,
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - An explanation of additional data (COC data, geotechnical data, exposure factors, physical and chemical properties of COCs, toxicity data, etc.) gathered and used at Tier 3,

- A discussion of the comparison of site-specific representative COC concentrations to Tier 3 site-specific target levels (SSTLs),
- An explanation of the actions warranted, if any, due to the comparison of site-specific representative COC concentrations to Tier 3 SSTLs,
- A schedule for conducting additional activities,
- Site maps showing the site, site features, area(s) and extent of contamination, sampling and monitoring points, surrounding land use, COC isoconcentration lines, and other information as warranted, and
- Other maps, figures, tables, graphs, diagrams, etc. as warranted.

12.5 CORRECTIVE ACTION PLAN (CAP)

12.5.1 **Corrective Action Plan** (narrative)

- **Schedule**: As stipulated by MDNR
- **Intent of plan**: The CAP is intended to explain methods to be used to address excess risks posed by contaminants at a site. The CAP may include one or more of the following: corrective action, activity and use limitations (AULs), monitoring (performance, verification, stability, etc.), etc.
- **Contents to include, but not necessarily be limited to, the following**:
  - A discussion of the results of the tier analysis,
  - Identification of the reason why corrective action is needed,
  - An explanation of the purpose, scope, and intent of corrective action activities,
  - A description of the corrective action activities to be used and how they will be applied,
  - An explanation of the field and laboratory methods and procedures to be used,
  - An explanation of monitoring necessary during implementation of the CAP (such activities might require an additional work plan, see below),
  - An explanation of the activities necessary to demonstrate CAP efficacy,
  - A schedule for implementation of the CAP,
  - An explanation of the anticipated duration of corrective action activities,
  - A discussion of the potential need for activities beyond those outlined in the work plan,
  - An explanation of how and why implementation of the CAP will result in MDNR's issuance of a No Further Action letter,
  - Site maps identifying the site, the area(s) of contamination, all relevant sampling and monitoring points, surrounding land use, and the proposed location and extent of corrective action activities, and
  - Other information as warranted.

12.5.2 Interim Corrective Action Work Plan (narrative)

- **Schedule:** As stipulated by MDNR
- **Intent of Work Plan:** The Interim Corrective Action Work Plan is a component of the CAP and shall propose specific corrective actions to address excessive risk posed by contamination at a site. An Interim Corrective Action Work Plan must be submitted when corrective actions will be conducted as part of the overall CAP.
- **Contents to include, but not necessarily be limited to, the following:**
  - A brief history of the site, including a chronology of events,
  - An explanation of the corrective actions proposed, how they will be implemented, and what particular risks they are intended to address,
  - A discussion of the time needed to complete the corrective actions, including a schedule covering implementation through completion,
  - An explanation regarding how the interim corrective actions relate to the final remedy for the site,
  - If applicable, a description of monitoring necessary to evaluate the effects of the interim actions,
  - A site map showing the specific areas of the site to which the interim actions will apply, and
  - Other information, maps, tables, graphs, etc. as warranted.

12.5.3 Free Product Removal Work Plan

At sites where free product is discovered such that, in accordance with 10 CSR 26-2.075, free product removal is warranted, the report submitted within 45 days of the discovery of the free product must include all of the information required by 10 CSR 26-2.075. If free product removal activities are to be conducted on an ongoing basis, a free product removal report must be submitted to MDNR every 30 days unless a different reporting schedule is approved by MDNR. Free product removal activities that are conducted to address risks identified in the tiered risk assessments (as opposed to those conducted as part of initial hazard abatement activities) fall under the CAP. Refer to the following for guidance on the content of free product removal work plan and reports.

Free Product Removal Work Plan (narrative)

- **Schedule**: As stipulated by MDNR
- **Intent of work plan**: The Free Product Removal Work Plan is a component of the CAP and should propose one or more methods to remove free product from the environment to the extent warranted to adequately address excess risks associated with the free product.
- **Contents to include, but not necessarily be limited to, the following**:
  - A brief history of the site and the occurrence of free product on the site,
  - An explanation of the methods to be used to remove free product from the environment and to manage free product once removed,
  - As necessary, schematics or diagrams showing the proposed free product

recovery method or system,
- An explanation of the intended scope and duration of the removal activities,
- A proposal for monitoring to track free product occurrence and distribution at the site,
- A discussion of the proposed endpoint for removal activities,
- A site map identifying the extent of free product and identifying all free product removal points,
- A schedule for free product removal activities, and
- Other information, tables, graphs, maps, etc. as warranted.

12.5.4 Activity and Use Limitation Work Plan

For the purposes of the MRBCA process, AULs are differentiated from corrective actions to indicate that AULs are risk management mechanisms that have no direct effect on COCs found at a site. Rather, AULs are mechanisms that prevent completion of an exposure pathway or reduce the likelihood that a pathway will become complete by providing information regarding the concentrations and distribution of COCs to users of the site and/or by restricting certain uses or activities that may occur at a site. Refer to Section 6.9 and Section 11 of this guidance for further information regarding AULs.

When AULs are intended to serve as a means of addressing excess risks posed by contaminants at a site, an AUL Work Plan must first be submitted to, and approved by, MDNR, as discussed below.

Activity and Use Limitation Work Plan
- **Schedule**: As stipulated by MDNR
- **Intent of work plan**: The AUL Work Plan is a component of the CAP and is intended to describe how AULs will be used to address excess risks posed by contaminants at a site.
- **Contents to include, but not necessarily be limited to, the following**:
  - A brief history of the site, focusing on those aspects to which AULs will apply,
  - An explanation of the specific type or types of AULs being proposed to address excess risk,
  - Justification for the use of the AUL(s),
  - If AULs are one of two or more one risk management methods being proposed for a site, explain what other methods are proposed and refer to the applicable work plan in which such methods are discussed,
  - An explanation of how the AULs will be implemented and maintained; for a physical AUL, this includes plans showing the design and intended construction of the AUL,
  - A schedule for implementation of the AULs,
  - If a legal AUL is proposed (e.g., Deed Notice, Restrictive Covenant, etc.), a general copy of the proposed legal AUL shall be included,

- A site map clearly depicting that portion of the site to which the AUL(s) will apply, and
- Other information, maps, tables, graphs, etc. as warranted.

12.5.5 CAP Performance Monitoring Plan

- **Schedule**: As stipulated by MDNR
- **Intent of report**: A CAP Performance Monitoring Plan is a component of the CAP and describes the monitoring activities necessary to determine the effectiveness and completeness of corrective action activities.
- **Contents to include, but not necessarily be limited to, the following**:
  - A site description, including a discussion of known contamination,
  - An explanation of the corrective action activities to be conducted and why performance monitoring is needed,
  - A description of the type of performance monitoring to be conducted,
  - An explanation of the field and laboratory methods and procedures to be used as part of monitoring activities,
  - An explanation of the defined end point of monitoring,
  - If applicable, an explanation of the defined monitoring point at which alternate actions are warranted,
  - A schedule explaining the frequency and duration of proposed monitoring activities,
  - Site maps identifying the location of monitoring points, areas of contamination, relevant site features, and surrounding land use, and
  - Other information, maps, figures, tables, etc. as warranted.

12.6 CAP COMPLETION AND PERFORMANCE MONITORING REPORT

- **Schedule**: As proposed in the work plan and agreed to by MDNR or as stipulated by MDNR
- **Intent of report**: A CAP Completion and Performance Monitoring Report presents information to document the successful completion of all elements of the CAP and all monitoring data collected at a site to determine the effectiveness and completeness of corrective action activities.
- **Contents to include, but not necessarily be limited to, the following**:
  - A description of all corrective action activities conducted, the purpose of each, and the results of implementation of each
  - A description of the monitoring activities conducted, to include their purpose and scope,
  - If different from the work plan, a description of the field and laboratory methods and procedures used during monitoring,
  - Interpretation of the monitoring data, including an assessment of whether monitoring is complete or indicates that additional actions (investigative, remedial, or monitoring) are needed,
  - If an AUL is proposed or warranted, documentation that the AUL is in place or has otherwise been appropriately implemented must be included

in the report
  - Recommendations for further actions,
  - A schedule for future actions,
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - Site maps needed to illustrate monitoring results,
  - Other information, maps, figures, tables, etc. as warranted, and
  - A request for issuance of a NFA letter, as appropriate.

12.6.1 Interim Corrective Action Report

- **Schedule**: As stipulated by MDNR
- **Intent of report**: An Interim Corrective Action Report is a component of the CAP Completion and Performance Monitoring Report and is intended to document interim corrective actions and provide information regarding the results of the actions taken.
- **Contents to include, but not necessarily be limited to, the following**:
  - Identification of the site,
  - Release characterization,
  - An explanation of the interim corrective actions conducted,
  - An explanation of when the actions were conducted and their purpose, scope, and intent,
  - A description of the methods and procedures used to conduct the interim actions,
  - A presentation and discussion of data collected to determine the efficacy of the interim actions,
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - A discussion of the effect of interim actions on the site as a whole,
  - Identification of post-interim corrective action activities required,
  - Maps identifying the site, the area in which interim actions occurred, the extent of interim actions, pre and post-interim action sampling and monitoring points, known extent of contamination in all affected media both before and after interim actions, land use surrounding the site, and
  - Other maps, figures, tables, graphs, diagrams, etc. as warranted.

12.6.2 Free Product Removal Report

- **Schedule**: First report within 45 days of confirmed release, subsequent reports as proposed in the work plan and agreed or as stipulated by MDNR.
- **Intent of report**: A Free Product Removal Report can both be a component of the CAP Completion and Performance Monitoring Report and stand alone as part of release response reporting. Either way, the report is intended to document the free product removal activities conducted at a site to address excess risks associated with the free product, as identified in the tiered risk assessments.

- **Contents to include, but not necessarily be limited to, the following**:
  - Site history, including release discovery and initial abatement activities (including initial free product removal activities),
  - A discussion of free product location and extent, including maps illustrating location and extent and identifying existing and historical monitoring points,
  - A discussion of the composition of the free product (e.g., gasoline, diesel, etc.),
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - A discussion of removal activities conducted and the practicability of further removal given consideration of all available removal methods,
  - A table listing each free product removal event, the method of removal used, the volume of free product removed during each event, and the total volume of free product removed (the volume of free product removed should be differentiated from the total volume of fluid removed),
  - Text describing the expected duration of free product recovery activities and whether any changes have or will occur in the method or frequency of free product recovery or monitoring,
  - A discussion of planned future removal activities and a corresponding schedule, and
  - Other maps, figures, tables, graphs, diagrams, etc. as warranted.

12.6.3 Activity and Use Limitations Report

- **Schedule**: As stipulated by MDNR
- **Intent of report**: This report is a component of the CAP Completion and Performance Monitoring Report and documents that proposed AULs are in place.
- **Contents to include, but not necessarily be limited to, the following**:
  - A site description, focusing on that portion of the site to which the AUL(s) applies,
  - An explanation of the risk(s) to be managed via an AUL(s),
  - Identification of the AUL(s) used, its purpose, and how each AUL applies to the site,
  - For legal AULs, documentation that the AUL has been appropriately recorded in the property chain of title (i.e., property deed); for pre-existing AULs, the effective or established date of the AUL must be provided); a copy of the AUL, as recorded and documented as recorded, must be included in the report,
  - For physical AULs, documentation of the AUL's existence or construction and its effective placement or location relative to the exposure pathway(s) to which it applies (Note: this information shall also be conveyed via a site map on which the location of the contaminants and the AUL(s) are shown),
  - If an AUL(s) is one of two or more methods used or to be used to address excess risk at a site, the report must include a discussion of the other

method(s) to be used and refer to the applicable work plan or report, and
- Maps, tables, figures, and other information, as warranted.

12.6.4 Corrective Action Report

- **Schedule**: As stipulated in the work plan and agreed to by MDNR or as stipulated by MDNR
- **Intent of report**: The Corrective Action Report is a component of the CAP Completion and Performance Monitoring Report that provides documentation of corrective actions conducted at a site to address specific risks identified in the risk assessment report.
- **Contents to include, but not necessarily be limited to, the following:**
  - A description of why corrective actions were warranted and each corrective action chosen,
  - A description of the purpose and scope of corrective actions,
  - A discussion of the methods and procedures used in implementing the corrective actions,
  - Efficacy monitoring or verification sampling results,
  - All applicable laboratory analytical data sheets, QA/QC data, and chain of custody forms (must be submitted as received from the laboratory),
  - A discussion of the effect of corrective actions,
  - Identification of post-corrective action activities required (e.g., monitoring, further corrective action, etc.),
  - A schedule for conducting follow up activities,
  - Maps identifying the site, the area in which corrective actions occurred, the extent of corrective actions, pre and post-corrective action sampling and monitoring points, known extent of contamination in all affected media both before and after corrective action, land use surrounding the site, and
  - Other information, maps, figures, tables, etc. as warranted.

13.0
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APPENDIX A
APPEALS

RESERVED

APPENDIX B
DEVELOPMENT OF RISK-BASED TARGET LEVELS

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A. INTRODUCTION

The procedure used to calculate Tier 1 risk-based target levels (RBTLs) and Tier 2 site-specific target levels (SSTLs) is presented in this appendix. This procedure requires quantitative values of:

- Target risk levels,
- Chemical-specific toxicological factors,
- Physical and chemical properties of the chemicals of concern (COCs),
- Receptor-specific exposure factors,
- Fate and transport parameters, and
- Mathematical models.

Each of these factors is discussed below. Additionally, this appendix discusses the (i) target levels for lead (Section B.8), and (ii) estimation of target levels when LNAPL is present on the groundwater surface (Section B.9).

For Tier 1 risk assessments, MDNR has calculated RBTLs for each of the COCs (refer to Section 5.3.3 and Table 5-1), the receptors (refer to Section 6.1.2), and the commonly encountered routes of exposure (refer to Section 6.1.3) using conservative assumptions applicable to most Missouri sites. The resultant Tier 1 RBTLs are presented in Tables 7-1 through 7-6(c).

For Tier 2 and Tier 3 risk assessments, the risk evaluator will calculate the SSTLs using technically justifiable site-specific data and, for Tier 3, pathway-specific models. For Tier 2 risk assessments, the models used for developing the Tier 1 RBTLs must be used. A Tier 3 risk assessment may include different models, though the model to be used must be approved by MDNR.

B.1 TARGET RISK LEVELS

A risk-based decision making process requires the specification of a target risk levels for both carcinogenic and non-carcinogenic adverse health effects. For carcinogenic effects, MDNR will use an **individual excess lifetime cancer risk (IELCR) of 1 x 10^{-5}** as the target risk for both current and future receptors. For non-carcinogenic effects, the acceptable level is a hazard quotient of one (1) for current and future receptors. Due to the limited number of COCs, additivity of risk is not considered.

For evaluating the ingestion of groundwater and protection of groundwater resource pathways, Maximum Contaminant Levels (MCLs) or, where MCLs are not available, health advisories were used as the target concentrations at the point of exposure. For chemicals that do not have such levels, the target concentration at the point of exposure (POE) was estimated assuming ingestion of groundwater, inhalation of vapors from indoor water use, and dermal contact with water under residential conditions.

Potential impacts to streams and other surface water bodies from a release must be evaluated and surface water quality protected as per 10 CSR 20-7.031. Allowable concentrations in surface water for COCs are presented in Table 6-1.

B.2 QUANTITATIVE TOXICITY FACTORS

Toxicity values for the COCs are presented in Table B-1. MDNR may update the data in Table B-1 as new information becomes available.

Typically, the toxicity values in Table B-1 will also be used for Tier 3 risk assessments, although alternate values may be used at Tier 3 with adequate justification and the approval of MDNR. Current toxicity values were obtained from the *Departmental Missouri Risk-Based Corrective Action Technical Guidance* (MDNR, April 2006) which were extracted from the hierarchy of sources as per *"Human Health Toxicity Values in Superfund Risk Assessments," OSWER directive 9285.7-53, December 5, 2003.* Specifically it included:

1. Tier 1: Integrated Risk Information System (IRIS),
2. Tier 2: Provisional Peer Reviewed Toxicity Values (PPRTVs),
3. Tier 3: Miscellaneous Sources:
   - (i) National Center for Environmental Assessment (NCEA) as listed in USEPA's Region IX Preliminary Remediation Goal (PRG) Table,
   - (ii) California Office of Environmental Health Hazard Assessments (OEHHAs) chemical database,
   - (iii) Health Effects Assessment Summary Tables (HEAST) as listed in USEPA's Region IX PRG tables, and
   - (iv) Table for Texas Risk Reduction Program.

Dermal toxicity values are not available in the above sources; therefore the dermal toxicity values were calculated. The assumption underlying the calculation of dermal toxicity values is that the dermal toxicity of the chemical is the same as the oral toxicity values, except that a semi-permeable barrier (the skin) affects absorption. Using oral toxicity values to calculate dermal toxicity values is based on sound toxicological principles, and in the absence of direct measurement of dermal toxicity, considered an acceptable alternative by the USEPA. However, the calculation is complicated due to the fact that different chemicals pass through the skin with different efficiencies. These differing efficiencies are factored into the formulae for dermal toxicity as the term "oral absorption factors (RAF_o)."

The formulae for calculation of slope factor (SF_d) and reference dose (RfD_d) for dermal exposure are as below:

$$SF_d = \frac{SF_o}{RAF_o} \quad (1)$$

$$RfD_d = RfD_o \times RAF_o \quad (2)$$

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 absorption factor (dimensionless).

The oral absorption factors are not readily available. Conservatively, a value of 1.0 was assigned for all chemicals.

The dermal absorption factors were obtained from the ***Risk Assessment Guidance for Superfund (RAGS), Volume 1: Human Health Evaluation Manual, Part E Supplemental Guidance for Dermal Risk Assessment*** (USEPA, 2004). However, this guidance does not have any recommendations for volatile organic compounds (VOCs), or inorganic compounds. For these compounds, the absorption factors were obtained from the USEPA Region III and RAGS, Volume 1, Part A.

The parameters used for dermal contact pathway are shown in Table B-1 and are discussed below:

Permeability Coefficient

For organic chemicals, the chemical-specific permeability coefficients in water were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the permeability constant, K_p (cm/hr), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$\log K_p = -2.80 + 0.66(\log K_{ow}) - 0.0056MW \quad (3)$$

where,

K_{ow} = Octanol-water partition coefficient (dimensionless), and
MW = Molecular weight (g/mole).

Note the MW and K_{ow} are presented in Table B-3.

For metals and inorganics, the permeability coefficients were obtained from Exhibit B-4 of the *RAGS Volume I, Part E* (USEPA, 2004). If no value is available, the permeability coefficient of 1 x 10^{-3} cm/hr is recommended as default value (USEPA, 2004).

Relative Contribution of Permeability Coefficient

The relative contribution of permeability coefficients for the chemicals was obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the relative contribution of permeability coefficient, B (unitless), was estimated using the following equation as per the *RAGS Volume I, Part E* (USEPA, 2004):

$$B = K_p \frac{\sqrt{MW}}{2.6} \tag{4}$$

Lag Time

The lag times for the chemicals, τ_{event} (hr/event), were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004).

As per the *RAGS Volume I, Part E* (USEPA, 2004), the equation to estimate τ_{event} is derived as below:

$$\frac{D_{sc}}{l_{sc}} = 10^{(-2.80-0.0056MW)} \tag{5}$$

$$\tau_{event} = \frac{l_{sc}^2}{6 \times D_{sc}} \tag{6}$$

where,

D_{sc}	=	Effective diffusion coefficient for chemical transfer through the stratum corneum (cm^2/hr), and
l_{sc}	=	Apparent thickness of stratum corneum (cm).

The lag time is dependent on the effective diffusion coefficient for chemical transfer through the stratum corneum and the apparent thickness of stratum corneum. Assuming $l_{sc} = 10^{-3}$ cm as a default value for the thickness of the stratum corneum, τ_{event} becomes:

$$\tau_{event} = 0.105 \times 10^{(0.0056MW)} \; t^* = 2.4\tau_{event} \tag{6}$$

If B > 0.6,

$$t^* = 6\tau_{event} \times \left(b - \sqrt{b^2 - c^2}\right) \tag{7}$$

where b and c are correlation coefficient which have been fitted to the data from Flynn, G.L. (1990) and are expressed as below:

$$c = \frac{1 + 3B + 3B^2}{3(1+B)} \text{ and } b = 2 \times \frac{(1+B)^2}{\pi} - c\,.$$

Fraction Absorbed

The fraction absorbed for the chemicals considered were obtained from Exhibit B-3 of the *RAGS Volume I, Part E* (USEPA, 2004). For chemicals not listed in Exhibit B-3, the fraction absorbed water, *FA* (unitless), was estimated from Exhibit A-5 of the *RAGS Volume I, Part E* (USEPA, 2004).

B.3 PHYSICAL AND CHEMICAL PROPERTIES OF THE COCs

Physical and chemical properties of the COCs are listed in Table B-2. These values must be used for all MRBCA evaluations unless there are justifiable reasons to modify these values and MDNR concurs. The use of different values would be allowed only under a Tier 3 risk assessment.

B.4 EXPOSURE FACTORS

A list of the exposure factors and their values that were used to develop the Tier 1 RBTL values is presented in Table B-3. The exposure factors are typically estimated based on literature rather than site-specific measurements. The values listed in Table B-3 are conservative values that are exceeded by about 5% of the population, i.e. they are the upper 95th percentile values. For a Tier 3 risk assessment, site-specific exposure factor values may be used with thorough justification and MDNR approval.

A source of exposure factor information is U.S. 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 MDNR**.**

B.5 FATE AND TRANSPORT PARAMETERS

Fate and transport parameters are necessary to estimate the target levels for the indirect routes of exposure. These factors characterize the physical site properties such as depth to groundwater, soil porosity, and infiltration rate.

For a Tier 2 risk assessment, a combination of site-specific and default fate and transport values may be used. However, the value of each parameter used, whether site-specific or default, must be justified based on site-specific conditions. Where site- specific conditions are significantly different from the Tier 1 assumptions, site-specific values should be used.

For a Tier 3 risk assessment, the specific fate and transport parameters required to calculate the target levels will depend on the model used.

B.6 MATHEMATICAL MODELS

The input parameters mentioned above are used in two types of models, or equations, to calculate the risk-based target levels. These are the (i) uptake equations and (ii) fate and transport models. For Tier 1 and Tier 2 risk assessments, MDNR has selected the models and equations included in this appendix. These models have been programmed in the MRBCA Computational Software and were used to develop the Tier 1 RBTLs presented in Section 7.0.

For Tier 2 risk assessments, the same equations and models must be used. With the prior approval of MDNR through the submittal of a Tier 3 work plan, a different set of models may be used for Tier 3 risk assessments.

The equations and models used for estimating Tier 1 RBTLs and Tier 2 SSTLs are presented in Section B.10.

B.7 RISK-BASED TARGET LEVELS

The input parameters and models mentioned above are used to calculate RBTLs for each COC and each route of exposure. For certain COCs, the target levels developed for groundwater may exceed the solubility of the COC. In such cases, the values shown in Tables 7-1 through 7-6(c) are the actual calculated values, annotated with an asterisk indicating that the calculated values exceed solubility. Similarly, for certain COCs and pathways, soil target levels may exceed levels at which the soil is saturated by the chemical. As with the groundwater values, in such case, the values shown in Tables 7-1 through 7-6(c) represent the actual calculated values annotated with an asterisk indicating that the calculated value exceeds the soil saturation value. The saturated soil concentrations, effective soil concentrations, effective solubility, and effective soil vapor concentrations are presented in Table B-5.

For both the above cases, the results can be interpreted to mean that the chemical and the pathway do not need any further evaluation and that the site-specific concentrations are protective of the pathway. Further, if concentrations above the solubility level in groundwater and above the soil saturation level are measured in a sample, the implication is that the sample had some free product in it.

B.8 TARGET LEVELS FOR LEAD

Lead has a number of toxic effects, but the main target for lead toxicity is the nervous system. Young children are especially vulnerable from the standpoints of both exposure and toxicity. Certain behaviors, such as crawling and playing on the floor or ground, result in increased exposure, and the central nervous system of a young child is particularly susceptible because it is still developing. Chronic exposure to even low levels of lead that are not overly toxic can result in impaired mental development.

The U.S. EPA has developed the Integrated Exposure Uptake Biokinetic [IEUBK] Model

to predict 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 (ug/dL), the level associated with adverse health effects (EPA, 1999).

Because of the greater vulnerability of children to lead exposure and toxicity, the primary concern in a residential setting is the risk lead poses to children. In the non-residential scenario, children are not directly exposed, but fetuses carried by female workers can be exposed. The EPA has developed an adult lead methodology (ALM) to assess risk in this scenario (EPA, 1996b). The methodology is limited in terms of exposure media (soil/dust). Specifically, the methodology estimates the PbB concentrations in fetuses carried by women exposed to lead contaminated soils. Research is ongoing to develop a model capable of simulating multimedia exposures over the entire human lifetime. Until this model is developed, MDNR will require the use of the IEUBK model for residential scenarios and ALM for non-residential scenarios.

At petroleum impacted sites, use of the IEUBK or ALM to assess lead risk and determine cleanup goals is not necessary. Based on the above discussion, MDNR will use the following Tier 1 levels for lead (MDNR, 2001):

Residential land use soil (direct contact with soil)	260 mg/kg
Non-residential land use soil (direct contact with soil)	660 mg/kg

The groundwater target level where domestic use of groundwater is a complete pathway is 0.015 mg/L.

B.9 TARGET LEVEL CALCULATION FOR LNAPL

As discussed in Section 6.8, the MRBCA process allows for the calculation of risk and target levels when LNAPL is present. Under this condition, the primary routes of exposure are (i) indoor inhalation for a residential or a non-residential receptor, and, if the domestic use of groundwater pathway is complete or potentially complete, (ii) the protection of a current or potential future point of exposure (POE) groundwater well. For these pathways, the key step is the calculation of the vapor concentration and the dissolved concentration emanating from the LNAPL. Once these concentrations have been estimated, risk and target levels can be determined using the procedures presented in Section B.1 to B.7 above.

Soil Vapor Concentration: The soil vapor concentration in equilibrium with LNAPL is the effective soil vapor concentration. This concentration depends on (i) the chemical-specific saturated soil vapor concentration, and (ii) the mole fraction of the chemical in the LNAPL 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 (refer to Table 5-2), may be used. Alternatively, the evaluator may sample the LNAPL for laboratory analysis to determine site-specific values for the weight and mole fractions. The specific equations used to

calculate the effective soil vapor or effective dissolved concentrations are presented in Section B.10.

In the forward model of risk assessment, the effective soil vapor and dissolved concentrations can be used to calculate the risk due to indoor inhalation or to estimate the concentration in the POD and POE wells. In the backward mode of risk assessment, the Tier 1 RBTLs and Tier 2 and 3 SSTLs must be compared with the effective concentrations. The models and equations to be used are presented in Section B.10.

FIGURE B.1. INDOOR INHALATION OF VAPORS
(CHILD AND ADULT RESIDENT; AND NON-RESIDENTIAL WORKER)

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

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

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

where:

$RBTL_{ai}$	=	Risk-based target level in indoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_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]

FIGURE B.2. OUTDOOR INHALATION OF VAPORS (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

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

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

where:

$RBTL_{ao}$	=	Risk-based target level in outdoor air [mg/m^3]
TR	=	Target risk or the increased chance of developing cancer over a lifetime due to exposure to a chemical [-]
THQ	=	Target hazard quotient for individual constituents [-]
BW	=	Body weight [kg]
AT_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]

FIGURE B.3. DERMAL CONTACT WITH CHEMICALS IN WATER
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{dw} = \frac{TR \times BW \times AT_c \times 365 \times 1000}{SF_d \times SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

Non-carcinogenic effects

$$RBTL_{dw} = \frac{THQ \times BW \times AT_{nc} \times 365 \times 1000 \times RfD_d}{SA_{gw} \times EV_{gw} \times Z \times EF \times ED}$$

For organic chemicals,

If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$

If $t_{event} > t^*$, then $Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z = K_p \times t_{event}$

where:

$RBTL_{dw}$ = Risk-based target level for dermal contact with groundwater [mg/L]
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_{gw} = Skin surface area available for contact with water [cm^2]
EV_{gw} = Event frequency [event/day]
ED = Exposure duration [year]
EF = Exposure frequency [day/year]
RfD_d = Chemical-specific dermal reference dose [mg/kg-day]
SF_d = Chemical-specific dermal cancer slope or potency factor $[mg/(kg\text{-}day)]^{-1}$
365 = Converts AT_c, AT_{nc} in years to days [day/year]
1000 = Conversion factor from cm^3 to L [cm^3/L]
t_{event} = Event duration [hr/event]
t^* = Chemical-specific time to reach steady-state [hr]
Z = Chemical-specific dermal factor [cm/event]
K_p = Chemical-specific dermal permeability coefficient [cm/hr]
FA = Chemical-specific fraction absorbed in water [-]
τ_{event} = Chemical-specific lag time [hr/event]
B = Chemical-specific relative contribution of permeability coefficient [-]

$B = K_P \frac{\sqrt{MW}}{2.6}$ $\log K_P = -2.80 + 0.66 \log K_{OW} - 0.0056MW$ If B<0.6 or B=0.6, then, $t^* = 2.4\tau_{event}$ If B>0.6 then, $t^* = 6\tau_{event} \times (b - \sqrt{b^2 - c^2})$ where, $c = \frac{1 + 3B + 3B^2}{3(1 + B)}$ $b = 2 \times \frac{(1 + B)^2}{\pi} - c$ $\tau_{event} = 0.105 \times 10^{(0.0056MW)}$ Source: Modified from RAGS, Vol. I, Part E, 2004.	where: *MW* = Molecular weight [g/mole] K_{ow} = Octanol water partition coefficient [L/kg] *b, c* = Correlation coefficient which have been fitted to the data from Flynn, G.L. (1990)

FIGURE B.4. DOMESTIC WATER USE (CHILD AND ADULT RESIDENT)
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)

Carcinogenic effects

$$RBTL_w = \frac{TR \times BW \times AT_c \times 365}{ED \times EF \times \left[\left(SF_o \times IR_w \right) + \left(SF_i \times ET \times K_f \times IR_a \right) + \left(\frac{SF_d}{1000} \times SA_{wb} \times EV_{wb} \times Z_{wb} \right) \right]}$$

Non-carcinogenic effects

$$RBTL_w = \frac{THQ \times BW \times AT_{nc} \times 365}{ED \times EF \times \left[\left(\frac{1}{RfD_o} \times IR_w \right) + \left(\frac{1}{RfD_i} \times K_f \times ET \times IR_a \right) + \left(\frac{SA_{wb} \times EV_{wb} \times Z_{wb}}{RfD_d \times 1000} \right) \right]}$$

For organic chemicals,

If $t_{wb\text{-}event} \le t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: $K_f = 0$ for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10^{-4} or Henry's law constant (atm-m^3/mol) <1.5 x 10^{-5}).
Source: Modified from RAGS, Vol. I, Part E, 2004.

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]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
RfD_o	=	Chemical-specific oral reference dose [mg/kg-day]
RfD_i	=	Chemical-specific inhalation reference dose [mg/kg-day]
RfD_d	=	Chemical-specific dermal 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) $^{-1}$]
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]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

FIGURE B.5. DERMAL CONTACT WITH CHEMICALS IN SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

$$RBTL_{dcss} = \frac{TR \times BW \times AT_c \times 365}{EF \times ED \times SF_d \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Non-carcinogenic effects

$$RBTL_{dcss} = \frac{THQ \times BW \times AT_{nc} \times 365 \times RfD_d}{EF \times ED \times 10^{-6} \times SA_{soil} \times EV_{soil} \times AF \times RAF_d}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

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_{soil}	=	Skin surface area available for contact with soil [cm^2]
EV_{soil}	=	Event frequency [event/day]
AF	=	Soil to skin adherence factor [mg/cm^2-event]
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]

FIGURE B.6. INGESTION OF CHEMICALS IN 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 [$(mg/kg\text{-}day)^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

FIGURE B.7. INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

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

Non-carcinogenic effects

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

Note: $VF_{ss} = 0$ for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10E-04 or Henry's law constant (atm-m^3/mol) <1.5 x 10E-05.

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.

FIGURE B.8. INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL
(CHILD AND ADULT RESIDENT; NON-RESIDENTIAL WORKER; AND CONSTRUCTION WORKER)

Carcinogenic effects

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

Non-carcinogenic effects

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

Source: Modified from RAGS, Vol. 1, Part E, 2004

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]
EV_{soil}	=	Event frequency [event/day]
AF	=	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 [$(mg/kg\text{-}day)^{-1}$]
SF_i	=	Inhalation cancer slope factor [$(mg/kg\text{-}day)^{-1}$]
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 [$(mg/m^3\text{-}air)/(mg/kg\text{-}soil)$]
VF_{ss}	=	Volatilization factor for vapor emissions from surficial soil [$(mg/m^3\text{-}air)/(mg/kg\text{-}soil)$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]

FIGURE B.9. INDOOR INHALATION OF VAPORS (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

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

Non-carcinogenic effects

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

where

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

Source: Modified from RAGS, Vol. I, Part B, 1991

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]

FIGURE B.10. DERMAL CONTACT WITH CHEMICALS IN WATER (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{TR \times AT_c \times 365 \times 1000}{SF_d \times \left(DC_{w-c} \times Z_c + DC_{w-a} \times Z_a\right)}$$

Non-carcinogenic effects

$$RBTL_{dcw\text{-}adj} = \frac{THQ \times AT_{nc} \times 365 \times 1000 \times RfD_d}{DC_{w-c} \times Z_c + DC_{w-a} \times Z_a}$$

where :

$$DC_{w\text{-}c} = \frac{ED_c \times EF_c \times SA_{gw-c} \times EV_{gw-c}}{BW_c}$$

$$DC_{w\text{-}a} = \frac{ED_a \times EF_a \times SA_{gw-a} \times EV_{gw-a}}{BW_a}$$

For organic chemicals,

If $t_{event} \le t^*$, then $Z = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{event}}{\pi}}$

If $t_{event} > t^*$, then

$$Z = FA \times K_p \left[\frac{t_{event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$$

For inorganic chemicals, $Z = K_p \times t_{event}$

Source: Modified from RAGS, Vol. I, Part E, 2004.

where:

$RBTL_{dcw\text{-}adj}$	=	Age-adjusted risk-based target level for dermal contact with chemicals in groundwater [mg/L-water]
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 [$(mg/kg\text{-}day)^{-1}$]
365	=	Converts AT_c, AT_{nc} in years to days [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
t_{event}	=	Event duration [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]
$DC_{w\text{-}c}$	=	Child dermal contact rate with groundwater [cm^2-event/kg]
$DC_{w\text{-}a}$	=	Adult dermal contact rate with groundwater [cm^2-event/kg]
$EV_{gw\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{gw\text{-}a}$	=	Resident adult event frequency [event/day]
Z_c	=	Resident child chemical-specific dermal factor [cm/event]
Z_a	=	Resident adult chemical-specific dermal factor [cm/event]
$SA_{gw\text{-}c}$	=	Resident child skin surface area available for contact with water [cm^2]
$SA_{gw\text{-}a}$	=	Resident adult skin surface area available for contact with water [cm^2]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]

FIGURE B.11. DOMESTIC WATER USE (AGE-ADJUSTED RESIDENT)
(ONLY FOR CHEMICALS WITHOUT MAXIMUM CONTAMINANT LEVELS)

Carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{TR \times AT_c \times 365}{\left[\left(SF_o \times IR_{w\text{-}aa}\right) + \left(SF_i \times K_f \times IR_{a\text{-}aa}\right) + \left(\frac{SF_d}{1000} \times \left(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}\right)\right)\right]}$$

Non-carcinogenic effects

$$RBTL_{w\text{-}adj} = \frac{THQ \times AT_{nc} \times 365}{\left[\left(\frac{1}{RfD_o} \times IR_{w-aa}\right) + \left(\frac{1}{RfD_i} \times K_f \times IR_{a-aa}\right) + \left(\frac{\left(DC_{wb-c} \times Z_{wb-c} + DC_{wb-a} \times Z_{wb-a}\right)}{RfD_d \times 1000}\right)\right]}$$

where:

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

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

$$DC_{wb\text{-}c} = \frac{ED_c \times EF_c \times SA_{wb-c} \times EV_{wb-c}}{BW_c} \quad \text{and} \quad DC_{wb\text{-}a} = \frac{ED_a \times EF_a \times SA_{wb-a} \times EV_{wb-a}}{BW_a}$$

For organic chemicals,

If $t_{wb\text{-}event} \le t^*$, then $Z_{wb} = 2 \times FA \times K_p \sqrt{6\tau_{event} \frac{t_{wb-event}}{\pi}}$

If $t_{wb\text{-}event} > t^*$, then $Z_{wb} = FA \times K_p \left[\frac{t_{wb-event}}{1+B} + 2\tau_{event} \left(\frac{1+3B+3B^2}{(1+B)^2} \right) \right]$

For inorganic chemicals, $Z_{wb} = K_p \times t_{wb-event}$

Note: $K_f = 0$ for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2 x 10^{-4} or Henry's law constant (atm-m^3/mol) <1.5 x 10^{-5}).
Source: Modified from RAGS, Vol. I, Part E, 2004.

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]
RfD_d	=	Chemical-specific dermal 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) $^{-1}$]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [mg/(kg-day)]$^{-1}$
$IR_{w\text{-}aa}$	=	Age-adjusted groundwater ingestion rate [L/kg]
$IR_{w\text{-}c}$	=	Resident child groundwater ingestion rate [L/day]
$IR_{a\text{-}c}$	=	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]
$DC_{wb\text{-}c}$	=	Child dermal whole-body contact rate with groundwater [cm^2-event/kg]
$DC_{wb\text{-}a}$	=	Adult dermal whole-body contact rate with groundwater [cm^2-event/kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
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]
SA_{wb}	=	Skin surface area available for whole-body contact with water [cm^2]
EV_{wb}	=	Event frequency for whole-body contact with water [event/day]
365	=	Conversion factor [day/year]
1000	=	Conversion factor from cm^3 to L [cm^3/L]
$t_{wb\text{-}event}$	=	Event duration for whole-body contact [hr/event]
t^*	=	Chemical-specific time to reach steady-state [hr]
Z_{wb}	=	Chemical-specific dermal factor for whole-body contact [cm/event]
K_p	=	Chemical-specific dermal permeability coefficient [cm/hr]
FA	=	Chemical-specific fraction absorbed in water [-]
τ_{event}	=	Chemical-specific lag time [hr/event]
B	=	Chemical-specific relative contribution of permeability coefficient [-]

FIGURE B.12. DERMAL CONTACT WITH CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

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

Non-carcinogenic effects

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

where:

$$SA_{soil-aa} = \frac{ED_c \times EF_c \times AF_c \times SA_{soil-c} \times EV_{soil-c}}{BW_c} + \frac{ED_a \times EF_a \times AF_a \times SA_{soil-a} \times EV_{soil-a}}{BW_a}$$

Source: Modified from RAGS, Vol. I, Part E, 2004.

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 [-]
AF_c	=	Resident child soil to skin adherence factor [mg/cm^2-event]
AF_a	=	Resident adult soil to skin adherence factor [mg/cm^2-event]
RfD_d	=	Chemical-specific dermal reference dose [(mg/kg-day)]
SF_d	=	Chemical-specific dermal cancer slope or potency factor [(mg/kg-day)$^{-1}$]
SA_{aa}	=	Age-adjusted skin surface area [mg/ kg]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
$SA_{soil\text{-}c}$	=	Resident child skin surface area available for contact with soil [cm^2/day]
$SA_{soil\text{-}a}$	=	Resident adult skin surface area available for contact with soil [cm^2/day]
$EV_{soil\text{-}c}$	=	Resident child event frequency [event/day]
$EV_{soil\text{-}a}$	=	Resident Child event frequency [event/day]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

FIGURE B.13. INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

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

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 :

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

Source: Modified from RAGS, Vol. I, Part A, 1989

where:

$RBTL_{ingss\text{-}adj}$	=	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 [$(mg/kg\text{-}day)^{-1}$]
$IR_{s\text{-}aa}$	=	Age-adjusted soil ingestion rate [mg/kg]
$IR_{s\text{-}c}$	=	Resident child soil ingestion rate [mg/day]
$IR_{s\text{-}a}$	=	Resident adult soil ingestion rate [mg/day]
BW_c	=	Resident child body weight [kg]
BW_a	=	Resident adult body weight [kg]
ED_c	=	Resident child exposure duration [year]
ED_a	=	Resident adult exposure duration [year]
EF_c	=	Exposure frequency for a child [day/year]
EF_a	=	Exposure frequency for an adult [day/year]
365	=	Conversion factor [day/year]
10^{-6}	=	Conversion factor [kg/mg]

FIGURE B.14. INHALATION OF VAPORS AND PARTICULATES OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

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

Non-carcinogenic effects

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

where:

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

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2×10^{-4} or Henry's law constant (atm-m^3/mol) <1.5×10^{-5}).

Source: Modified from RAGS, Vol. I, Part B, 1991

where:

$RBTL_{ss\text{-}adj}$	=	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]
$IR_{ao\text{-}aa}$	=	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]
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]
$ET_{o\text{-}c}$	=	Outdoor exposure time for a child [hour/day]
$ET_{o\text{-}a}$	=	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 [$(mg/kg\text{-}day)^{-1}$]
365	=	Conversion factor [day/year]

FIGURE B.15. INHALATION OF VAPORS AND PARTICULATES, DERMAL CONTACT WITH, AND INGESTION OF CHEMICALS IN SOIL (AGE-ADJUSTED RESIDENT)

Carcinogenic effects

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

Non-carcinogenic effects

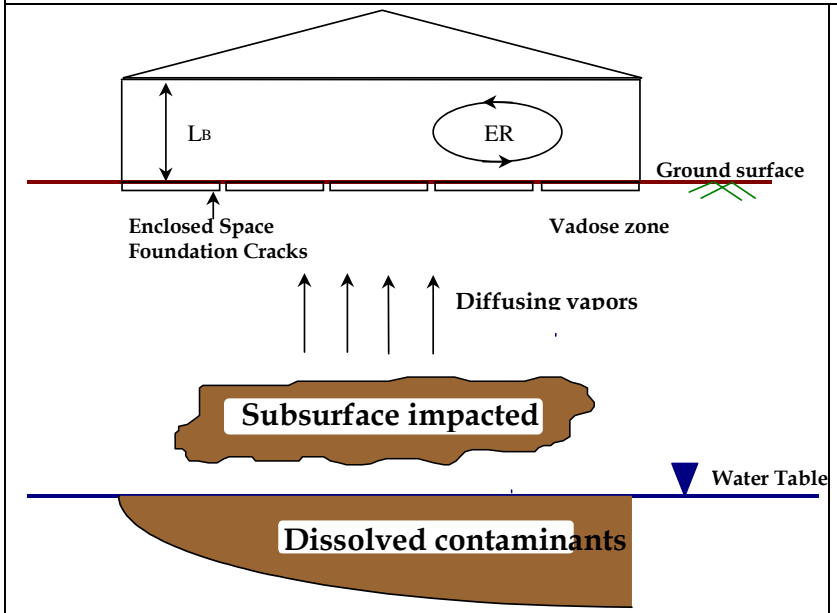
$$RBTL_{ss-combined} = \frac{THQ \times AT_{nc} \times 365}{\frac{1}{RfD_o} \times 10^{-6} \times IR_{s-aa} \times RAF_o + \frac{1}{RfD_d} \times 10^{-6} \times SA_{soil-aa} \times RAF_d + \frac{1}{RfD_i} \times IR_{ao-aa} \times \left(VF_{ss} + VF_p\right)}$$

Note: All parameters are defined under the individual pathway equations.

Note: VF_{ss} = 0 for non-volatile chemicals (i.e., chemicals with a molecular weight > 200 and Henry's law constant (dimensionless) < 4.2×10^{-4} or Henry's law constant (atm-m^3/mol) $<1.5 \times 10^{-5}$).

Source: Modified from RAGS, Vol. I, Part E, 2004.

FIGURE B.16. 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 [-]

Source: ASTM E1739-95

FIGURE B.17. SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

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

where:

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

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

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

Source: ASTM E1739-95

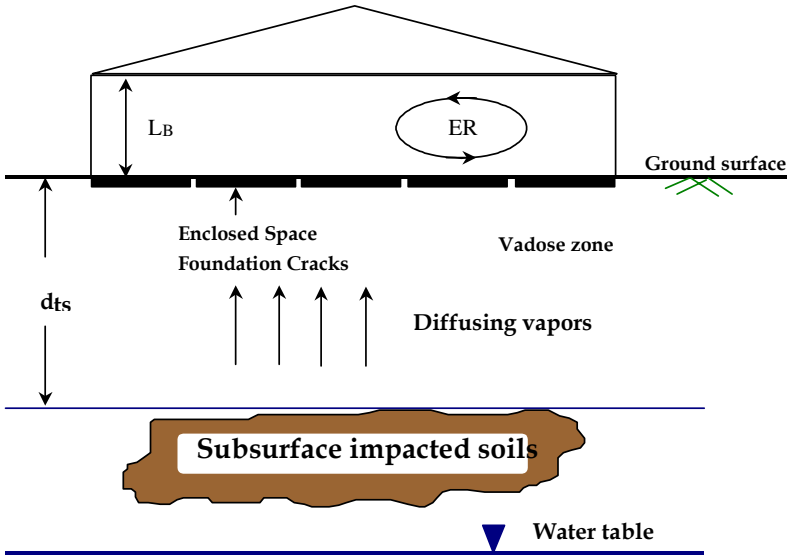


FIGURE B.18. GROUNDWATER CONCENTRATIONS PROTECTIVE OF INDOOR VAPOR INHALATION

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

where:

$RBTL_{wi}$ = Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]

$RBTL_{ai}$ = 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-water)]

Source: ASTM E1739-95

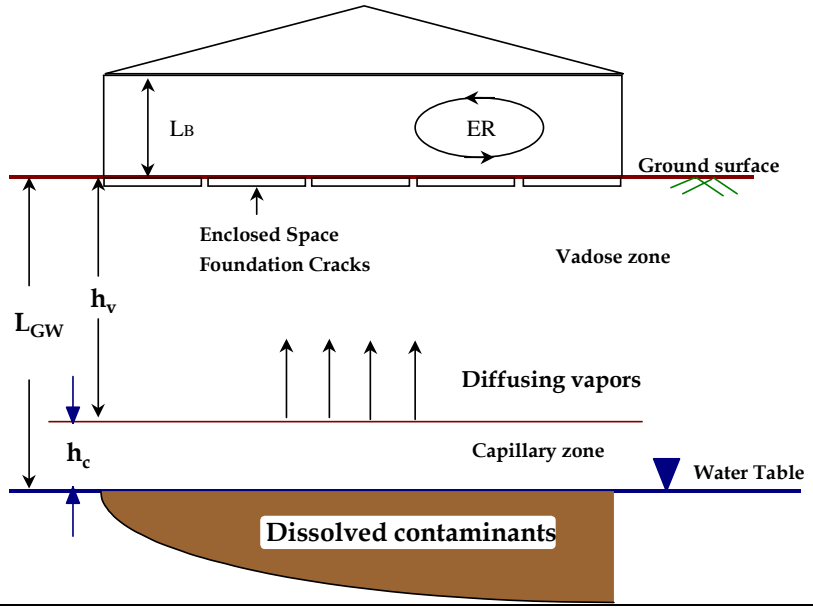


FIGURE B.19. GROUNDWATER CONCENTRATIONS PROTECTIVE OF OUTDOOR VAPOR INHALATION

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

where:

$RBTL_{wi}$ = Risk-based target level for indoor inhalation of vapors from groundwater [mg/L-water]
$RBTL_{ao}$ = 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-water)]

Source: ASTM E1739-95

FIGURE B.20.A. VOLATILIZATION FACTORS
(SURFICIAL SOIL TO OUTDOOR AIR)

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

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}.

Source: Soil Screening Guidance, 1996

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.

FIGURE B.20.B. VOLATILIZATION FACTORS
(PARTICULAR EMISSIONS FROM SURFICIAL SOIL)

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

Source: Soil Screening Guidance, 1996

where:

VF_p	=	Volatilization factor for particulate emissions from surficial soil [kg-soil/m^3-air]
Q/C	=	Inverse of the mean concentration at the center of square source [(g/m^2-s)/(kg/m^3)]
V	=	Fraction of vegetative cover [-]
U_m	=	Mean annual wind speed [m/s]
U_t	=	Equivalent threshold value of wind speed at 7 m [m/s]
$F(x)$	=	Function dependent on U_m/U_t derived using Cowherd *et al.* 1985 [-]
0.036	=	Empirical constant [g/m^2-hr]

FIGURE B.20.C. VOLATILIZATION FACTORS (SUBSURFACE SOIL VAPOR TO INDOOR AIR)

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

Source: ASTM E1739-95

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]

FIGURE B.20.D. VOLATILIZATION FACTORS (SUBSURFACE SOIL TO INDOOR AIR)

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

Source: ASTM E1739-95

where:

VF_{sesp}	=	Volatilization factor from subsurface soil to indoor (enclosed space) air [m^3-air/(mg/kg-soil)]
H	=	Vadose zone 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)]

FIGURE B.20.E. VOLATILIZATION FACTORS (GROUNDWATER TO INDOOR AIR)

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

Source: ASTM E1739-95

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]

FIGURE B.20.F. VOLATILIZATION FACTORS (GROUNDWATER TO OUTDOOR AIR)

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

Source: ASTM E1739-95

where:

VF_{wamb}	=	Volatilization factor from groundwater to outdoor air [(mg/m^3-air)/(mg/L-water)]
H	=	Vadose zone chemical specific Henry's Law constant [(L-water)/(L-air)]
U_m	=	Mean annual wind speed [m/s]
δ_a	=	Breathing zone height [cm]
L_{GW}	=	Depth to groundwater [cm]
D_{ws}^{eff}	=	Effective diffusion coefficient between groundwater and soil surface [cm^2/s]
W_{ga}	=	Dimension of soil source area parallel to wind direction [cm]
100	=	Conversion factor [cm/m]
10^3	=	Conversion factor [L/m^3]

FIGURE B.21. EFFECTIVE DIFFUSION COEFFICIENTS

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

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

where:

D^a	=	Chemical-specific diffusion coefficient in air [cm^2/s]
D^w	=	Chemical-specific diffusion coefficient in water [cm^2/s]
θ_{as}	=	Volumetric air content in 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]

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

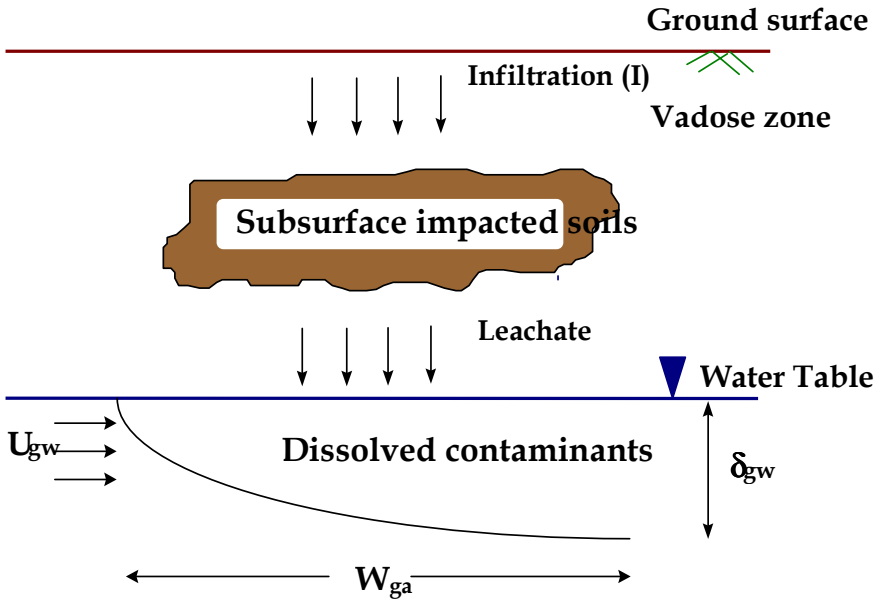
$$D_{crack}^{eff} = D^a \times \frac{\theta_{acrack}^{3.33}}{\theta_T^{2.0}} + D^w \times \frac{1}{H} \times \frac{\theta_{wcrack}^{3.33}}{\theta_T^{2.0}}$$

where:

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

Source: ASTM E1739-95

FIGURE B.22. SUBSURFACE SOIL CONCENTRATIONS PROTECTIVE OF LEACHING TO GROUNDWATER



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

where:

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

Source: ASTM E1739-95

FIGURE B.23. 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.

Source: ASTM E1739-95

FIGURE B.24. SOIL CONCENTRATION AT WHICH DISSOLVED PORE WATER AND VAPOR PHASES BECOME SATURATED

Single Component

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

Multiple Components

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

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]

Source: ASTM E1739-95

FIGURE B.25. SOIL VAPOR CONCENTRATION AT WHICH VAPOR PHASE BECOMES SATURATED

Single Component

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

Multiple Components

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

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)]

Source: ASTM E1739-95

FIGURE B.26. DOMENICO MODEL: DILUTION ATTENUATION FACTOR (DAF) IN THE SATURATED ZONE

Domenico model for multi-dimensional transport with decay and continuous source:

$$\frac{C(x,y,z,t)}{C_o} = (1/8)\ exp\left[\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]\right]\times erfc\left[\frac{\left[(x-vt)\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]}{2\sqrt{\alpha_x\times v\times t}}\right]\times$$

$$\left[erf\left[\frac{(y+Y/2)}{2\sqrt{\alpha_y x}}\right]-erf\left[\frac{(y-Y/2)}{2\sqrt{\alpha_y x}}\right]\right]\times\left[erf\left[\frac{(z+Z)}{2\sqrt{\alpha_z x}}\right]-erf\left[\frac{(z-Z)}{2\sqrt{\alpha_z x}}\right]\right]$$

where:

C	=	Dissolved-phase concentration [mg/L]
C_o	=	Dissolved-phase concentration at the source (at x=y=z=0) [mg/L]
v	=	Retarded seepage velocity [m/sec]
λ	=	Overall first order bio-decay rate [1/day]
α_x	=	Longitudinal dispersivity [m]
α_y	=	Lateral dispersivity [m]
α_z	=	Vertical dispersivity [m]
x, y, z	=	Spatial coordinates [m]
t	=	Time [day]
x	=	Distance along the centerline measured from the downgradient edge of the groundwater source [m]
Y	=	GW source dimension perpendicular to GW flow direction [m]
Z	=	GW source (mixing zone) thickness [m]
DA F	=	$C_o/C(x)$

At the centerline, for steady-state (after a long time) the concentration can be obtained by setting $y = 0$, $z = 0$, and $x << v \times t$ as:

$$\frac{C(x)}{C_o} = exp\left[\frac{x}{2\alpha_x}\left[1-\sqrt{1+\frac{4\lambda\alpha_x}{v}}\right]\right]\times erf\left[\frac{Y}{4\sqrt{\alpha_y x}}\right]\times erf\left[\frac{Z}{2\sqrt{\alpha_z x}}\right]$$

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

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

Note: Compare to ASTM E1739-95, p. 31, where $Y = S_w$ $Z = S_d$, $v = u$, and $C_o = C_{source}$

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

FIGURE B.27. ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION FOR GROUNDWATER RESOURCE PROTECTION

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

Allowable groundwater concentration at the POC [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
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration at POE is expressed in mg/L-water. 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]

FIGURE B.28. ALLOWABLE SOIL AND GROUNDWATER CONCENTRATION PROTECTIVE OF INDOOR INHALATION FOR RESIDENT AND NON-RESIDENTIAL WORKER

$$\text{Allowable soil concentration at the source [mg/kg]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{LF_{SW}} \times DAF_{unsat}$$

$$\text{Allowable groundwater concentration at the POD [mg/L]} = \text{Target groundwater concentration below on/off - site building} \times \frac{DAF_{bldg}}{DAF_{POD}}$$

where:

POD	=	Point of demonstration
DAF_{bldg}	=	Dilution attenuation factor between the on/off-site building and source estimated using Domenico's equation
DAF_{POD}	=	Dilution attenuation factor between the point of demonstration and source estimated using Domenico's equation
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
LF_{SW}	=	Dry soil leaching factor [(mg/L-water)/(mg/kg-soil)]

Concentration below on/off-site building is expressed in mg/L-water

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

FIGURE B. 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* $\times \frac{DAF_{POE}}{LF_{SW}}$ x DAF_{unsat}

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
DAF_{unsat}	=	Dilution attenuation factor in the unsaturated zone
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.

Table B-1
Toxicological Properties of Chemicals of Concern

Chemicals of Concern	CAS #	Slope Factor			Reference Dose			Absorption Factor		Permeability Constant, K_p	Relative Contribution of Permeability Coefficient, B	Lag Time, τ_{event}	Duration of Event, t*	Fraction Absorbed Water, FA
		Oral, SF_o	Inhalation, SF_i	Dermal, SF_d	Oral, RfD_o	Inhalation, RfD_i	Dermal, RfD_d	Dermal, RAF_d	Oral, RAF_o					
		$(mg/kg\text{-}day)^{-1}$	$(mg/kg\text{-}day)^{-1}$	$(mg/kg\text{-}day)^{-1}$	(mg/kg-day)	(mg/kg-day)	(mg/kg-day)	(unitless)	(unitless)	(cm/hr)	(unitless)	(hr/event)	(hr)	(unitless)
Benzene	71-43-2	3.5E-02	1.8E-02	3.5E-02	4.0E-03	8.6E-03	4.0E-03	N/A	1.0	0.015	5.05E-02	2.92E-01	7.00E-01	1.00
Toluene	108-88-3	NA	NA	NA	8.0E-02	1.4E+00	8.0E-02	N/A	1.0	0.031	1.15E-01	3.50E-01	8.39E-01	1.00
Ethylbenzene	100-41-4	NA	NA	NA	1.0E-01	2.9E-01	1.0E-01	N/A	1.0	0.049	1.95E-01	4.20E-01	1.01E+00	1.00
Xylenes (total)	1330-20-7	NA	NA	NA	2.0E-01	2.9E-02	2.0E-01	N/A	1.0	0.029	1.14E-01	4.13E-01	9.92E-01	1.00
Ethylene dibromide (EDB)	106-93-4	2.0E+00	2.1E+00	2.0E+00	9.0E-03	2.6E-03	9.0E-03	N/A	1.0	0.003	1.46E-02	1.21E+00	2.90E+00	1.00
Ethylene dichloride (EDC)	107-06-2	9.1E-02	9.1E-02	9.1E-02	2.0E-02	1.4E-03	2.0E-02	N/A	1.0	0.004	1.61E-02	3.82E-01	9.18E-01	1.00
Methyl tertiary butyl ether (MTBE)	1634-04-4	1.8E-03	9.1E-04	1.8E-03	8.6E-01	8.6E-01	8.6E-01	N/A	1.0	0.003	1.23E-02	3.28E-01	7.87E-01	1.00
Acenaphthene	83-32-9	NA	NA	NA	6.0E-02	6.0E-02	6.0E-02	0.13	1.0	0.102	4.89E-01	7.68E-01	1.84E+00	1.00
Anthracene	120-12-7	NA	NA	NA	3.0E-01	3.0E-01	3.0E-01	0.13	1.0	0.192	9.88E-01	1.05E+00	4.04E+00	0.97
Benzo(a)anthracene	56-55-3	7.3E-01	3.9E-01	7.3E-01	NA	NA	NA	0.13	1.0	0.474	2.75E+00	2.03E+00	8.53E+00	1.00
Benzo(a)pyrene	50-32-8	7.3E+00	3.9E+00	7.3E+00	NA	NA	NA	0.13	1.0	0.701	4.27E+00	2.69E+00	1.17E+01	1.00
Benzo(b)fluoranthene	205-99-2	7.3E-01	3.9E-01	7.3E-01	NA	NA	NA	0.13	1.0	0.702	4.29E+00	2.77E+00	1.20E+01	1.00
Benzo(k)fluoranthene	207-08-9	7.3E-02	3.9E-01	7.3E-02	NA	NA	NA	0.13	1.0	0.869	5.31E+00	2.72E+00	1.20E+01	0.79
Chrysene	218-01-9	7.3E-03	3.9E-02	7.3E-03	NA	NA	NA	0.13	1.0	0.474	2.75E+00	2.03E+00	8.53E+00	1.00
Dibenzo(a,h)anthracene	53-70-3	7.3E+00	4.1E+00	7.3E+00	NA	NA	NA	0.13	1.0	1.508	9.68E+00	3.88E+00	1.76E+01	0.60
Fluoranthene	206-44-0	NA	NA	NA	4.0E-02	4.0E-02	4.0E-02	0.13	1.0	0.224	1.22E+00	1.45E+00	5.68E+00	1.00
Fluorene	86-73-7	NA	NA	NA	4.0E-02	4.0E-02	4.0E-02	0.13	1.0	0.136	6.75E-01	8.97E-01	3.50E+00	1.00
Naphthalene	91-20-3	1.2E-01	1.2E-01	1.2E-01	2.0E-02	8.6E-04	2.0E-02	0.13	1.0	0.047	2.03E-01	5.58E-01	1.34E+00	1.00
Pyrene	129-00-0	NA	NA	NA	3.0E-02	3.0E-02	3.0E-02	0.13	1.0	0.326	1.79E+00	1.43E+00	5.76E+00	0.95
TPH-GRO														
TPH-DRO														
TPH-ORO														
Aliphatics - > C6-C8	NA	NA	NA	NA	5.0E+00	5.3E+00	5.0E+00	N/A	1.0	NA	NA	NA	NA	NA
Aliphatics - > C8-C10	NA	NA	NA	NA	1.0E-01	2.9E-01	1.0E-01	N/A	1.0	NA	NA	NA	NA	NA
Aliphatics - >C10-C12	NA	NA	NA	NA	1.0E-01	2.9E-01	1.0E-01	0.1	1.0	NA	NA	NA	NA	NA
Aliphatics - >C12-C16	NA	NA	NA	NA	1.0E-01	2.9E-01	1.0E-01	0.1	1.0	NA	NA	NA	NA	NA
Aliphatics - >C16-C21	NA	NA	NA	NA	2.0E+00	NA	2.0E+00	0.1	1.0	NA	NA	NA	NA	NA
Aliphatics - >C21-C35	NA	NA	NA	NA	2.0E+00	NA	2.0E+00	0.1	1.0	NA	NA	NA	NA	NA
Aromatics - >C8-C10	NA	NA	NA	NA	4.0E-02	5.7E-02	4.0E-02	N/A	1.0	NA	NA	NA	NA	NA
Aromatics - >C10-C12	NA	NA	NA	NA	4.0E-02	5.7E-02	4.0E-02	0.1	1.0	NA	NA	NA	NA	NA
Aromatics - >C12-C16	NA	NA	NA	NA	4.0E-02	5.7E-02	4.0E-02	0.1	1.0	NA	NA	NA	NA	NA
Aromatics - >C16-C21	NA	NA	NA	NA	3.0E-02	NA	3.0E-02	0.13	1.0	NA	NA	NA	NA	NA
Aromatics - >C21-C35	NA	NA	NA	NA	3.0E-02	NA	3.0E-02	0.13	1.0	NA	NA	NA	NA	NA
Tertiary-amyl-methyl-ether (TAME)	994-05-8	NA	NA	NA	4.0E-02	2.3E-02	4.0E-02	N/A	1.0	0.007	2.63E-02	3.92E-01	9.40E-01	1.00
Tertiary-butyl-alcohol (TBA)	75-65-0	NA	NA	NA	9.0E-02	8.6E-02	9.0E-02	N/A	1.0	0.002	7.08E-03	2.73E-01	6.56E-01	1.00
Ethyl-tert-butyl-ether (ETBE)	637-92-3	NA	NA	NA	1.0E-03	8.6E-02	1.0E-03	N/A	1.0	0.006	2.44E-02	3.92E-01	9.40E-01	1.00
Diisopropyl ether (DIPE)	108-20-3	NA	NA	NA	1.0E-01	1.1E-01	1.0E-01	N/A	1.0	0.009	3.51E-02	3.92E-01	9.40E-01	1.00
Ethanol	64-17-5	NA	NA	NA	3.3E+01	5.4E-01	3.3E+01	N/A	1.0	0.001	1.40E-03	1.93E-01	4.63E-01	1.00
Methanol	67-56-1	NA	NA	NA	5.0E-01	1.1E+00	5.0E-01	N/A	1.0	0.000	6.94E-04	1.61E-01	3.86E-01	1.00
Arsenic	7440-38-2	1.5E+00	1.5E+01	1.5E+00	3.0E-04	8.6E-06	3.0E-04	0.03	1.0	0.001	NA	NA	NA	NA
Barium	7440-39-3	NA	NA	NA	2.0E-01	1.4E-04	2.0E-01	0.01	1.0	0.001	NA	NA	NA	NA
Cadmium	7440-43-9	3.8E-01	6.3E+00	3.8E-01	1.0E-03	NA	1.0E-03	0.001	1.0	0.001	NA	NA	NA	NA
Chromium (III) total chromium	7440-47-3	NA	NA	NA	1.5E+00	2.9E-05	1.5E+00	0.01	1.0	0.001	NA	NA	NA	NA
Chromium (VI)	18540-29-9	4.2E+01	4.2E+01	4.2E+01	3.0E-03	2.3E-06	3.0E-03	0.01	1.0	0.002	NA	NA	NA	NA
Lead	7439-92-1	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Selenium	7782-49-2	NA	NA	NA	5.0E-03	5.7E-05	5.0E-03	0.01	1.0	0.001	NA	NA	NA	NA

Notes:
NA: Not available
N/A: Not applicable

Table B-2
Physical and Chemical Properties of Chemicals of Concern

Chemicals of Concern	CAS #	Molecular Weight, MW (g/mol)	Water Solubility, S (mg/L)	Henry's Law Constant, H (L-water/L-air)	Organic Carbon Adsorption Coefficient, K_{oc} (cm^3/g)	Soil-Water Partition Coefficient, K_d (L/kg)	Diffusion Coefficient in Air, D_a (cm^2/s)	Diffusion Coefficient in Water, D_w (cm^2/s)	Vapor Pressure, P (mmHg)	Octanol-Water Partition Coefficient, K_{ow} (cm^3/g)
Benzene	71-43-2	78.11	1.75E+03	2.28E-01	5.89E+01	NA	8.80E-02	9.80E-06	9.50E+01	9.77E+01
Toluene	108-88-3	92.14	5.26E+02	2.72E-01	1.82E+02	NA	8.70E-02	8.60E-06	2.82E+01	3.47E+02
Ethylbenzene	100-41-4	106.17	1.69E+02	3.23E-01	3.63E+02	NA	7.50E-02	7.80E-06	9.60E+00	1.07E+03
Xylenes (total)	1330-20-7	106.17	1.61E+02	3.01E-01	4.07E+02	NA	7.00E-02	7.80E-06	8.06E+00	1.23E+03
Ethylene dibromide (EDB)	106-93-4	188	4.32E+03	2.93E-02	5.37E+01	NA	2.17E-02	1.90E-05	1.10E+01	1.02E+02
Ethylene dichloride (EDC)	107-06-2	98.96	8.52E+03	4.01E-02	1.74E+01	NA	1.04E-01	9.90E-06	8.13E+01	6.76E+01
Methyl tertiary butyl ether (MTBE)	1634-04-4	88.15	5.10E+04	2.41E-02	1.12E+01	NA	8.00E-02	1.00E-05	2.49E+02	7.59E+01
Acenaphthene	83-32-9	154.21	4.24E+00	6.36E-03	7.08E+03	NA	4.21E-02	7.69E-06	3.75E-03	1.41E+04
Anthracene	120-12-7	178.24	4.34E-02	2.95E-02	2.95E+04	NA	3.24E-02	7.74E-06	2.55E-05	2.24E+04
Benzo(a)anthracene	56-55-3	228.3	9.40E-03	1.37E-04	3.98E+05	NA	5.10E-02	9.00E-06	1.54E-07	3.31E+05
Benzo(a)pyrene	50-32-8	252.32	1.62E-03	4.63E-05	1.02E+06	NA	4.30E-02	9.00E-06	4.89E-09	1.29E+06
Benzo(b)fluoranthene	205-99-2	252.32	1.50E-03	4.55E-03	1.23E+06	NA	2.26E-02	5.56E-06	8.06E-08	1.29E+06
Benzo(k)fluoranthene	207-08-9	252.32	8.00E-04	3.40E-05	1.23E+06	NA	2.26E-02	5.56E-06	9.59E-11	1.29E+06
Chrysene	218-01-9	228.3	1.60E-03	3.88E-03	3.98E+05	NA	2.48E-02	6.21E-06	7.80E-09	3.31E+05
Dibenzo(a,h)anthracene	53-70-3	278.4	2.49E-03	6.03E-07	3.80E+06	NA	2.02E-02	5.18E-06	2.10E-11	5.01E+06
Fluoranthene	206-44-0	202.26	2.06E-01	6.60E-04	1.07E+05	NA	3.02E-02	6.35E-06	8.13E-06	8.51E+04
Fluorene	86-73-7	166.22	1.98E+00	2.61E-03	1.38E+04	NA	3.63E-02	7.88E-06	3.24E-03	1.05E+04
Naphthalene	91-20-3	128.18	3.10E+01	1.98E-02	2.00E+03	NA	5.90E-02	7.50E-06	8.89E-02	1.48E+03
Pyrene	129-00-0	202.26	1.35E-01	4.51E-04	1.05E+05	NA	2.72E-02	7.24E-06	4.25E-06	8.51E+04
TPH-GRO										
TPH-DRO										
TPH-ORO										
Aliphatics - > C6-C8	NA	100	5.40E+00	5.00E+01	3.98E+03	NA	1.00E-01	1.00E-05	4.79E+01	NA
Aliphatics - > C8-C10	NA	130	4.30E-01	8.00E+01	3.16E+04	NA	1.00E-01	1.00E-05	4.79E+00	NA
Aliphatics - >C10-C12	NA	160	3.40E-02	1.20E+02	2.51E+05	NA	1.00E-01	1.00E-05	4.79E-01	NA
Aliphatics - >C12-C16	NA	200	7.60E-04	5.20E+02	5.01E+06	NA	1.00E-01	1.00E-05	3.65E-02	NA
Aliphatics - >C16-C21	NA	270	2.50E-06	4.90E+03	6.31E+08	NA	1.00E-01	1.00E-05	8.40E-04	NA
Aliphatics - >C21-C35	NA	270	2.50E-06	4.90E+03	6.31E+08	NA	1.00E-01	1.00E-05	8.40E-04	NA
Aromatics - >C8-C10	NA	120	6.50E+01	4.80E-01	1.58E+03	NA	1.00E-01	1.00E-05	4.79E+00	NA
Aromatics - >C10-C12	NA	130	2.50E+01	1.40E-01	2.51E+03	NA	1.00E-01	1.00E-05	4.79E-01	NA
Aromatics - >C12-C16	NA	150	5.80E+00	5.30E-02	5.01E+03	NA	1.00E-01	1.00E-05	3.65E-02	NA
Aromatics - >C16-C21	NA	190	6.50E-01	1.30E-02	1.58E+04	NA	1.00E-01	1.00E-05	8.36E-04	NA
Aromatics - >C21-C35	NA	240	6.60E-03	6.70E-04	1.26E+05	NA	1.00E-01	1.00E-05	3.34E-07	NA
Tertiary-amyl-methyl-ether (TAME)	994-05-8	102	4.29E+03	1.30E-01	4.17E+01	NA	6.99E-02	7.37E-06	9.97E+01	8.91E+01
Tertiary-butyl-alcohol (TBA)	75-65-0	74.1	2.35E+05	5.42E-04	4.22E+00	NA	8.52E-02	9.11E-06	3.14E+01	4.90E+00
Ethyl-tert-butyl-ether (ETBE)	637-92-3	102	5.03E+03	9.99E-02	3.72E+01	NA	6.95E-02	7.34E-06	9.00E+01	7.59E+01
Diisopropyl ether (DIPE)	108-20-3	102	2.67E+03	1.63E-01	6.46E+01	NA	6.81E-02	7.15E-06	7.76E+01	1.55E+02
Ethanol	64-17-5	46.1	2.96E+05	2.77E-04	1.19E+00	NA	1.15E-01	1.22E-05	7.76E+01	9.95E-01
Methanol	67-56-1	32.04	1.00E+06	1.87E-04	9.00E+00	NA	1.50E-01	1.64E-05	1.22E+02	2.33E-01
Arsenic	7440-38-2	74.9	NA	NA	NA	2.90E+01	NA	NA	NA	4.78E+00
Barium	7440-39-3	137	NA	NA	NA	4.10E+01	NA	NA	NA	NA
Cadmium	7440-43-9	112.4	NA	NA	NA	7.50E+01	NA	NA	NA	8.49E-01
Chromium (III) total chromium	7440-47-3	52	NA	NA	NA	1.80E+06	NA	NA	NA	NA
Chromium (VI)	18540-29-9	52	NA	NA	NA	1.90E+01	NA	NA	NA	NA
Lead	7439-92-1	207	NA	NA	NA	1.00E+01	NA	NA	NA	5.36E+00
Selenium	7782-49-2	78.96	NA	NA	NA	5.00E+00	NA	NA	NA	1.73E+00

Notes:
NA: Not available

Table B-3
Exposure Factors

Parameter	Symbol	Unit	Default
Averaging Time for Carcinogen	AT_c	year	70
Averaging Time for Non-Carcinogen	AT_{nc}	year	=ED
Body Weight:			
Resident Child	BW	kg	15
Resident Adult	BW	kg	70
Non-Residential Worker	BW	kg	70
Construction Worker	BW	kg	70
Exposure Duration:			
Resident Child	ED	year	6
Resident Adult	ED	year	24
Non-Residential Worker	ED	year	25
Construction Worker	ED	year	1
Exposure Frequency:			
Resident Child	EF	day/year	350
Resident Adult	EF	day/year	350
Non-Residential Worker	EF	day/year	250
Construction Worker	EF	day/year	90
Soil Ingestion Rate:			
Resident Child	IR_{soil}	mg/day	200
Resident Adult	IR_{soil}	mg/day	100
Non-Residential Worker	IR_{soil}	mg/day	100
Construction Worker	IR_{soil}	mg/day	100
Groundwater Ingestion Rate:			
Resident Child	IR^w	L/day	1
Resident Adult	IR^w	L/day	2
Indoor Inhalation Rate (hourly):			
Resident Child	IRai	m^3/hr	0.416
Resident Adult	IRai	m^3/hr	0.833
Non-Residential Worker	IRai	m^3/hr	0.833
Exposure Time for Indoor Inhalation:			
Resident Child	ET_{in}	hr/day	18
Resident Adult	ET_{in}	hr/day	18
Non-Residential Worker	ET_{in}	hr/day	18
Indoor Inhalation Rate (daily)*:			
Resident Child	IR_a	m^3/day	7.5
Resident Adult	IR_a	m^3/day	15.0
Non-Residential Worker	IR_a	m^3/day	15.0
Outdoor Inhalation Rate (hourly):			
Resident Child	IR_{ao}	m^3/hr	0.416
Resident Adult	IR_{ao}	m^3/hr	0.833
Non-Residential Worker	IR_{ao}	m^3/hr	0.833
Construction Worker	IR_{ao}	m^3/hr	1.62

Table B-3
Exposure Factors

Parameter	Symbol	Unit	Default
Exposure Time for Outdoor Inhalation:			
Resident Child	ET_{out}	hr/day	6
Resident Adult	ET_{out}	hr/day	6
Non-Residential Worker	ET_{out}	hr/day	6
Construction Worker	ET_{out}	hr/day	10
Outdoor Inhalation Rate (daily):**			
Resident Child	IR_a	m^3/day	2.5
Resident Adult	IR_a	m^3/day	5.0
Non-Residential Worker	IR_a	m^3/day	5.0
Construction Worker	IR_a	m^3/day	16.2
Skin Surface Area for Incidental Dermal Contact with Soil:			
Resident Child	SA_{soil}	cm^2/day	2800
Resident Adult	SA_{soil}	cm^2/day	5700
Non-Residential Worker	SA_{soil}	cm^2/day	3300
Construction Worker	SA_{soil}	cm^2/day	3300
Skin Surface Area for Incidental Dermal Contact with Water:			
Resident Child	SA_{gw}	cm^2/day	2800
Resident Adult	SA_{gw}	cm^2/day	5700
Non-Residential Worker	SA_{gw}	cm^2/day	3300
Construction Worker	SA_{gw}	cm^2/day	3300
Skin Surface Area for Whole-Body Dermal Contact with Water:			
Resident Child	$SA_{gw\text{-}wb}$	cm^2/day	6600
Resident Adult	$SA_{gw\text{-}wb}$	cm^2/day	18000
Soil to Skin Adherence Factor:			
Resident Child	AF	mg/cm^2	0.2
Resident Adult	AF	mg/cm^2	0.07
Non-Residential Worker	AF	mg/cm^2	0.2
Construction Worker	AF	mg/cm^2	0.3
Event Frequency for Incidental Dermal Contact with Soil			
Resident Child	EV_{soil}	event/day	1
Resident Adult	EV_{soil}	event/day	1
Non-Residential Worker	EV_{soil}	event/day	1
Construction Worker	EV_{soil}	event/day	1
Event Frequency for Incidental Dermal Contact with Water			
Resident Child	EV_{gw}	event/day	1
Resident Adult	EV_{gw}	event/day	1
Non-Residential Worker	EV_{gw}	event/day	1
Construction Worker	EV_{gw}	event/day	1
Event Frequency for Whole-Body Dermal Contact with Water			
Resident Child	EV_{gw_wb}	event/day	1
Resident Adult	EV_{gw_wb}	event/day	1

Table B-3
Exposure Factors

Parameter	Symbol	Unit	Default
Event Duration for Incidental Dermal Contact with Water			
Resident Child	t_{event}	hr/event	1
Resident Adult	t_{event}	hr/event	1
Non-Residential Worker	t_{event}	hr/event	1
Construction Worker	t_{event}	hr/event	1
Event Duration for Whole-Body Dermal Contact with Water			
Resident Child	t_{event_wb}	hr/event	0.33
Resident Adult	t_{event_wb}	hr/event	0.25

Notes:
*: Calculated as hourly indoor inhalation rate times exposure time for indoor inhalation
**: Calculated as hourly outdoor inhalation rate times exposure time for outdoor inhalation

Table B-4
Fate and Transport Parameters

Parameter	Symbol	Unit	Default Value
SOIL PARAMETERS:			
Soil Source Dimension Parallel to Wind Direction	W_a	cm	1500
Depth to Subsurface Soil Sources	d_{ts}	cm	91.44
Depth of Surficial Soil Zone	d_s	cm	91.44
Depth to Soil Vapor Measurement	dsv	cm	91.44
VADOSE ZONE:			
Total Soil Porosity	θ_T	cm^3/cm^3-soil	0.38
Volumetric Water Content	θ_{ws}	cm^3/cm^3	0.08
Volumetric Air Content	θ_{as}	cm^3/cm^3	**0.30**
Thickness	h_v	cm	**295**
Dry Soil Bulk Density	ρ_s	g/cm^3	1.5
Fractional Organic Carbon Content	f_{ocv}	g-C/g-soil	0.006
SOIL IN CRACKS:			
Total Soil Porosity	θ_{Tcrack}	cm^3/cm^3-soil	0.38
Volumetric Water Content	θ_{wcrack}	cm^3/cm^3	0.08
Volumetric Air Content	θ_{acrack}	cm^3/cm^3	**0.30**
CAPILLARY FRINGE:			
Total Soil Porosity	θ_{Tcap}	cm^3/cm^3-soil	0.38
Volumetric Water Content	θ_{wcap}	cm^3/cm^3	**0.34**
Volumetric Air Content	θ_{acap}	cm^3/cm^3	**0.038**
Thickness	h_c	cm	5
GROUNDWATER PARAMETERS:			
Depth to Groundwater	L_{gw}	cm	300
GW Source Dimension Perpendicular to GW Flow Direction	Y	cm	1500
GW Source Dimension Parallel to GW Flow Direction	W_{ga}	cm	1500
Total Porosity in the Saturated Zone*	θ_{TS}	cm^3/cm^3	0.38
Dry Soil Bulk Density (Saturated Zone)*	ρ_{ss}	g/cm^3	1.5
Fractional Organic Carbon Content in the Saturated Zone*	f_{ocs}	g-C/g-soil	0.006
Groundwater Mixing Zone Thickness	δ_{gw}	cm	200
Hydraulic Conductivity in the Saturated Zone	K	cm/year	625000
Hydraulic Gradient in the Saturated Zone	i	cm/cm	0.004
Groundwater Darcy Velocity	U_{gw}	cm/year	**2500**
Infiltration Rate of Water Through Vadose Zone	I	cm/year	14
AMBIENT AIR PARAMETERS:			
Breathing Zone Height	δ_a	cm	200
Inverse of Mean Concentration at Center of Square Source	Q/C	g/m^2-s)/(kg/m^3	81.64
Fraction of Vegetative Cover	V	m^2/m^2	0.5
Mean Annual Wind Speed	U_m	m/s	4.69
Equivalent Threshold Value of Windspeed	U_t	m/s	11.32
Windspeed Distribution Function from Cowherd et. al, 1985	F(x)	unitless	0.194

Table B-4
Fate and Transport Parameters

Parameter	Symbol	Unit	Default Value
ENCLOSED SPACE PARAMETERS:			
Enclosed Space Air Exchange Rate:			
Residential Structure	ER	1/24 hrs	12.096
Non-Residential Structure	ER	1/24hrs	19.872
Enclosed Space Volume/Infiltration Area:			
Residential Structure	L_B	cm	200
Non-Residential Structure	L_B	cm	300
Volatalization Factor for Domestic Water Use (K)	K	L/m^3	0.5
Enclosed Space Foundation or Wall Thickness:			
Residential Structure	L_{crack}	cm	15
Non-Residential Structure	L_{crack}	cm	15
Area Fraction of Cracks in Foundation/Walls:			
Residential Structure	η	cm^2/cm^2	0.001
Non-Residential Structure	η	cm^2/cm^2	0.001

Notes:
The values in **bold** are calculated .
* These parameters not used for DTL or Tier 1 RBTL caculations, but may be required for Tier 2 SSTL

Table B-5
Effective/Saturated Soil, Solubility/Effective Solubility, and Saturated Vapor Concentrations

Chemicals of Concern	CAS #	Saturated Soil Concentration (mg/kg)	Effective/Saturated Soil Concentration for Gasoline (mg/kg)	Effective/Saturated Soil Concentration for Diesel (mg/kg)
		Default	Default	Default
Benzene	71-43-2	7.92E+02	2.02E+01	6.76E-01
Toluene	108-88-3	6.31E+02	5.83E+01	2.84E+00
Ethylbenzene	100-41-4	3.88E+02	6.52E+00	5.72E-01
Xylenes (total)	1330-20-7	4.11E+02	3.66E+01	4.46E+00
Ethylene dibromide (EDB)	106-93-4	1.65E+03	1.65E+03	1.65E+03
Ethylene dichloride (EDC)	107-06-2	1.41E+03	1.41E+03	1.41E+03
Methyl tertiary butyl ether (MTBE)	1634-04-4	6.39E+03	6.39E+03	6.39E+03
Acenaphthene	83-32-9	1.80E+02	1.80E+02	1.80E+02
Anthracene	120-12-7	7.68E+00	7.68E+00	5.75E-04
Benzo(a)anthracene	56-55-3	2.24E+01	2.24E+01	2.17E-05
Benzo(a)pyrene	50-32-8	9.91E+00	9.91E+00	1.99E-05
Benzo(b)fluoranthene	205-99-2	1.11E+01	1.11E+01	1.56E-05
Benzo(k)fluoranthene	207-08-9	5.91E+00	5.91E+00	8.34E-06
Chrysene	218-01-9	3.82E+00	3.82E+00	1.73E-06
Dibenzo(a,h)anthracene	53-70-3	5.68E+01	5.68E+01	5.68E+01
Fluoranthene	206-44-0	1.32E+02	1.32E+02	8.87E-03
Fluorene	86-73-7	1.64E+02	1.64E+02	1.95E-01
Naphthalene	91-20-3	3.74E+02	7.65E-01	1.74E+00
Pyrene	129-00-0	8.51E+01	8.51E+01	4.45E-03
TPH-GRO	NA	8.98E+02	8.98E+02	8.98E+02
TPH-DRO	NA	7.00E+02	7.00E+02	7.00E+02
TPH-ORO	NA	1.44E+01	1.44E+01	1.44E+01
Aliphatics - > C6-C8	NA	1.83E+02	1.83E+02	1.83E+02
Aliphatics - > C8-C10	NA	8.84E+01	8.84E+01	8.84E+01
Aliphatics - >C10-C12	NA	5.20E+01	5.20E+01	5.20E+01
Aliphatics - >C12-C16	NA	2.29E+01	2.29E+01	2.29E+01
Aliphatics - >C16-C21	NA	9.47E+00	9.47E+00	9.47E+00
Aliphatics - >C21-C35	NA	9.47E+00	9.47E+00	9.47E+00
Aromatics - >C8-C10	NA	6.26E+02	6.26E+02	6.26E+02
Aromatics - >C10-C12	NA	3.79E+02	3.79E+02	3.79E+02
Aromatics - >C12-C16	NA	1.75E+02	1.75E+02	1.75E+02
Aromatics - >C16-C21	NA	6.18E+01	6.18E+01	6.18E+01
Aromatics - >C21-C35	NA	4.98E+00	4.98E+00	4.98E+00
Tertiary-amyl-methyl-ether (TAME)	994-05-8	1.41E+03	1.41E+03	1.41E+03
Tertiary-butyl-alcohol (TBA)	75-65-0	1.85E+04	1.85E+04	1.85E+04
Ethyl-tert-butyl-ether (ETBE)	637-92-3	1.49E+03	1.49E+03	1.49E+03
Diisopropyl ether (DIPE)	108-20-3	1.26E+03	1.26E+03	1.26E+03
Ethanol	64-17-5	1.79E+04	1.79E+04	1.79E+04
Methanol	67-56-1	1.07E+05	1.07E+05	1.07E+05
Arsenic	7440-38-2	NA	NA	NA
Barium	7440-39-3	NA	NA	NA
Cadmium	7440-43-9	NA	NA	NA
Chromium (III) total chromium	7440-47-3	NA	NA	NA
Chromium (VI)	18540-29-9	NA	NA	NA
Lead	7439-92-1	NA	NA	NA
Selenium	7782-49-2	NA	NA	NA

Notes:
NA: Not available
When weight percent is not available, saturated soil concentration, solubility,

Table B-5
Effective/Saturated Soil, Solubility/Effective Solubility, and Saturated Vapor Concentrations

Chemicals of Concern	CAS #	Effective/Solubility (mg/L)					Effective/Saturated Vapor Concentration (mg/m^3)	
		Gasoline	Diesel	Jet Fuel (JP-4 & JP-5)	Kerosene	Fuel Oil No. 6	Gasoline	Diesel
Benzene	71-43-2	4.47E+01	1.49E+00	1.74E+01	1.75E+03	1.75E+03	1.02E+04	3.41E+02
Toluene	108-88-3	4.86E+01	2.36E+00	1.51E+01	5.26E+02	5.26E+02	1.29E+04	6.28E+02
Ethylbenzene	100-41-4	2.84E+00	2.49E-01	1.73E+00	1.69E+02	1.69E+02	9.22E+02	8.08E+01
Xylenes (total)	1330-20-7	1.43E+01	1.74E+00	3.60E+00	1.61E+02	1.61E+02	4.10E+03	4.99E+02
Ethylene dibromide (EDB)	106-93-4	4.32E+03	4.32E+03	4.32E+03	4.32E+03	4.32E+03	1.11E+05	1.11E+05
Ethylene dichloride (EDC)	107-06-2	8.52E+03	8.52E+03	8.52E+03	8.52E+03	8.52E+03	4.33E+05	4.33E+05
Methyl tertiary butyl ether (MTBE)	1634-04-4	5.10E+04	5.10E+04	5.10E+04	5.10E+04	5.10E+04	1.18E+06	1.18E+06
Acenaphthene	83-32-9	4.24E+00	4.24E+00	4.24E+00	1.36E-04	4.24E+00	3.11E+01	3.11E+01
Anthracene	120-12-7	4.34E-02	3.25E-06	4.34E-02	3.07E-08	2.80E-06	2.45E-01	1.83E-05
Benzo(a)anthracene	56-55-3	9.40E-03	9.09E-09	9.40E-03	9.40E-03	5.21E-06	1.89E-03	1.83E-09
Benzo(a)pyrene	50-32-8	1.62E-03	3.25E-09	1.62E-03	1.62E-03	6.50E-08	6.64E-05	1.33E-10
Benzo(b)fluoranthene	205-99-2	1.50E-03	2.12E-09	1.50E-03	1.50E-03	3.01E-07	1.09E-03	1.55E-09
Benzo(k)fluoranthene	207-08-9	8.00E-04	1.13E-09	8.00E-04	8.00E-04	1.60E-07	1.30E-06	1.84E-12
Chrysene	218-01-9	1.60E-03	7.25E-10	1.60E-03	1.60E-03	1.11E-06	9.58E-05	4.34E-11
Dibenzo(a,h)anthracene	53-70-3	2.49E-03	2.49E-03	2.49E-03	2.49E-03	2.49E-03	3.15E-07	3.15E-07
Fluoranthene	206-44-0	2.06E-01	1.38E-05	2.06E-01	9.20E-07	5.62E-05	8.85E-02	5.94E-06
Fluorene	86-73-7	1.98E+00	2.36E-03	1.98E+00	1.98E+00	1.98E+00	2.90E+01	3.45E-02
Naphthalene	91-20-3	6.35E-02	1.45E-01	1.64E-01	7.87E-02	2.34E-03	1.26E+00	2.86E+00
Pyrene	129-00-0	1.35E-01	7.06E-06	1.35E-01	1.68E-07	3.53E-06	4.63E-02	2.42E-06
TPH-GRO	NA	7.08E+01	7.08E+01	7.08E+01	7.08E+01	7.08E+01	3.22E+05	3.22E+05
TPH-DRO	NA	3.15E+01	3.15E+01	3.15E+01	3.15E+01	3.15E+01	8.18E+03	8.18E+03
TPH-ORO	NA	6.60E-03	6.60E-03	6.60E-03	6.60E-03	6.60E-03	1.22E+01	1.22E+01
Aliphatics - > C6-C8	NA	5.40E+00	5.40E+00	5.40E+00	5.40E+00	5.40E+00	2.58E+05	2.58E+05
Aliphatics - > C8-C10	NA	4.30E-01	4.30E-01	4.30E-01	4.30E-01	4.30E-01	3.35E+04	3.35E+04
Aliphatics - >C10-C12	NA	3.40E-02	3.40E-02	3.40E-02	3.40E-02	3.40E-02	4.12E+03	4.12E+03
Aliphatics - >C12-C16	NA	7.60E-04	7.60E-04	7.60E-04	7.60E-04	7.60E-04	3.93E+02	3.93E+02
Aliphatics - >C16-C21	NA	2.50E-06	2.50E-06	2.50E-06	2.50E-06	2.50E-06	1.22E+01	1.22E+01
Aliphatics - >C21-C35	NA	2.50E-06	2.50E-06	2.50E-06	2.50E-06	2.50E-06	1.22E+01	1.22E+01
Aromatics - >C8-C10	NA	6.50E+01	6.50E+01	6.50E+01	6.50E+01	6.50E+01	3.09E+04	3.09E+04
Aromatics - >C10-C12	NA	2.50E+01	2.50E+01	2.50E+01	2.50E+01	2.50E+01	3.35E+03	3.35E+03
Aromatics - >C12-C16	NA	5.80E+00	5.80E+00	5.80E+00	5.80E+00	5.80E+00	2.95E+02	2.95E+02
Aromatics - >C16-C21	NA	6.50E-01	6.50E-01	6.50E-01	6.50E-01	6.50E-01	8.55E+00	8.55E+00
Aromatics - >C21-C35	NA	6.60E-03	6.60E-03	6.60E-03	6.60E-03	6.60E-03	4.31E-03	4.31E-03
Tertiary-amyl-methyl-ether (TAME)	994-05-8	4.29E+03	4.29E+03	4.29E+03	4.29E+03	4.29E+03	5.47E+05	5.47E+05
Tertiary-butyl-alcohol (TBA)	75-65-0	2.35E+05	2.35E+05	2.35E+05	2.35E+05	2.35E+05	1.25E+05	1.25E+05
Ethyl-tert-butyl-ether (ETBE)	637-92-3	5.03E+03	5.03E+03	5.03E+03	5.03E+03	5.03E+03	4.94E+05	4.94E+05
Diisopropyl ether (DIPE)	108-20-3	2.67E+03	2.67E+03	2.67E+03	2.67E+03	2.67E+03	4.26E+05	4.26E+05
Ethanol	64-17-5	2.96E+05	2.96E+05	2.96E+05	2.96E+05	2.96E+05	1.92E+05	1.92E+05
Methanol	67-56-1	1.00E+06	1.00E+06	1.00E+06	1.00E+06	1.00E+06	2.10E+05	2.10E+05
Arsenic	7440-38-2	NA	NA	NA	NA	NA	NA	NA
Barium	7440-39-3	NA	NA	NA	NA	NA	NA	NA
Cadmium	7440-43-9	NA	NA	NA	NA	NA	NA	NA
Chromium (III) total chromium	7440-47-3	NA	NA	NA	NA	NA	NA	NA
Chromium (VI)	18540-29-9	NA	NA	NA	NA	NA	NA	NA
Lead	7439-92-1	NA	NA	NA	NA	NA	NA	NA
Selenium	7782-49-2	NA	NA	NA	NA	NA	NA	NA

Notes:
NA: Not available
When weight percent is not available, saturated soil concentration, solubility,

APPENDIX C
EVALUATION OF THE VAPOR INTRUSION PATHWAY

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C.1 Introduction and Scope

The procedure used to quantitatively evaluate the vapor intrusion pathway is presented in this appendix. This protocol or other MDNR-approved guidance must be used. Figure C-1 shows the step-by-step approach to evaluate the vapor intrusion pathway. Each of the steps illustrated in the flowchart is described below. Specific equations used to calculate the soil vapor target levels are presented in Appendix B.

For consistency, MDNR prefers that soil vapor sampling be conducted using this protocol unless extenuating circumstances make application impractical.[1]

The objective of this step is to determine whether any of the following vapor intrusion-related pathways are complete:

- Vapor intrusion from sub-surface soils, and
- Vapor intrusion from groundwater.

Determining whether the vapor intrusion pathway is complete typically occurs during the development of the exposure model, (refer to Section 6.1) and is based on a combination of site-specific information and professional judgment.

This protocol does not specifically pertain to sub-slab vapor sampling (a means of collecting soil gas samples from beneath a building via the installation of monitoring points through the foundation of the building). If site conditions warrant collection of sub-slab vapor samples, MDNR recommends that procedures under development by the United States Environmental Protection Agency ("USEPA") be used. USEPA's current sub-slab sampling guidance is included as Attachment 1. Sub-slab sampling, whether in accordance with USEPA or other guidance or procedures, must be conducted under a MDNR-approved work plan.

This protocol is designed to facilitate a quantitative evaluation of soil gas. Passive soil gas monitoring is generally a qualitative activity used to guide the installation of permanent sampling points. As such, passive soil gas monitoring may not be used to quantitatively monitor soil gas or assess risks associated with vapor intrusion. Passive soil gas monitoring may be used preliminarily to assist in planning a quantitative soil gas sampling event.

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[1] MDNR anticipates the US EPA will issue new guidance regarding petroleum vapor intrusion in early 2013. The MDNR may subsequently revise this appendix after discussion with stakeholders, public notice and rulemaking.

C.2. Soil Gas Probe Installation

C.2.1 Installation Requirements.

A. The Missouri Well Construction Rules at 10 CSR 23-1.010 through 10 CSR 23-6.060 govern the installation and abandonment of monitoring wells, the definition of which includes wells used for soil gas monitoring. Refer to these rules prior to installing soil gas sampling points in the field.

C.2.2 Sampling Depth.

A. To the extent possible, soil gas sample depths should be chosen to minimize the effects of changes in barometric pressure, temperature, or breakthrough of ambient air from the surface, and to ensure that consistent and representative samples are collected. In determining appropriate sampling depths, strong consideration should be given to the lithology of the subsurface. Under no circumstances may soil gas samples be collected from a depth of less than 18 inches.

B. Soil gas sampling depths must be consistent from sampling point to sampling point. Samples may be collected at multiple depths (see C.2.2.C below) but, in comparing data, be certain that all of the data used in the comparison was collected from a consistent depth; for instance, do not compare soil vapor data collected at 60 inches with data collected from 18 inches.

C. Generally, soil gas samples must be collected at a minimum of two discrete depths at each sampling point. Where contamination in soil is very shallow or groundwater is very shallow (i.e., less than approximately 5 feet below the ground surface), one sample from a single depth might be sufficient.

D. One of the two soil gas samples collected at each sampling point must be collected at a depth no greater than 3 feet below the foundation of the enclosed space or potential future enclosed space. The depth at which the second sample is collected will be dependent on site conditions, primarily the depth to contamination.

E. For structures having basements, one or more soil gas samples must be collected adjacent to basement walls (i.e., no further than 5 feet from the wall and, generally, at a depth approximately equal to the midpoint of the

wall; this depth might need to vary depending on the characteristics of the structure). Unless soil or groundwater contamination is found below the building, soil gas sampling adjacent to the basement walls need only occur on the side or sides of the building where the contamination is found (e.g., if the soil or groundwater contamination is south of the building, soil gas sampling must, at a minimum, occur on the south side of the building). If soil or groundwater contamination is found below the elevation of the basement floor, soil gas samples must also be collected just below the elevation of the floor.

F. For structures without basements, soil gas samples should be collected below the depth of the foundation, with the first sample collected at a depth of no more than 3 feet below the bottom of the foundation.

G. For hypothetical future buildings, if there is no other information available to select depth, soil vapor samples should be taken at target depths of approximately 3 feet and 10 feet below ground surface[2]. This method assures that data is available to assess vapor intrusion threats to both "slab-on-grade" buildings and those having basements. If groundwater is too shallow to allow sampling at one or both of these depths, samples should be collected immediately above the capillary fringe or the top of soil contamination. If soil contamination extends to the surface, sample at a depth approximately equal to the anticipated depth of the future structure's foundation.

H. In all cases, if groundwater is too shallow to allow soil gas sampling at the depths specified above, samples shall be collected immediately above the capillary fringe[3]. If soil contamination extends to the surface, sample at a depth just below the expected or actual foundation or floor of the structure.

C.2.3 Lateral Spacing of Soil Gas Sampling Points

A. Soil gas sampling is intended to assess vapor intrusion threats from soil and groundwater to existing and hypothetical future buildings. Therefore,

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[2] When sampling to evaluate the potential for vapor intrusion into future buildings, unless physical site constraints or an activity and use limitation prevents where and what type of building may be constructed on the property, the sampler must assume a building with a basement and a building without a basement could be built anywhere on the site, including within all areas of contamination, and collect samples accordingly.

[3] In some cases where groundwater is very shallow, the capillary fringe might extend to or very near the ground surface. In such cases, soil vapor sampling may not be possible.

sampling points should be laterally spaced to adequately represent soil gas concentrations proximate to such structures, taking into consideration the location of contamination relative to the structures. The actual number of soil gas sampling points necessary for a given site will depend on the size and number of buildings, the location of the buildings relative to soil and groundwater contamination, and, for the evaluation of hypothetical future structures, the extent or size of the contamination plume. The following provisions should be considered as general guidelines rather than specific requirements. The locations and spacing of soil gas sampling points will ultimately be dependent on site-specific characteristics.

B. Generally, soil gas sampling points should be located along each side of each existing building that is proximate to soil or groundwater contamination. In addition, for existing buildings, samples should be collected above the area of highest contamination. However, if contamination is located to one side of an existing structure, the collection of samples only from that side of the structure might be adequate. If any wall of the structure exceeds 50 feet in length, a minimum of two sampling points is required along that wall.

C. To assess vapor intrusion threats to future structures, sampling points must be installed in the area having the highest contaminant concentrations on the site. Generally, four sampling points should be utilized to evaluate future structures. However, if the size of the plume exceeds 2,500 square feet, more than four sampling points will be required, with the total number dependent on the overall size of the plume. In general, sampling points should be spaced no greater than 50 feet apart and preferentially placed within the anticipated footprint of the future structure, if known.

C.2.4 Probe Construction Materials.

A. Sample probes consist of a probe tip through which the soil gas sample is collected, and probe tubing that extends from the probe tip to the ground surface.

B. Sample probe tubing should be of a small diameter (1/8 to 1/4 inch). Diameter selection should consider site soil types. In general, smaller tubing diameters can result in higher sample vacuum conditions, which can make sample collection more difficult. Tubing must be inert and non-

adsorptive. Polyethylene and other flexible tubing tend to adsorb COCs and skew results and should not be used.

C. The sample probe should be constructed of materials that will not react or interact with target compounds. Suggested materials are nylon, copper, Teflon, poly vinyl chloride (PVC), and stainless steel. If copper or stainless steel is used, the material must first be adequately cleaned to remove oil residue that might be present from the manufacturing process.

D. The probe tip should be covered with fine screen or connected to a short (< 2 feet) section of perforated pipe, glass frit, tubing, or screen mesh.

C.2.5 Probe Installation.

A. MDNR recommends that permanent probes, wells, or other soil gas sampling devices be installed to allow for the assessment of seasonal variability (a minimum of two soil gas sampling events are required at any site at which soil gas sampling is conducted, as discussed at C.3.2 below). However, data may also be collected from temporary sampling points, such as through the probe rods of a direct push drill machine .

B. Boreholes may be installed using direct push or hollow-stem auger drilling equipment or hand-driven using a rotary hammer or a hand auger. Note, however, that direct push probes might not be suitable for all soil conditions, as smearing of the sidewalls can occur in fine-grained soils. Such smearing could preclude passage of vapor from the soil into the borehole.

C. Before any drilling activities, utility clearance for the installation area should be obtained. In addition, utilities proximate to the contamination must be identified and assessed as possible soil gas conduits. Utilities near or above contamination must be screened using a PID or FID (as appropriate) and the results recorded.

D. The borehole is advanced to the target sampling depth. If samples will be collected at multiple depths within the same borehole, the borehole is initially advanced to the deepest sampling point and the deepest sampling point installed first.

E. The probe tip is placed midway between the top and bottom of the sampling interval within a sand pack extending 6 inches above and below

the sampling interval. The grain size of the sand pack should be appropriately sized (for example, no smaller than the adjacent formation) and installed to minimize disruption of airflow to the sampling tip.

F. At least 1 foot of dry granular bentonite should be placed on top of the sand pack to preclude the infiltration of hydrated bentonite grout into the sand pack. Refer to Figure 1 for an illustration of this sealing method.

G. The borehole should be grouted to the surface (or, for nested samplers, the bottom of the next sampling interval) with hydrated bentonite. Adequately sealing soil gas sampling probes is very important to minimize the exchange of atmospheric air with the soil gas and to maximize the representativeness of the sample. The surface seal should be a minimum of 2.5 feet thick. If conditions warrant shallow sampling depths, great care should be taken in installing the surface seal to limit atmospheric infiltration.

H. If multiple sampling points are installed within a single borehole, the borehole must be grouted between sampling points. One foot of dry granular bentonite must be placed between the filter pack and the grout at each sampling location within the borehole, as illustrated by Figure 1.

I. Tubing must be properly marked at the surface to identify the probe location and depth. Particularly when multiple probes are installed within a single borehole, tubing must be labeled immediately upon installing each separate probe.

J. To minimize any separation between the soils and the outside of the probe, avoid lateral movement of probes once they have been installed.

K. Examples of a single depth soil gas probe and a multi-depth or “nested” soil gas probe are shown in Figure 1. Figure 1 is only an example: soil gas sampling points need not necessarily be constructed in strict accordance with the figure.

L. Documentation of subsurface soil stratigraphy via borehole logging and other methods can be very important in evaluating soil gas data. While delineation of contamination should be largely complete at any site undergoing soil gas sampling, MDNR recommends that soils be logged, field screened, and sampled for COC analysis during probe installation for the purpose of providing further information regarding the distribution of

contamination. Soil stratigraphy data can be very important in determining soil gas fate and transport.

C.2.6 Surface Completion.

A. Unless soil gas probes are properly abandoned the same day they are installed, probes must be properly secured, capped, and completed to prevent infiltration of water or ambient air into the subsurface and to prevent accidental damage or vandalism. For surface completions, the following components may be installed, as necessary:

   i. Gas-tight valve or fitting for capping the vapor point;

   ii. Fitting for connection to above ground sampling equipment;

   iii. Protective flush mounted or above ground well vaults, and/or

   iv. Guard posts.

C.2.7 Probe Abandonment

A. All monitoring wells, including those used for soil gas monitoring, must be abandoned in accordance with Missouri Well Construction Rule 10 CSR 23-4.080, "Plugging of Monitoring Wells." This rule states, in part, that monitoring wells less than 10 feet in depth must be plugged with grout or by returning uncontaminated native material into the hole it was taken from.

B. 10 CSR 23-4.080 also states, in part, that temporary monitoring wells (i.e., closed within 30 days) greater than 10 feet in depth must be plugged by removing any temporary pipe and filling the well from total depth to 10 feet from the surface with approved grout, with the remainder of the well filled with uncontaminated native material or grout. The plugging of all monitoring wells greater than 10 feet in depth must be reported to MDNR on a registration report form supplied by MDNR's Missouri Geological Survey (MGS).

C. A monitoring well that is abandoned in accordance with 10 CSR 23-1.010 must be plugged immediately.

C.3 Sampling Frequency

C.3.1 Factors affecting soil gas values.

A. Certain atmospheric and seasonal factors that are not within human control can affect soil gas values. For instance, temperature, barometric pressure, and precipitation can affect soil gas values as these factors fluctuate over time. Because these factors will fluctuate, actions must be taken to ensure soil gas data collected at a site is representative of a variety of atmospheric conditions. MDNR has determined that the best way to account for these factors is to require multiple soil gas sampling events over time.

C.3.2 Sampling frequency.

A. At a minimum, two soil gas sampling events must occur, with no less than three months between events. In cases where measured soil gas values vary significantly from the first to the second event, additional sampling may be required. In most cases, the maximum number of sampling events will be four, with events spaced evenly over a period of one year. Samples must be collected from the same location and depth during each sampling event.

C.3.3 Duplication of sampling events.

A. Under this guidance, soil gas samples may be collected from either permanent or temporary sampling points. Clearly, sampling may be easily duplicated if permanent sampling points are installed. However, if temporary points are used (i.e., those closed within at most 30 days), actions must be taken to ensure that subsequent samples are collected from the same location and depth as the initial samples. To do so, MDNR requires that the location and depth of temporary sampling points be accurately and durably recorded. Sampling points should be marked in the field to ensure that they can be subsequently found. MDNR recommends that the location of each sampling point be recorded using Global Positioning System (GPS) coordinates. GPS coordinates should be accurate to ± 5 feet. The methods used to record the temporary sampling locations and depths and a copy of the actual written record of such information must be included in the soil gas sampling report submitted to MDNR.

C.4 Soil Gas Probe Equilibration and Purging

C.4.1 Monitoring Point Equilibration.

A. During probe installation, subsurface conditions are unavoidably disturbed. The subsurface soil gas profile should be allowed to equilibrate following this disturbance. The following equilibration times are recommended:

- For probes installed using the direct push method, soil gas sampling should not be conducted for at least 30 minutes following probe installation. MDNR recommends waiting several hours.
- For probes installed with hollow stem auger drilling methods, soil gas sampling should not be conducted for at least 48 hours following probe installation.

B. Prior to sampling, soil gas sampling probes should be purged to ensure that stagnant or ambient air is removed from the sampling system and to assure samples collected are representative of subsurface conditions. The following purge procedure is recommended:

- Calculate the volume of the sampling system by summing the volume of the probe screened interval (including filter pack void space, accounting for porosity of sand pack), the volume of tubing from the probe tip to the ground surface, and the volume of above ground tubing connecting the soil probe to the sample collection device.
- Purge the monitoring point until at least three volumes of the full sampling system have been evacuated. Purging should be conducted at flow rates and vacuum conditions similar to those for sample collection (described below).
- If the soil matrix is such that purging as recommended above is not possible due to low or no flow conditions (i.e., gas will not flow or flow is severely restricted), the probe should be advanced deeper to look for zones of higher permeability. If the deeper probe does not encounter a higher permeability zone and low or no flow conditions persist, the probe should be abandoned and a new probe advanced elsewhere on the site.
- If low or no flow conditions are found across the site and soil gas sampling is therefore not possible, an alternative method of soil gas

sampling, such as sub-slab sampling, may be proposed. Because sub-slab gas samples are generally extracted from the porous granular material underlying a slab, sub-slab sampling may be a practical method of soil gas sampling when subsurface sampling is not. As discussed at C.1 above, if site conditions warrant sub-slab sampling, the sampling should be conducted in accordance with current EPA sub-slab sampling guidance.

C.5 Soil Gas Sample Collection Procedures

C.5.1 Sample Containers.

A. Samples may be collected in Tedlar bags or gas-tight syringes if samples are analyzed on-site in a mobile laboratory. Syringes may not be used if samples are analyzed off-site at a fixed laboratory. For samples to be analyzed off-site at a fixed laboratory, Summa canisters or Tedlar bags or equivalent containers may be used. MDNR recommends working with the laboratory that will analyze the samples in choosing appropriate sample containers. MDNR prefers that small volume – 1 L or 500 mL – Summa canisters be used. Certain situations might warrant the use of a larger Summa canister but, in general, the small volume canisters should be used.

B. The analytical laboratory or other supplier of sample containers must certify that all sample containers supplied by them are free of contaminants at concentrations exceeding contaminant detection levels.

C.5.2 Sampling Flow Rate.

A. An initial sampling rate of 200 milliliters per minute (mL/min) or less is recommended.

B. A regulated flow meter should be placed between the probe and the sample container to control and measure the flow rate.

C. The sampling rate may be modified based on specific field conditions, including the vacuum observed. Data for samples collected at a flow rate exceeding the recommended rate of 200 mL/min shall be flagged in the report submitted to MDNR. MDNR will not necessarily reject flagged data. Flagging is intended to facilitate a more thorough review of the data.

C.5.3 Vacuum Conditions.

A. To measure sample collection vacuum, a vacuum gauge must be placed between the probe and the sample container. MDNR recommends a sampling vacuum of less than 100 inches of water. Note, however, that when using a Summa canister, the vacuum gauge reading is dominated by the vacuum in the canister and does not reflect the vacuum at the probe tip. Therefore, with a canister, the vacuum gauge reading becomes meaningless as does the 100 inches of water requirement at C.5.3.C below.

B. To achieve the target sampling vacuum, the sampling flow rate should be adjusted using the flow regulator.

C. If the sampling vacuum exceeds 100 inches of water, and a reduction in the sampling flow rate does not reduce the vacuum, continue to attempt to collect the sample, recording flow rate and vacuum conditions. Data for samples collected under a vacuum of greater than 100 inches of water must be flagged. MDNR will not necessarily reject or consider such data suspect; flagging simply facilitates a more thorough review of the data.

D. If the sample container cannot be filled within an expected time frame, such time being dependent on the size and type of the sample container and sampling equipment (e.g., tube diameter), discontinue sampling and document vacuum observations. Generally, data from samples collected under such conditions will not be valid.

C.5.4 Field Conditions.

A. Generally, soil gas sampling should not be conducted within 48 hours of a significant precipitation event (for example, 0.5 inch or greater of rain) or comparable on-site watering. However, whether sampling is conducted is dependent on the depth to which soil is wetted relative to the planned depth of sample collection. The depth to which the soil is wetted is dependent, at least in part, on the ground cover, the type of soil, and the soil moisture content prior to the precipitation event. Sampling should not occur if soils are wetted at a depth equal to or greater than the planned sampling depth.

C.5.5 Sample Collection.

A. Aboveground sampling equipment consists of connector tubing, regulated flow meter, pressure gauge, and purging equipment. An example sampling train is shown in Figure 2.

B. Connect aboveground sampling equipment to probe at the surface. Check all sampling system connections and fittings for tightness and obvious deterioration.

C. Quick connect fittings and nylon tubing should be used to ensure vacuum tightness of the system and that chemicals in the air stream are not reacting with or adsorbing to the tubing. Compression fittings should be avoided for all connections except at the Summa canister (if used).

D. Purge at least three volumes of air from the sampling system as described at C.4.1.B above. After purging is complete, close the valve to the purge line and/or disconnect purge apparatus, as appropriate.

E. Connect the sample container to the sampling line, using quick-connect, airtight fittings.

F. Follow the leak test procedures described in Section C.6, below.

G. Open valve and collect sample into sample container, following the sample flow rate and vacuum guidelines discussed above. During sampling, measure and record sample flow rate and vacuum every two to five minutes.

H. Disconnect sample container and immediately label the container with sample identification information.

I. If Summa canisters are used, measure the final pressure of the canister using a pressure gauge. Record the final canister pressure.

J. Store sample containers out of direct sunlight, and do not chill.

C.5.6 Quality Control Samples.

A. The collection of at least one field duplicate per sampling event or one per twenty samples, whichever is greater, is required.

B. Duplicate samples shall be collected in separate sample containers, using the same procedures and at the same location and depth as the original sample.

C. Preferably, duplicate samples should be collected simultaneous to collection of the primary sample using a sampling tee. Alternatively, the duplicate may be collected immediately after the collection of the primary sample.

D. At least one equipment blank must be collected per sampling event or per 25 samples, whichever is greater.

C.5.7 Recordkeeping.

The following information should be recorded in a field notebook or on sampling forms (Figure 3 shows an example field form) and reported to MDNR as necessary to document the procedures utilized at a specific site to collect soil gas data.

A. MDNR recommends using a relatively simple conceptual site model related to the vapor intrusion pathway. Such a model can be very useful before, during, and after a soil gas sampling investigation. The conceptual site model should, at a minimum, include information on the location of utility corridors and other potential preferential pathways for soil gas migration, depth to groundwater, distances between sources and receptors (include both current and potential future structures), and soil type and soil stratigraphy.

B. Sample identification information, including the locations and depths at which the samples were collected, sample identifiers, date, and time.

C. Field personnel involved in sample collection.

D. Weather conditions (e.g., temperature, wind speed, barometric pressure, precipitation, etc.).

E. Sampling methods, devices, and equipment used.

F. Purge volumes prior to sample collection. Relate the purge volumes to the volume of the sampling equipment, including the tubing connecting the sampling interval to the surface.

G. Volume of soil gas extracted (i.e., volume of each sample).

H. Vacuum of canisters before and after samples collected.

I. If observable, the apparent moisture content of the sampling zone (e.g., dry, moist, saturated). An alternative to a qualitative measurement of soil

moisture is to collect a soil sample from the soil gas sampling interval for laboratory measurement of soil moisture. If a soil sample is collected for this purpose, include a copy of the laboratory data sheet.

J. Shipment information, including chain of custody protocols and records.

C.6 Leak Testing

C.6.1 Requirements.

A. Leakage during soil gas sampling may dilute samples with ambient air and produce results that underestimate actual site concentrations or contaminate the sample with external contaminants. Therefore, MDNR is requiring that a leak test be conducted each time a soil gas sample is collected to determine whether leakage has occurred. Leak testing may be conducted with or without a shroud.

B. For each sample, use a hand pump to vacuum test the sampling equipment after assembly.

C. A leak check, or tracer, compound such as isopropanol is recommended to determine if leaks are present. Other compounds such as helium, pentane, isobutane, propane, and butane, may be used as leak check compounds. MDNR may approve the use of other leak check compounds on a request-specific basis. Select a leak check compound that is not known or suspected to be site- related or otherwise associated with the site or nearby properties.

D. Immediately before sampling, place the leak check compound at each location where ambient air could enter the sampling system or where cross contamination may occur. For liquid compounds (for example, isopropanol), wet a paper towel with the leak check compound and place the towel over each location where ambient air could enter the sampling system. These areas include: the base of the soil probe at ground surface, the connection from the soil gas probe to the sampling line, and any connections within the sampling line. Gaseous leak check compounds require a device to hold the vapor near the test location, such as a shroud at the surface. The type of device and leak check compound to be used must be specified in the soil gas sampling work plan.

E. The leak check compound must be included in the list of analytes looked for during laboratory analysis of each sample.

C.6.2 Detection of leak check compound.

A. If greater than 100 ug/L of the leak check compound is detected in a sample, the following actions must be taken:

- Review the analytical results that show a detection of the leak check compound.
- If a review of the data indicates that the analytical data is accurate, evaluate the cause of the leak through system testing.
- Based on the concentration of the leak check compound detected, evaluate the impacts of the leak on sample collection and sample integrity. Document the findings and the evaluation in the soil gas investigation report submitted to MDNR.
- In certain cases, MDNR will reject data in which a leak check compound has been detected at a concentration in excess of 100 ug/L unless it can be demonstrated that the data remains valid.

C.7 Laboratory Analysis

C.7.1 Off-site and On-site Analysis.

A. Samples may be analyzed either off-site in a fixed laboratory or on-site in a mobile laboratory. On-site analyses can provide for a more timely indication of problems with sample system leaks or short-circuiting, thus allowing corrections to be made and resampling to occur while drilling and sampling equipment remains on the site. Whether samples are analyzed on or off-site, the probes from which the samples are collected should either be installed as permanent sampling points or their location clearly and durably marked so that sampling can be duplicated during subsequent gas sampling events. Procedures for on-site sampling and analysis must be clearly documented in the work plan submitted to MDNR and approved by MDNR prior to implementation.

C.7.2 Analyses Required.

A. Contaminants of concern (COCs): For petroleum product spills, COCs include benzene, toluene, xylenes, ethylbenzene, MTBE, TPH-GRO, and naphthalene.

B. Leak test compound. The leak test compound used must be included in the analyses except when the leak testing method used involves real-time monitoring for the leak check compound. Real-time monitoring must be proposed in a work plan submitted to and approved by MDNR.

C. The entity performing the work may also analyze vapor samples for oxygen, carbon dioxide, nitrogen, methane, and other indicators of the biodegradation of hydrocarbon vapors, though these analyses are not required. Of these, MDNR recommends analyzing for oxygen and carbon dioxide, at least. If samples for oxygen analysis are collected, the oxygen sample should be collected after the COC sample, as oxygen sampling requires the use of an oxygen meter and pump.

C.7.3 Analytical Methods.

A. Fixed laboratory analysis: Gas chromatograph by EPA Method TO-14A, TO-15, or an equivalent air analysis method. Summa canisters are required for these analytical methods. SW-846 Methods 8260B and 8021 may be used if detection limits below applicable target levels can be achieved.

B. On-site laboratory analysis: Gas chromatography using SW-846 Methods 8260B or 8021. Method detection limits must be below applicable target levels. Other methods may be used only with prior approval of MDNR.

C. Selected laboratory analyses must meet detection limits that support site objectives (i.e., detection limits must be lower than applicable target levels).

D. Regardless of whether the analyses are conducted at an off-site, fixed laboratory or an on-site mobile laboratory, the laboratory must provide adequate and complete Quality Assurance and Quality Control (QA/QC) data for each analysis. QA/QC data should be developed in accordance with the provisions of the analytical method used or as stipulated in SW-846.

C.8 Documentation of Soil Gas Sampling Event.

C.8.1 Soil gas investigation report.

A. A soil gas investigation report that includes a discussion of field operations, any deviations from this protocol, data inconsistencies, soil gas sampling results, calculation of representative soil gas COC concentrations, other significant procedural and analytical details, and conclusions and recommendations must be prepared and submitted to MDNR. The report may be included as part of a risk assessment report.

B. At a minimum, the soil gas investigation report must contain the following:

- A site plan map, a map identifying soil gas probe locations, and a map showing soil and groundwater contamination relative to the locations of the soil gas probes and any current and known future structures.
- A site map on which soil gas concentration data has been plotted. The map must be at the same scale as the maps discussed above.
- A narrative description of probe installation and sampling procedures, including leak check testing.
- Analytical data summary tables.
- Laboratory data sheets.
- A table showing applicable target levels and, if target levels are calculated at Tier 2, appropriate documentation showing how the site-specific target levels were calculated.
- A narrative discussion of analytical results, including a comparison of soil gas sampling results to soil vapor target levels.
- If data was collected to demonstrate whether and to what degree COC vapors are biodegrading, all relevant supporting data plus a narrative interpretation of the data must be included[4].
- Legible copies of field forms, logs, and associated notes pertinent to probe installation and soil gas sampling.

[4] An investigation of biodegradation must include soil gas samples collected at multiple depths from the same sampling location. In addition to sampling for COCs at each depth, samples shall also be collected for analysis of oxygen and carbon dioxide concentrations.

- As-built diagrams of probes or wells showing overall construction and the depth at which samples were collected.
- QA/QC data.
- Conclusions and recommendations.

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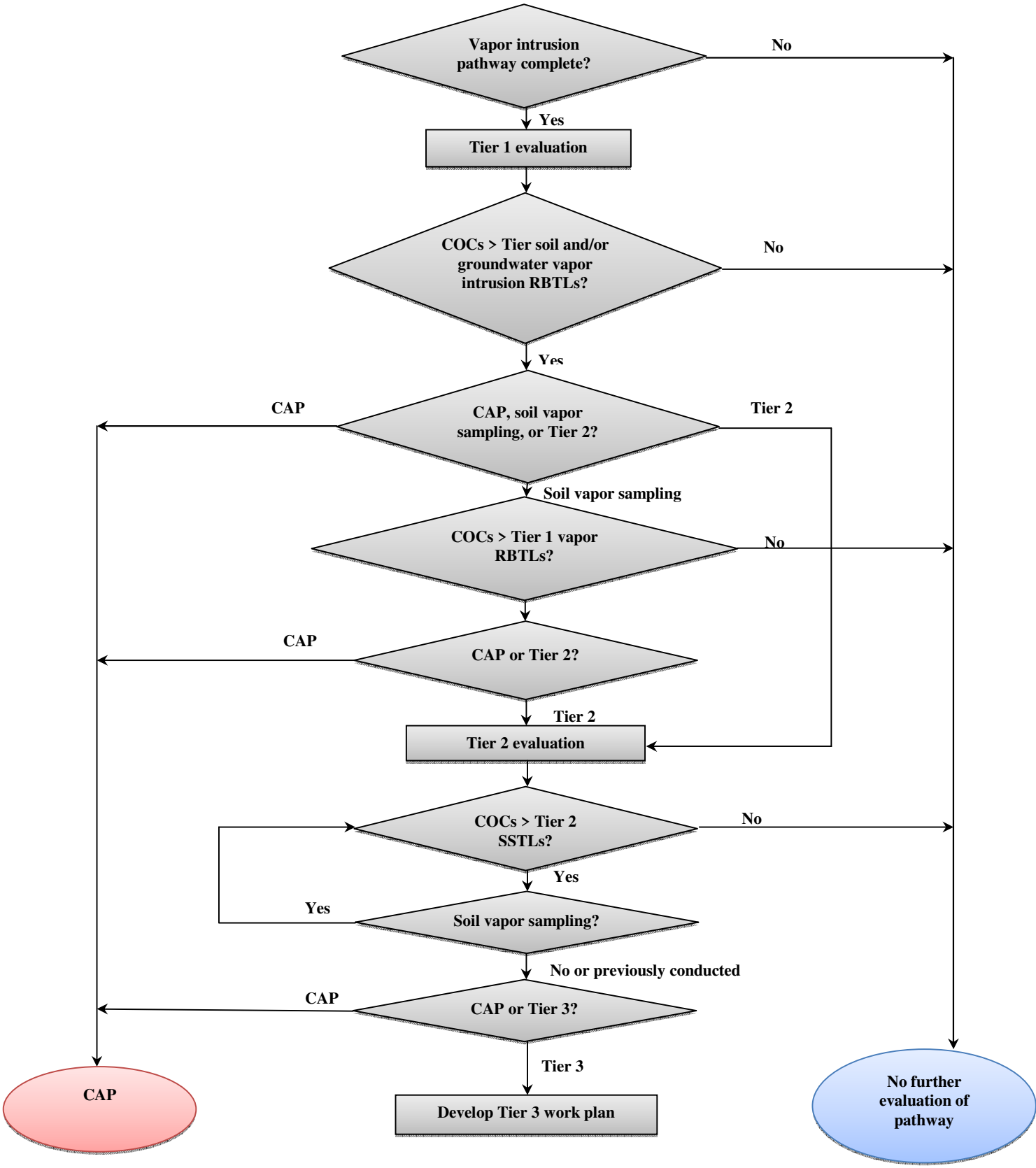
FIGURES



CAP: Corrective Action Plan
RBTL: Risk-Based Target Level
SSTL: Site-Specific Target Level

Figure C-1. Flowchart for Vapor Intrusion

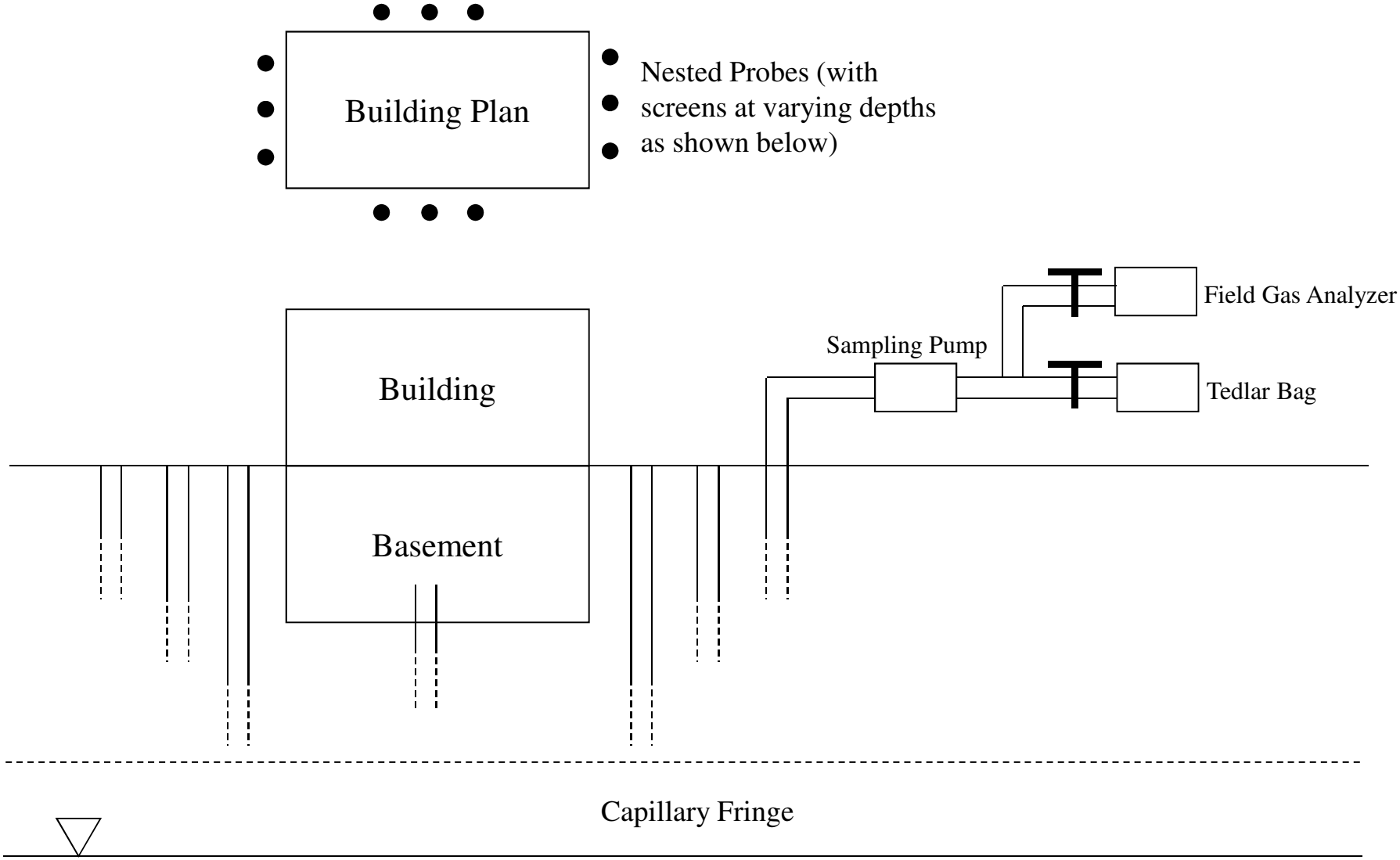


Figure C-2. Location of Nested Soil Gas Probes

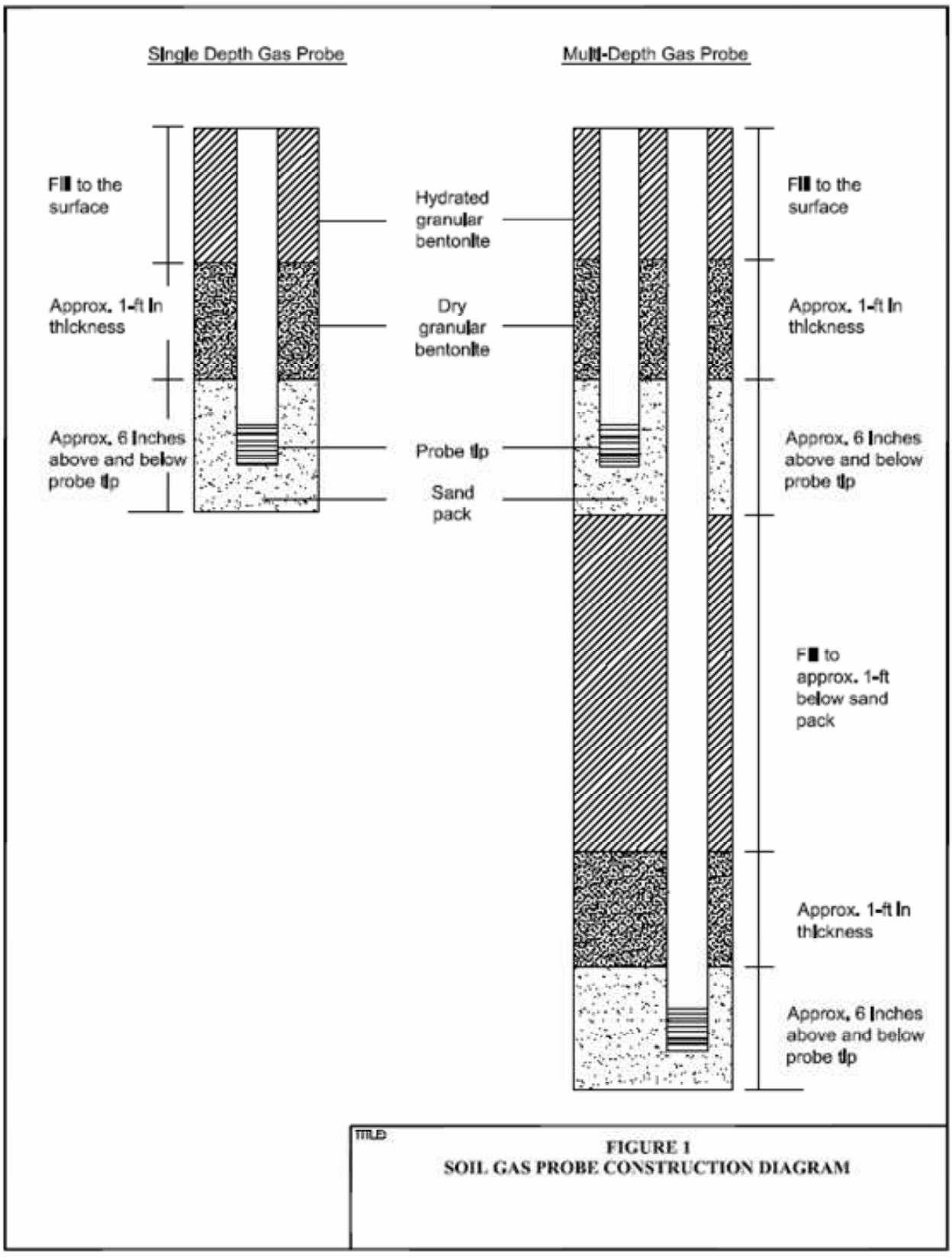


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FIGURE 1
SOIL GAS PROBE CONSTRUCTION DIAGRAM

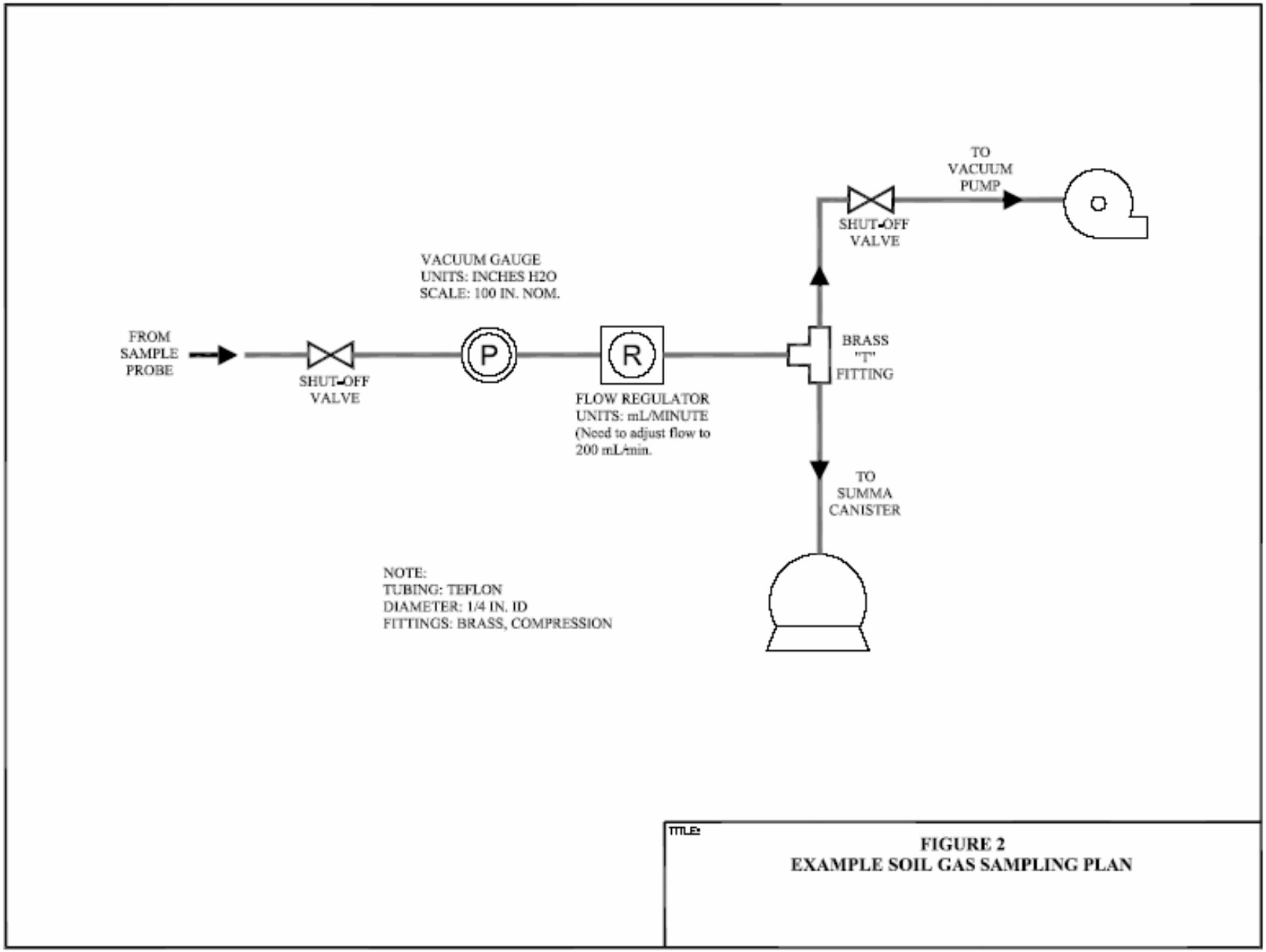

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FIGURE 2
EXAMPLE SOIL GAS SAMPLING PLAN

Figure 3
Example Soil Gas Sampling Form

Date		Sampler	
Client		Project#:	
Container Type:		Container ID:	
Sample ID:			
Weather Conditions:	Temperature: Precipitation:		
Sampling Device:			
Purge Start Time:		End Time:	
Sample Start Time:		End Time:	
Canister start pressure:		End pressure:	
Volume gas extracted:			

Field Measurements

Time	Flow (mL/min)	Pressure (in H20)	Comments

Comments:

ATTACHMENT

Draft

Standard Operating Procedure (SOP) for Installation of Sub-Slab Vapor Probes and Sampling Using EPA Method TO-15 to Support Vapor Intrusion Investigations

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Background

Vapor intrusion is defined as vapor phase migration of volatile organic and/or inorganic compounds into occupied buildings from underlying contaminated ground water and/or soil. Until recently, this transport pathway was not routinely considered in RCRA, CERCLA, or UST investigations. Therefore the number of buildings or homes where vapor intrusion has occurred or is occurring is undefined. However, considering the vast number of current and former industrial, commercial, and waste processing facilities in the United States capable of causing volatile organic or inorganic ground-water or soil contamination, contaminant exposure via vapor intrusion could pose a significant risk to the public. Also, consideration of this transport pathway may necessitate review of remedial decisions at RCRA and CERCLA sites as well as implementation of risk-reduction technologies at Brownsfield sites where future development and subsequent potential exposure may occur. EPA's Office of Solid Waste and Emergency Response (OSWER) recently (2002) developed guidance to facilitate assessment of vapor intrusion at sites regulated by RCRA and CERCLA where halogenated organic compounds constitute the bulk of risk to human health. EPA's Office of Underground Storage Tanks (OUST) is considering modifying this guidance to include underground storage tank sites where petroleum compounds primarily determine risk and biodegradation in subsurface media may be a dominant fate process.

The OSWER guidance recommends indoor air and sub-slab gas sampling in potentially affected buildings at sites containing elevated levels of soil-gas and ground-water contamination. To support the guidance and improve site-characterization and data interpretation methods to assess vapor intrusion, EPA's Office or Research and Development is developing a protocol for sub-slab gas sampling. When used in conjunction with indoor air, outdoor air, and soil gas and/or ground-water sampling, sub-slab gas sampling can be used to differentiate indoor and outdoor sources of volatile organic and/or inorganic compounds from compounds emanating from contaminated subsurface media. This information can then be used to assess the need for sub-slab depressurization or other risk-reduction technologies to reduce present or potential future indoor air contamination due to vapor intrusion.

Sub-Slab Vapor Probe Construction and Installation

1. Prior to drilling holes in a foundation or slab, contact local utility companies to identify and mark utilities coming into the building from the outside (e.g., gas, water, sewer, refrigerant, and electrical lines). Consult with a local electrician and plumber to identify the location of utilities inside the building.

2. Prior to fabrication of sub-slab vapor probes, drill a pilot hole to assess the thickness of a slab. As illustrated in **Figure 1**, use a rotary hammer drill to create a "shallow" (e.g., 2.5 cm or 1 in) "outer" hole (e.g., 2.2 cm or 7/8 in diameter) that partially penetrates the slab. Use a small portable vacuum cleaner to remove cuttings from the hole if penetration has not occurred. Removal of cuttings in this manner in a competent slab will not compromise sampling because of lack of pneumatic communication between sub-slab material and the source of vacuum.

3. Then use the rotary hammer drill to create a smaller diameter "inner" hole (e.g., 0.8 cm or 5/16 in) through the remainder of the slab and some depth (e.g., 7 to 8 cm or 3 in) into sub-slab material. **Figure 2** illustrates the appearance of "inner" and "outer" holes. Drilling into sub-slab material will create an open cavity which will prevent obstruction of

probes during sampling by small pieces of gravel.

4. The basic design of a sub-slab vapor probe is illustrated in **Figure 3**. Once the thickness of the slab is known, tubing should be cut to ensure that probes "float" in the slab to avoid obstruction of the probe with sub-slab material. Construct sub-slab vapor probes from small diameter (e.g., 0.64 cm or 1/4 in OD x 0.46 cm or 0.18 in ID) chromatography grade 316 stainless steel tubing and stainless-steel compression to thread fittings (e.g., 0.64 cm or 1/4 in OD x 0.32 cm or 1/8 in NPT Swagelok female thread connectors) as illustrated in **Figure 4**. Use of stainless-steel materials to ensure that construction materials are not a source of VOCs.

5. Set sub-slab vapor probes in holes. As illustrated in **Figure 5**, the top of the probes should be completed flush with the slab and have recessed stainless steel or brass plugs so as not interfere with day-to-day use of buildings. Mix a quick-drying portland cement which expands upon drying (to ensure a tight seal) with water to form a slurry and inject or push into the annular space between the probe and outside of the "outer" hole. Allow cement to cure for at least 24 hours prior to sampling.

6. Install at least 3 sub-slab vapor probes in each residence. As illustrated in **Figure 6**, create a schematic identifying the location of each sub-slab probe.

Sub-Slab Sampling

1. Connect dedicated a stainless-steel fitting and tubing (e.g., 1/8 in NPT to 1/4 in tube Swagelok fitting and 30 cm or 1 ft of 1/4 in I.D. Teflon tubing to a sub-slab vapor probe as illustrated in **Figure 7**. Use of dedicated fitting and tubing will avoid cross-contamination issues.

2. Connect the Teflon tubing to 1/4" ID Masterflex (e.g., 1.4 in ID high performance Tygon LFL) tubing and a peristaltic pump and 1-L Tedlar bag as illustrated in **Figure 8**. Use of a peristaltic pump will ensure that sampled air does not circulate through a pump causing potential cross contamination and leakage.

3. Purge vapor probe by filling two dedicated 1-L Tedlar bags. The internal volume of sub-slab probes is insignificant (< 5 cm^3). A purge volume of 2 L was chosen based on the assumption of a 0.64 cm (1/4") air space beneath a slab and an affected sample diameter of 0.61 m (2 ft).

4. Use a portable landfill gas meter to analyze for O_2, CO_2 and CH_4 in Tedlar bags as illustrated in **Figure 9**.

5. Collect sub-slab vapor samples in evacuated 10% or 100% certified 1-L Summa polished canisters and dedicated particulate filters as illustrated in **Figure 10**. Check vacuum in canisters prior to sampling. Sampling will cease when canister pressure reaches atmospheric pressure. Submit canisters to a commercial laboratory for analysis by EPA Method TO-15.

6. Collect at least one duplicate sub-slab sample per building using dedicated stainless-steel tubing as illustrated in **Figure 11.**

Figure 1. Drilling through a slab

Figure 2. "inner and "outer

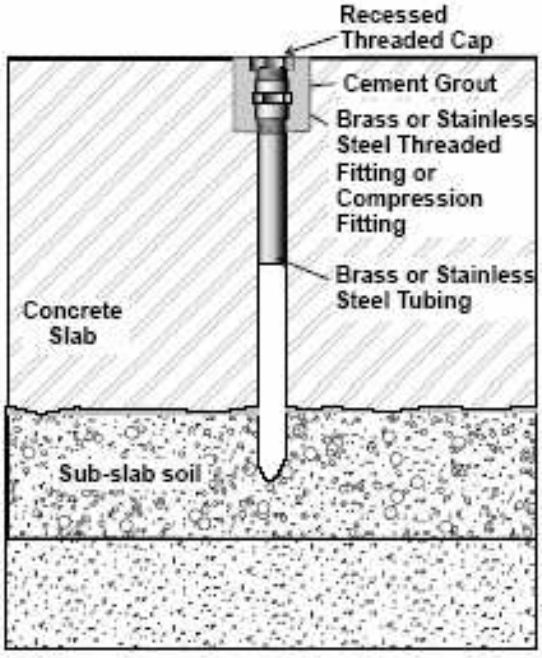

Figure 3. General schematic of sub-slab vapor probe

Figure 4. Stainless steel sub-slab vapor probe components

Figure 5. Competed vapor probe installation

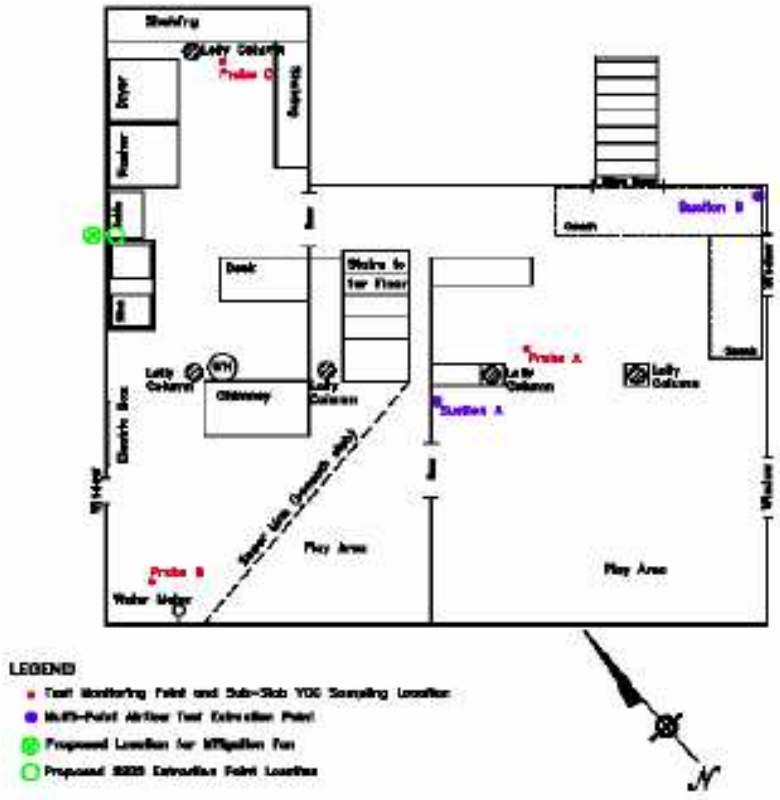

Figure 6. Schematic illustration location of vapor probes in a basement

Figure 7. Compression fitting to probe

Figure 8. Purge prior to sampling

Figure 9. Analysis of O2, CO2, and CH4

Figure 10. Sampling in 1-L evacuated canister for TO-15 analysis

Figure 11. Collection of duplicate sample

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APPENDIX D
A METHOD FOR DETERMINING IF A WATER BEARING UNIT SHOULD BE CONSIDERED AN AQUIFER

A METHOD FOR DETERMINING IF A WATER BEARING UNIT SHOULD BE CONSIDERED AN AQUIFER

Several criteria must be met for a water-bearing zone to be considered a potentially usable aquifer. First, the water quality must be such that consuming the water does not pose an immediate or long-term risk to human health. Second, the water-bearing materials must yield at least enough water to serve a useful purpose. Realistically, if the water-bearing materials cannot adequately supply a single household then it is doubtful if they would be considered an aquifer. Two factors controlling the volume of groundwater that can be produced from water-bearing materials are the hydraulic conductivity and the saturated thickness of the potential aquifer. It is necessary for both of these factors to be considered. The greater the hydraulic conductivity of the water-bearing materials, the greater the yield potential. However, a thick sequence of low hydraulic conductivity materials may actually yield more water than a thinner unit having a much higher hydraulic conductivity.

The technique described below was developed to aid in determining if a water-bearing unit should be considered an aquifer. A series of calculations were made based on several assumptions. It was assumed that, to be considered a viable water supply, a well would need to be able to produce a minimum of 0.25 gallons of water per minute (360 gallons per day) for a period of 10 days. The calculated drawdown at the well at the end of this period could not exceed one-third of the saturated thickness of the water-bearing unit. A storage coefficient of 0.001 was assumed. The well was assumed to have an efficiency of 100 percent. The Theis nonequilibrium well equation (a.k.a., nonleaky artesian formula) was used to calculate the aquifer transmissivity necessary to meet these parameters for aquifer thickness between 10 to 200 feet. Hydraulic conductivity values were determined by dividing the calculated transmissivity values by the full saturated thickness.

The calculated hydraulic conductivity values were plotted against the saturated thickness of the aquifer (see attached graph). The data plotted as a power function. A curve-fitting program was applied to derive an empirical equation that best fits the line. The equation is:

$$K = b^{-2.04} \times 1447 \quad \text{(equation 1)}$$

Where: K = hydraulic conductivity (gpd/ft^2)
b = aquifer saturated thickness (feet)

If the saturated thickness of the water-bearing zone under consideration is known, then the equation can be used to calculate the average hydraulic conductivity that will be necessary to meet the minimum aquifer requirements listed above. Conversely, if a representative value for the hydraulic conductivity has been determined, then the equation can be re-written to determine the minimum saturated thickness that will be needed to meet the minimum aquifer requirements shown above. That equation is:

$$b = K^{-0.496} \text{ X } 35.33 \quad \text{(equation 2)}$$

Where: K = hydraulic conductivity (gpd/ft^2)
b = aquifer saturated thickness (feet)

Hydraulic conductivity values in units of gpd/ft^2 and ft/day are commonly used in the water supply field but are not widely used in environmental work where hydraulic conductivity values are typically reported in units of cm/sec. To convert a hydraulic conductivity value measured in gpd/ft^2 to cm/sec, multiply it by 4.72 x 10^{-5}.

Below are two examples:

Test drilling and slug tests show that a water-saturated sandy silt has a hydraulic conductivity of 2.5 x 10^{-4} cm/sec. A thick clay unit underlies the materials, and the saturated thickness of the sandy silt unit is 23 feet. Does it meet the criteria necessary to be considered a potentially usable aquifer?

We will assume the water quality meets minimum requirements for potability. A hydraulic conductivity of 2.5 x 10^{-4} cm/sec is equal to 3.2 gpd/ft. With this hydraulic conductivity, the minimum saturated thickness needed is:

$3.2^{-0.496}$ x 35.33 or 19.8 feet

Based on the above, the zone would be considered a potentially usable aquifer.

Test drilling below a site shows 80 feet of fairly uniform sandy clay till. What would be the minimum average hydraulic conductivity necessary for this material to comprise an aquifer?

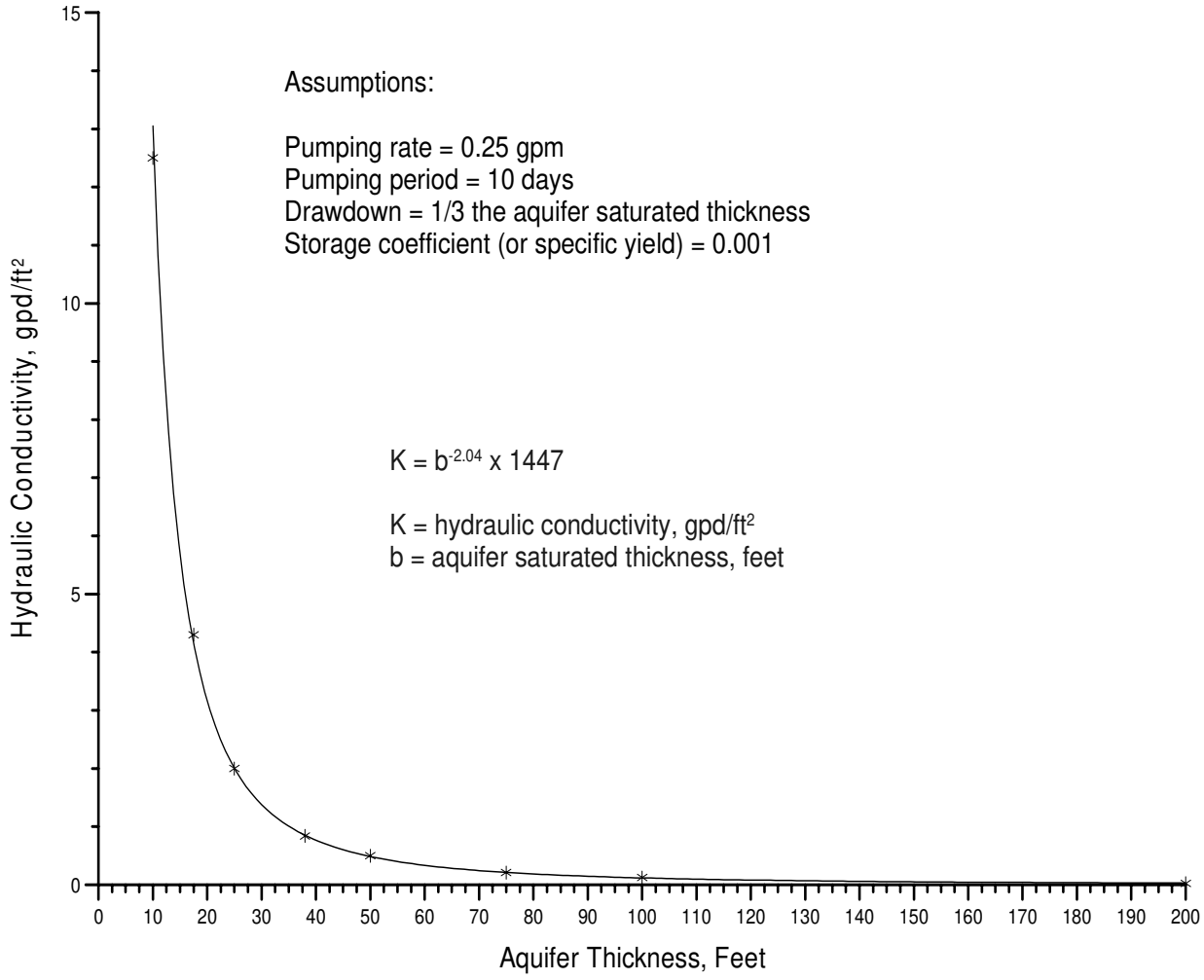
$K = 80^{-2.04}$ x 1447
K = 0.19 gpd/ft^2 or 1.47 x 10^{-5} cm/sec

Based on this technique, 80 feet of sandy clay till having an average hydraulic conductivity of 1.47 x 10^{-5} cm/sec (or 0.19 gpd/ft^2) would be considered a usable aquifer.

Changing any of the aquifer parameters and yield assumptions listed above would, of course, change equations 1 and 2 above. Some argument could be made as to the assumed pumping period of 10 days. Perhaps a pumping period of 1 day might seem more appropriate. However, it must be remembered that the Theis nonequilibrium equation assumes confined (artesian) conditions. For it to be entirely valid, the saturated thickness of the aquifer must remain essentially unchanged. The drawdown must not lower the potentiometric surface an appreciable distance below the top of the aquifer. Most shallow aquifers that will be considered under this rule will likely be unconfined. As drawdown occurs in an unconfined aquifer, the saturated thickness of the aquifer within the drawdown cone decreases. Thus, the transmissivity (which is the product of the hydraulic conductivity and the saturated thickness) also decreases. Reducing the saturated thickness of an unconfined aquifer by one-third will reduce its transmissivity proportionally. Because of this, the assumed drawdown of one-third the aquifer thickness is probably optimistic for an unconfined aquifer. The actual drawdown will be somewhat larger if the well is actually pumped 0.25 gpm for 10 days. If a shorter

pumping period is selected for consideration, then the allowable drawdown should be changed from one-third the saturated thickness of the aquifer to a more conservative value, such as 10 percent of the saturated thickness of the aquifer.

Jim Vandike


Assumptions:
Pumping rate = 0.25 gpm
Pumping period = 10 days
Drawdown = 1/3 the aquifer saturated thickness
Storage coefficient (or specific yield) = 0.001
K = b-2.04 x 1447
K = hydraulic conductivity, gpd/ft2
b = aquifer saturated thickness, feet
Hydraulic Conductivity, gpd/ft2
Aquifer Thickness, Feet
0
5
10
15
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140 150 160 170 180 190 200

APPENDIX E
ESTIMATION OF REPRESENTATIVE SOIL AND GROUNDWATER CONCENTRATIONS

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E.1 BACKGROUND

Application of the MRBCA process results in the calculation of target levels for each complete pathway identified in the exposure model (EM) and each chemical of concern (COC). Risk management decisions require these target concentrations to be compared with appropriate representative concentrations for the site.

The calculation of representative concentrations is complicated by several factors. These include (i) spatial variability in the concentrations, (ii) temporal variability in the concentrations, and (iii) lack of sufficient site-specific concentration data. This appendix discusses the methodology used to estimate the representative concentrations for each complete route of exposure.

E.2 CALCULATION OF REPRESENTATIVE CONCENTRATIONS

E.2.1 Surficial Soil (0-3 feet below ground surface)

The MRBCA process requires the evaluation of two routes of exposure associated with surficial soil. These are (i) the ingestion of chemicals in groundwater due to leaching of residual chemicals present in the surficial soil, and (ii) accidental ingestion of soil, outdoor inhalation of vapors and particulate from surficial soil emissions, and dermal contact with surficial soil. These pathways are referred to as the protection of groundwater and the direct contact pathway, respectively. Thus two different surficial soil representative concentrations are required. Note, however, that, depending on use of the site and characteristics of the area of release, a single representative concentration might suffice for both pathways.

E.2.1.1 Representative Surficial Soil Concentration for Protection of Groundwater

The representative surficial soil concentration should be calculated using the surficial soil data collected within the release area. Thus, prior to calculating the representative concentration, it is necessary to (i) clearly locate the horizontal dimensions of the release area, and (ii) identify the surficial soil data available within the release area. Refer to Section 5.8.1 for a definition of the release area.

E.2.1.2 Representative Concentrations for Direct Contact Pathway

The representative surficial soil concentration has to be based on the receptor's exposure domain, that is, the area of the site over which the receptor might be exposed to the surficial soil. The exact domain of the receptor is difficult to estimate especially since the domain has to be representative of a period of time equal to the receptor's exposure duration. However, in the absence of specific information about the receptor's activities, the unpaved portion of a site should be considered as the receptor's domain. For potential future exposures, assume that the pavement will be removed and exposure to surficial soil will occur. In such a case, the entire site should be considered as the receptor's domain.

To calculate the representative concentration for the direct contact pathway, one must (i) estimate the receptor's domain(s), and (ii) determine the number of soil samples available within this domain or the number of samples necessary to represent the domain. For a non-resident or a construction worker, the average concentration over the domain may be used. For a child receptor, the maximum concentration must be used and, therefore, a representative concentration need not be calculated if a child is an actual or potential receptor.

E.2.2 Subsurface Soil (greater than 3 feet below ground surface)

The MRBCA process includes the following two routes of exposure associated with subsurface soil: (i) leaching of residual COC concentrations in the subsurface soil to groundwater, and (ii) indoor inhalation of vapor emissions. Thus, a representative concentration must be calculated for each complete pathway. Additional representative concentrations are required if the receptor's domain differs under current and future conditions.

E.2.2.1 Representative Subsurface Soil Concentration for Protection of Groundwater

The representative concentration for this pathway should be the average concentration in subsurface soil measured within the area of release.

E.2.2.2 Representative Subsurface Soil Concentration for Protection of Indoor Inhalation

Subsurface soil concentrations protective of indoor inhalation are estimated using the Johnson and Ettinger (2001) model, excluding the advection component. This model assumes that chemicals volatilize from the subsurface soil source, travel vertically upwards without any lateral or transverse spreading, and enter the building through cracks in the foundation and floor. To ensure consistency with the model, the representative concentration for this pathway should be based on soil concentrations measured directly below the footprint of the enclosed space.

To evaluate the potential future indoor inhalation pathway, (i.e., an enclosed structure is constructed over contaminated soil), the size (footprint) and location of a hypothetical structure must be estimated. In the absence of site-specific information regarding planned structures, the future location and size of the structure must be approximated based on the evaluator's professional judgement. A conservative option is to locate the hypothetical structure over the area or release (i.e., the area of maximum COC concentrations). For tank sites, the default size of this structure is 30 ft by 30 ft. For sites where the footprint of a current on-site structure is or might be different from that of a structure erected in the future, a representative subsurface soil concentration must be calculated for both the current and potential future structure.

To estimate the representative subsurface soil concentration for the indoor inhalation pathway, the evaluator must: (i) identify the footprint of the structure within which the receptor is located, (ii) identify the footprint of the potential future enclosed structure, (iii) identify the soil concentration data available within each of these two footprints, and (iv) calculate the average of these concentrations. If sufficient data are not available within the footprint, data collected within 10 ft of the footprint may be used. In no case may data collected more than 10 ft away from the footprint be used.

If several samples within and adjacent to the footprint are available, more weight should be given to the samples collected within and close to the footprint. Two scenarios are possible: (i) the building footprint is located entirely within the contaminated area, and (ii) the building footprint is partially located within the contaminated area. For both scenarios, the representative soil concentration should be based on data collected within and no more than 10 ft. from the footprint of the building. In the second scenario, the representative concentration is effectively reduced because a portion of the structure lies over unimpacted soil.

E.2.3 Representative Concentration for Construction Worker

The MRBCA process requires the evaluation of the following three routes of exposure for the construction worker: (i) accidental ingestion, dermal contact, and outdoor inhalation of vapors and particulates from soil, (ii) outdoor inhalation of vapors from groundwater, and (iii) dermal contact with groundwater. Thus three representative concentrations are required. Each of these is discussed below.

E.2.3.1 Representative Soil Concentration

For the construction worker, no distinction is made between surficial and subsurface soil because, during construction, the construction worker might be exposed to both. To estimate the representative concentration for the construction worker, it is necessary to identify the (i) depth of construction, (ii) areal extent of construction, and (iii) the number of samples within the zone of construction. The potential future depth of construction should be estimated based on the likely type of structure that might be built and by identifying 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. The representative concentration would be the averaged concentration within this zone of construction.

E.2.3.2 Representative Groundwater Concentration

As in the case of estimating representative groundwater concentrations, it is necessary to estimate the areal extent of the construction zone and identify the groundwater data available for this zone. The representative concentration would then be calculated as the average concentration within this zone. Temporal variations in groundwater concentrations should be evaluated as discussed in Section E.2.4.1.

E.2.4 Groundwater

The MRBCA process requires the evaluation of the following three routes of exposure associated with shallow groundwater: (i) ingestion of groundwater, (ii) dermal contact with groundwater, and (iii) indoor inhalation of vapor emissions from groundwater. Where multiple aquifers are present, the shallowest aquifer would be considered for the volatilization pathway. The specific aquifers that are or might be used for domestic use or in another manner in which dermal contact could occur must be considered for the ingestion and dermal contact pathways. Representative concentrations must be calculated for each aquifer this is or is reasonably likely to be used for domestic purposes. Thus, at least three different groundwater representative concentrations, one for each compete pathway, must be calculated.

E.2.4.1 Representative Demonstration Well Concentration for Protection of Groundwater Ingestion (Drinking Water Pathway)

For the ingestion of groundwater pathway, maximum contaminant levels (MCLs) or, where MCLs are lacking, other literature or calculated risk-based concentrations must be met at the point of exposure (POE) well. Often the point of exposure well is hypothetical and, therefore, data for the POE might not be available. In addition, one or more point of demonstration (POD) wells must be identified and target concentrations must be calculated for these wells.

The representative concentration at the POD or POE should be calculated based on measured COC concentrations, as discussed below:

- If COC 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 COC 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 (6 months) on at least a quarterly basis.

E.2.4.2 Representative Groundwater Concentration for Protection of Indoor Inhalation

Groundwater concentrations protective of indoor inhalation are estimated using the Johnson and Ettinger (2001) model (without the advection component). This model assumes no lateral or transverse spreading of the vapors as they migrate upward from the water table through the capillary fringe and the vadose zone and into the enclosed space. Thus, representative concentrations for this pathway should be based on groundwater concentrations measured within the footprint of the building. Refer to Section E.2.2.2 for a discussion of the evaluation of future structures and their relationship to the impacted area.

For the groundwater to indoor air pathway, multiple representative concentrations might be needed if the plume has migrated below several current or potential future buildings. For example, if a plume has migrated or is likely to migrate below two different buildings, one on-site and one off-site, representative concentrations would have to be calculated for each.

Since the target groundwater concentrations for this pathway are based on the assumption of no lateral or transverse spreading of the vapors as they diffuse upwards to the building, the representative concentrations should be based on data collected within the footprint(s) of the structure(s). After identifying the location of the building footprints (whether real or hypothetical) and the available groundwater monitoring data within or adjacent to each footprint, the average concentration within each footprint must be estimated, as discussed in Section E.2.2.2. However groundwater data might not be available for each footprint, in which case it would be reasonable to install additional monitoring wells within the footprint lacking data, interpolate data between existing wells, or, as a conservative approach, use data from upgradient wells. (Note: In the case where the plume originates under a building, extrapolated data gathered from areas adjacent to the footprint might not be adequate.)

E.2.4.3 Representative Groundwater Concentration for Dermal Contact

The average concentration of COCs in the groundwater that a receptor might come in contact with is used as the representative concentration. Note that temporal variations in COC concentrations will be considered as discussed in Section E.3. More than one representative concentration might be needed where a receptor might contact groundwater from more than one aquifer or saturated zone.

E.3 GENERAL CONSIDERATIONS FOR CALCULATING REPRESENTATIVE CONCENTRATIONS

Calculating representative concentrations requires considerable professional judgement. Prior to performing the computations identified in Section E.2, the following should be considered:

- Evaluate whether the spatial resolution of the data is sufficient. While an exact number of samples cannot be specified herein due to the variability in conditions from site to site, data should be available from known or likely release areas and the various receptors' exposure domains.
- If the data are "old" (> 4 years old) and the COC concentrations exceed the Tier 1 risk-based target levels (RBTLs), or if a new spill has been documented or is suspected, new data should be collected. If sufficient new data are collected, the new data may be used for risk evaluation and the old data disregarded. A new release will always require the collection of additional data.
- Non-detect soil samples located at the periphery of the exposure domain of interest shall not be used.

- Non-detect samples located within the exposure domain of interest shall be replaced by half the detection limit.
- If multiple surficial soil samples and/or multiple subsurface soil samples are available from the same borehole within the domain of interest, the average concentration of these samples may be used.
- The maximum concentration of any COC may not exceed ten times the representative concentration. If this situation occurs, further evaluation and, potentially, remediation, will be required by MDNR.

The following considerations are necessary to evaluate representative groundwater concentrations:

- To account for temporal variations in groundwater concentrations, the representative concentration in a well may be estimated as:

    - For a demonstration well where the plume is stable or shrinking, the representative concentration is the arithmetic average of the most recent one to three year's measurements, provided that the measurements account for seasonal variation. When calculating the arithmetic average, any concentration below detection limits shall be replaced by half the detection limit.
    - Data from wells on the periphery of the exposure domain having COC concentrations consistently below detection limits shall not be used.

- For wells that contain or have contained free product within the most recent two years, the concentration representative of the well should be the effective solubility of the various chemicals representing the free product in the well. Table B-5 lists the effective solubility of selected chemicals in gasoline, diesel, and jet fuel.

Table E-1
Calculation of Representative Concentrations

Route of Exposure	Calculation of Representative Concentration
Surficial Soil (0-3 ft bgs)	
Soil concentration protective of leaching to groundwater or surface water body	Average of the surface soil concentrations collected within the area of release.
Direct contact with soil including ingestion of soil, dermal contact with soil, and the outdoor inhalation of vapors and particulates emitted by surficial soils	Average of the surface soil concentrations within exposure domain for non-residential receptor. Maximum concentration for residential receptor.
Subsurface Soil (> 3 ft bgs)	
Indoor inhalation of vapor emissions	Average of the subsurface soil concentrations collected below or within 10 ft of the real or hypothetical footprint of the building (Excluding concentrations below water table and capillary fringe).
Soil concentration protective of leaching to groundwater	Average of the subsurface soil concentration within the area of release (Excluding concentrations below water table and capillary fringe).
Groundwater	
Indoor inhalation of vapor emissions	Average of the groundwater concentrations around the footprint of the real or hypothetical building
Dermal contact with groundwater	Average of the groundwater concentrations that a receptor may come in contact with
Groundwater domestic use pathway	
• Concentration at POE	Average of the groundwater concentrations*
• Concentration at POD	Average of the groundwater concentrations*

* If the measured concentrations are stable, the representative concentration is the arithmetic average of the most recent eight consecutive measurements, of which no two shall be less than three months apart. If the measured concentrations are decreasing, the representative concentration is the arithmetic average of the most recent six consecutive measurements, of which no two shall be less than three months apart.

APPENDIX F
CONSIDERATION OF TOTAL PETROLEUM HYDROCARBONS WITHIN THE MRBCA PROCESS

Page

F.1 INTRODUCTION **F-2**

F.2 DEVELOPMENT OF TARGET LEVELS FOR TPH-GRO, TPH-DRO, AND TPH-ORO **F-2**

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F.2.2 Physical and Chemical Properties of Various Fractions F-4
F.2.3 Development of Target Levels F-4

F.3 SITE-SPECIFIC IMPLEMENTATION OF THIS APPROACH **F-4**

F.4 ANALYSIS OF SPECIFIED PETROLEUM CARBON FRACTIONS **F-5**

Table F-1 Constituent Fraction of TPH Groups

F.1 INTRODUCTION

Petroleum compounds contain a mixture of several hundred chemicals ranging from light, volatile, short chained organic compounds to heavy, long chained, branched compounds. These various compounds exhibit a range of physical, chemical, and toxicological properties. However, the properties of several of these compounds are not known and, therefore, calculating risk-based target levels for them is not possible. Further, analyzing the concentration of each of these compounds in the environmental media affected by a petroleum release is not practical. Thus a variety of methods have been developed to identify key constituents of the products and to estimate media-specific target levels for these constituents. These methods include:

1. Development of target levels for total petroleum hydrocarbons (TPH),
2. Development of target levels for specified ranges of petroleum hydrocarbons, e.g. TPH-GRO (gasoline range organics), TPH-DRO (diesel range organics), and TPH-ORO (oil range organics),
3. Development of target levels for a few constituents, (those considered most toxic and for which sufficient data are available), e.g. benzene, toluene, ethylbenzene, xylenes, naphthalene, and polynuclear aromatic hydrocarbons (PAHs),
4. Development of target levels for a specified size range of aromatic and aliphatic fractions, e.g. aliphatics >C6-C8, aliphatics >C8-C10, aromatics >C10-C12, etc., and
5. A combination of the above approaches.

MDNR has determined that petroleum hydrocarbon impacts will be evaluated using the following approach:

- Depending on the product released, indicator chemicals (i.e., chemicals of concern or COCs) will be selected from Table 5-1 and analyzed using the method indicated in Table 5-1.
- All soil and groundwater samples will be analyzed for TPH-GRO using SW-846 Method 8260 and for TPH-DRO and TPH-ORO using SW-846 Method 8270.
- If the product released is not known, the relative concentrations of TPH-GRO, TPH-DRO, and TPH-ORO can be used to identify the product that has been released and to select the relevant COCs from Table 5-1.

As appropriate on a case-by-case basis and as further discussed in section F.4 below, selected samples may also be analyzed for specified petroleum carbon fractions. Site-specific application of this method requires pre-approval by MDNR.

F.2 DEVELOPMENT OF TARGET LEVELS FOR TPH-GRO, TPH-DRO, AND TPH-ORO

As mentioned in Section 6.2, development of target levels requires the following information:

- Target risk level for carcinogenic and non-carcinogenic adverse health effects. For specific discussion, refer to Section 6.2.1 and Appendix B.1. Note that, currently, TPH-GRO, TPH-DRO, and TPH-ORO fractions are evaluated for non-carcinogenic effects only.
- Quantitative toxicity values for each fraction range. These are presented in Table B-1 and discussed in Section 6.2.2 and at B.2 of Appendix B.
- Fraction-specific physical and chemical properties. These are presented in Table B-2 and discussed in Section 6.2.5 and at B.3 of Appendix B.
- Receptor-specific exposure factors. These are presented in Table B-3 and discussed in Section 6.2.3 and at B.4 of Appendix B.
- Fate and transport parameters. These are presented in Table B-4 and discussed in Section 6.2.4 and at B.5 of Appendix B.
- Intake equations and fate and transport models. For specific discussion, refer to Section 6.2.6 and at B.6 of Appendix B.

The overall approach for developing target levels for each petroleum fraction is the same as that described in Appendix B, except for the chemical-specific properties discussed below.

F.2.1 Toxicological Properties of Various Fractions

Table B-1 lists the toxicological properties of the petroleum fractions that are necessary to develop target levels for TPH-GRO, TPH-DRO, and TPH-ORO. These values have been obtained from Toxicity Factors Table for Texas Risk Reduction Program Rule (March 31, 2003).

F.2.2 Physical and Chemical Properties of Various Fractions

Table B-2 lists the chemical-specific properties of the petroleum fractions that are necessary to develop target levels for TPH-GRO, TPH-DRO, and TPH-ORO. These values have been obtained from Chemical/Physical Properties Table for Texas Risk Reduction Program Rule (March 31, 2003).

F.2.3 Development of Target Levels

Table F-1 lists the aromatic and aliphatic fractions included in the TPH groups TPH-GRO, TPH-DRO, and TPH-ORO. These fractions are consistent with the chosen analytical methods, though they may not be consistent with other methods used to analyze TPH-GRO, TPH-DRO, and TPH-ORO. Therefore, for TPH analyses, consultants and laboratories should use Methods 8260 and 8270 and the ranges specified in this document.

Risk-based target levels for TPH-GRO, TPH-DRO, and TPH-ORO are developed using the following steps:

Step 1: Calculate target levels for individual TPH fractions within the group. These fractions are listed in Table F-1. (Each TPH fraction is treated as an individual chemical and the computation software is set up to calculate target levels for each fraction.)

Step 2: Add the target levels calculated at Step 1 for each fraction within a TPH group to obtain the target level for that particular TPH group.

Step 3: In Step 1, if the target levels for all the fractions within a particular TPH group exceeded the theoretical maximum concentration (soil saturation for soil and solubility for groundwater), the target level calculated in Step 2 for that particular group is assumed to exceed the theoretical maximum concentration.

The computation software performs the above steps so that TPH-GRO, TPH-DRO, and TPH-ORO target levels as well as the levels for individual fractions will be generated and displayed. The calculated Tier 1 target levels are tabulated in Tables 7-1 through 7-6(c).

F.3 SITE-SPECIFIC IMPLEMENTATION OF THIS APPROACH

For Tier 1 and Tier 2 evaluations, the evaluator should collect and analyze soil and groundwater samples to determine the concentrations of the three TPH groups using Method 8260 for TPH-GRO and Method 8270 for TPH-DRO and TPH-ORO. Samples should be analyzed using the methods indicated in Table 5-1. Since the measured value of TPH-GRO includes the concentration of BTEX, the total BTEX concentration should be subtracted from the TPH-GRO concentration prior to comparing the TPH-GRO value with Tier 1 and Tier 2 target levels. This correction will ensure that comparison of the measured and target values are consistent with the assumptions used to estimate the Tier 1 and Tier 2 target levels. The measurement of TPH-GRO, TPH-DRO, and TPH-ORO may also be affected by the presence of polar compounds naturally present in the subsurface (e.g. leafwax and biodegradation products such as carboxylic acids). If possible, these polar compounds should be removed prior to analysis using a silica gel or alumina column.

For Tier 3 risk assessment, the person performing the MRBCA evaluation may either compute target levels for (i) the three TPH fractions, or (ii) individual aromatic and aliphatic carbon fractions listed in Table F-1. If the latter approach is used, soil and groundwater concentrations shall be analyzed using Methods 8260 and/or 8270.

F.4 Analysis of Specified Petroleum Carbon Fractions

Petroleum carbon fraction analysis is a Tier 3 activity and shall be by Texas Natural Resource Conservation Commission (TNRCC) Method 1006[1] or another method approved by the Department.

Analytical methods are available to identify and quantify the specific petroleum carbon fractions listed in Table F-1 of this appendix. The resulting data can be useful in characterizing the type of petroleum detected; evaluating compositional changes due to chemical, physical, and biological attenuation processes; and assessing risk.

[1] TNRCC Method 1006 may not be used for the analysis of individual chemicals of concern other than carbon fractions. Individual chemicals of concern shall be analyzed by the methods listed in Table 5-1 of this guidance.

Table F-1
Constituent Fraction of TPH Groups

TPH Group	TPH Fractions	
	Aliphatics	Aromatics
TPH-GRO	>C6-C8 >C8-C10	>C8-C10
TPH-DRO	>C10-C12 >C12-C16 >C16-C35*	>C10-C12 >C12-C16 >C16-C21*
TPH-ORO	>C16-C35*	>C21-C35*

* The fate and transport and toxicity properties of the aliphatic fraction >C16-C35 used in the DRO calculation are identical to the properties of the aliphatic fraction >C16-C35 used in the ORO calculation. Likewise, the properties of the aromatic fraction >C16-C21 used in the DRO calculation are identical to the properties of the aromatic fraction >C21-C35 used in the ORO calculation. The target levels for these aliphatic and aromatic fractions are identical.