Montana Risk-Based Corrective Action Guidance for Petroleum Releases

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Risk-Based Corrective Action Guidance for Petroleum Releases			

Purpose:	The purpose of this document is to establish a risk-based approach to remediation of releases of petroleum products.
Scope:	This guidance applies to petroleum products, crude oil, and constituents of petroleum products and crude oil released into the environment.

Revision Date	Revision Description
August 2002	Leaching RBSL update
October 2003	Fraction toxicity update
October 2007	Exposure factor, toxicity, and leaching update
September 2009	Fraction toxicity update and removal of soil beneficial use RBSLs
September 2016	Exposure factor, toxicity, leaching, and text update; addition of Tier 2; see Executive Summary
May 2018	January 2017 benzo(a)pyrene toxicity update and May 2017 Montana DEQ-7 update; see Executive Summary

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Definitions and Acronyms

1 x 10^{-5} cancer risk – The added risk of one in 100,000 people developing cancer in their lifetime.

ARM – Administrative Rules of Montana

APH – Air phase hydrocarbon. The Massachusetts Method for analysis of the volatile petroleum hydrocarbon fractions in vapor samples.

AST – Aboveground storage tank used to store petroleum. Also see petroleum storage tank definition.

bgs – Below ground surface

BTEX – Benzene, toluene, ethylbenzene, and xylenes.

Carcinogen – A compound that the EPA has determined causes cancer based on the weight of peer-reviewed scientific evidence. Some carcinogens may also have non-carcinogenic effects.

Chemicals of concern (COCs) – Specific petroleum compounds that are identified for evaluation in a RBCA evaluation or a risk assessment.

Circular DEQ-7 – The Montana Numeric Water Quality Standards, applicable to state surface water and groundwater, adopted by rule and published by DEQ.

COC – See chemicals of concern.

Commercial/industrial property - Property used as a place of business with employees present with no one living on the property.

Conceptual site model (CSM) - A representation of the nature, fate and transport of releases that allows assessment of potential and/or actual exposure to contaminants.

Construction scenario - An exposure scenario based on the limited exposure of any individual to surface (0-2 feet below ground surface) and subsurface soils (2-10 feet below ground surface) during excavation.

Corrective action - Actions at a petroleum release that may include, but are not limited to, investigation, site assessment, emergency response, abatement, underground storage tank removal, cleanup, operation and maintenance of equipment, monitoring, reclamation, and termination of the corrective action.

CSM – See conceptual site model.

DAF – See dilution attenuation factor.

DCA 1,2 - See dichloroethane, 1,2.

DEQ - The Montana Department of Environmental Quality.

DEQ-7 - See Circular DEQ-7.

DGE – See down gradient edge.

Dibromoethane, 1,2- (also known as Ethylene dibromide - EDB) - Gasoline additive that was used until leaded gasoline was phased out. EDB may still be found in some leaded aviation gasoline.

Dichloroethane, 1,2- (1,2-DCA) - Leaded gasoline additive that was used until leaded gasoline was phased out. 1,2-DCA is still used as an industrial solvent and it may still be found in some leaded aviation gasoline.

Diesel range organics (DRO) – A lab analysis of petroleum hydrocarbons within the diesel range (C10 to C28). DRO was an accepted analytical method used to determine if a petroleum release was present at a level significant enough to require cleanup. DEQ ceased using DRO with the first RBCA publication in 1998 and uses Montana EPH instead.

Dilution attenuation factor (DAF) –The ratio of soil leachate concentration to the receptor concentration point. The DAF represents the reduction in concentration of a contaminant moving through soil and groundwater.

Down Gradient Edge (DGE) - A term established to describe a hypothetical monitoring well that could be constructed at the down gradient edge of the hypothetical contaminated source zone. This hypothetical well is used in the leaching model to calculate the worst-case groundwater contamination created from the hypothetical contaminant source to calculate RBSLs.

DRO - See diesel range organics.

EDB - See ethylene dibromide or 1,2-dibromoethane.

EPA - The United States Environmental Protection Agency.

EPH - See extractable petroleum hydrocarbons.

Ethylene dibromide (EDB) - See dibromoethane, 1,2.-

Exposure - The contact of a receptor with a chemical of concern.

Exposure pathway - The route a chemical or physical agent takes from a source to an exposed receptor. An exposure pathway describes the mechanism by which an individual or population is exposed to chemicals of concern at or originating from a release. Each exposure pathway includes a source, an exposure point, and an exposure route. If the exposure point differs from the source, a transport/exposure medium (e.g., air) or media (in cases of transfer between media) will also be included. Some examples of complete exposure pathways include:
- Inhalation of vapors from impacted soils by a person.
- Impacted soils leaching into potable groundwater and being used by a nearby resident for drinking and bathing.
- Inhalation of vapors by a neighbor resulting from the migration of contamination.
- Impacted groundwater discharging to wetlands or other surface water bodies.

Extractable petroleum hydrocarbons (EPH) - A group of petroleum hydrocarbons that includes the petroleum fractions typically found in diesel and other heavier petroleum products that are not analyzed and reported as specific compounds, like naphthalene. EPH is also the analytical method developed by the Massachusetts Department of Environmental Protection to determine the fractional composition of these compounds.

foc –See fraction organic carbon.

Fraction Organic Carbon (foc) – The fraction of organic carbon (%) in the media (soil/water/air) being evaluated.

Gasoline range organics (GRO) - A lab analysis of petroleum hydrocarbons within the gasoline range (C6 to C12). GRO was an accepted analytical method used to determine if a petroleum release was present at a level significant enough to require cleanup. DEQ ceased using GRO with the first RBCA publication in 1998 and uses Montana VPH instead.

GRO - See gasoline range organics.

H_2SO_4 – Sulfuric acid

Hazard index (HI) - The sum of hazard quotients for multiple substances and/or multiple exposure pathways.

Hazard quotient (HQ) - The ratio of the dose of a single substance related to exposure over a specified time period, to a reference dose for that substance derived from a similar exposure period.

HCl – Hydrochloric acid

HDPE – High-density polyethylene.

HHS – See Human Health Standard.

HI – See hazard index.

HQ – See hazard quotient.

Human Health Standard (HHS) – Standards for groundwater and surface water provided in Circular DEQ-7.

Lead scavengers - Compounds such as 1,2-DCA and EDB added to leaded gasoline to help volatilize or scavenge tetraethyl lead so it would not accumulate in the engine.

MBTEXN - Methyl tertiary-butyl ether, benzene, toluene, ethylbenzene, xylenes, and naphthalene. A set of compounds commonly found in gasoline.

MCA - Montana Code Annotated.

Methyl tertiary-butyl ether (MTBE) - A synthetic chemical formerly (1979 to 2005) added to commercial gasolines as an anti-knock additive or oxygenate.

MTBE - See methyl tertiary-butyl ether.

Non-carcinogen - A compound that the EPA has determined to have toxic effects, but has not determined to be a carcinogen. Some carcinogens may also have non-carcinogenic effects.

PAHs - See polycyclic aromatic hydrocarbons.

Petroleum or petroleum product - Crude oil or any fraction of crude oil that is liquid at standard conditions of temperature and pressure (60 degrees Fahrenheit and 14.7 pounds per square inch absolute) such as gasoline, fuel oil, diesel oil, lubricating oil, hydraulic fluids, oil sludge, or refuse, and any other petroleum related product or waste or fraction of the product or waste. The definition also includes additives that may be blended with the product to enhance its properties as a fuel or lubricant. Specific legal definitions relevant to the investigation of petroleum products may be found at § 75-10-302, MCA and § 75-10-701, MCA.

Petroleum release - A release of petroleum product into the environment, with "release" defined below.

Petroleum storage tank (PST) - A tank that contains or contained petroleum or petroleum products and that is: an underground storage tank defined in 75-11-503, MCA; a storage tank that is situated in an underground area, such as a basement, cellar, mine, drift, shaft, or tunnel; an aboveground storage tank (AST) with a capacity less than 30,000 gallons; including aboveground or underground pipes associated with these tanks. The definition of PST excludes pipelines regulated by the Natural Gas Pipeline Safety Act of 1968 (49 U.S.C. 1671, et seq.), the Hazardous Liquid Pipeline Safety Act of 1979 (49 U.S.C. 2001, et seq.), and comparable state laws, if the facility is intrastate (see § 75-11-302(21), MCA).

Polycyclic aromatic hydrocarbons (PAHs) - A group of petroleum hydrocarbons that includes several semivolatile compounds typically found in petroleum products, especially petroleum products that are heavier than diesel (Also referred to as polynuclear aromatic hydrocarbons).

ppb – Parts per billion.

ppm – Parts per million.

PPRTV – EPA Provisional Peer-Reviewed Toxicity Values

PST – See petroleum storage tank.

RBCA - See risk-based corrective action.

RBSL - See risk-based screening level.

RCRA – See Resource Conservation and Recovery Act.

RCRA metals - A group of eight heavy metals that are listed and monitored by RCRA because they are considered toxic even at low concentrations. These metals include arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), lead (Pb), mercury (Hg), selenium (Se), and silver (Ag).

Resource Conservation and Recovery Act – The federal law that creates the framework for the proper management of hazardous and non-hazardous solid waste. The law describes the waste management program mandated by Congress that gave EPA authority to develop the RCRA program. RCRA includes regulations associated with underground storage tanks.

Reasonably anticipated future uses - Likely future land or resource uses that take into consideration:
- local land and resource use regulations, ordinances, restrictions, or covenants;
- historical and anticipated uses of the site;
- patterns of development in the immediate area; and
- relevant indications of anticipated land use from the owner of the site and local planning officials.

Receptor - Any person, plant, or animal that is or could potentially be adversely affected by a petroleum release.

Regional Screening Levels (RSL) – Risk-based screening levels published by the EPA to screen chemicals at contaminated sites. RSLs are calculated using the latest toxicity values, default exposure assumptions and physical and chemical properties and are updated semi-annually.

Release - Any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing of petroleum or a petroleum product into the environment.

Residential property - Any property used as a temporary or permanent place of residence. Residential properties also used for businesses are considered residential (e.g., a farm or ranch or a gas station with an on-site residence). Residential properties that include other uses not defined here are evaluated on a case-by-case basis.

Resolved petroleum release – A categorization status used for petroleum releases meaning that DEQ has determined all cleanup requirements have been met and the conditions at the site ensure present and long-term protection of human health, safety and the environment as defined in §75-11-521(5), MCA (also called "closed"). For the purposes of this document, "resolved" can also refer to a suspected petroleum release that DEQ has determined did not release petroleum into the environment exceeding applicable RBSLs.

Risk-based corrective action (RBCA) - A decision-making process based on the protection of public health, safety, and welfare, and the environment, which results in the consistent assessment, remediation and/or resolving (closure) of petroleum releases.

Risk-based screening level (RBSL) - A chemical concentration considered acceptable for a given exposure scenario based on estimated risk to potential receptors.

RSL – See regional screening levels.

Soil Screening Levels (SSLs) – A risk-based concentration used for initial comparison of site soil data to identify contaminants of concern for leaching to groundwater.

SPLP – See Synthetic Precipitation Leaching Procedure.

SSL – See soil screening level.

Synthetic Precipitation Leaching Procedure (SPLP) – A sample preparation method developed to model an acid rain leaching environment. It is used for quantifying contaminant partitioning and mobility in site soils.

TEH – Total extractable hydrocarbons. The total amount of hydrocarbon compounds calculated in a petroleum mixture or product using the EPH Method (Montana Method) that falls within the molecular carbon molecule range of C-9 and C-36.

TPH – Total petroleum hydrocarbons. TPH may also refer to total purgeable hydrocarbons but that term is not used in this guidance.

Total Petroleum Hydrocarbons - This term is generally applied to analytical methods that report one concentration for the petroleum hydrocarbons present and that are no longer approved by DEQ to assess risks posed by petroleum contamination.

Tier 1 – The simplest level of RBCA for petroleum releases in Montana. In Tier 1 RBCA, petroleum contaminant levels are compared to pre-determined RBSLs for COCs to determine whether additional evaluation and/or cleanup is necessary. It involves situations where the petroleum contaminant is confined to soil and/or is present in the groundwater at concentrations below DEQ-7 human health standards or groundwater RBSLs. The Tier 1 process may not be applicable to sites where site-specific cleanup levels have already been chosen or will be identified through an appropriate authority.

Tier 2 – A potential site-specific alternative risk-based approach for sites where Tier 1 RBSLs have been exceeded. Tier 2 involves adjusting Tier 1 RBSLs based upon site-specific information such as the number of COCs or the characteristics of the vadose zone.

Tier 3 – A potential site-specific alternative risk-based approach for sites where Tier 1 RBSL and Tier 2 site-specific screening levels have been exceeded. Tier 3 involves conducting site-specific human health and/or ecological risk assessments and fate and transport analyses and calculating site-specific cleanup levels.

TSP – Trisodium phosphate.

Vadose zone – The part of the soil column extending down from the Earth surface to the depth where the subsurface materials are saturated with groundwater. It is also known as the unsaturated zone.

Vapor Intrusion (VI) - Vapor intrusion is the migration of volatile chemicals from the subsurface into overlying or subterranean structures. Volatile chemicals in contaminated soil or groundwater can emit vapors that may migrate through subsurface soils and into air spaces of adjacent or overlying structures. Depending upon the chemicals, some vapors inhaled by occupants can cause adverse health effects, including an increased lifetime cancer risk. In some cases, the vapors may accumulate in buildings to levels that may pose near-term safety hazards, acute health effects or aesthetic problems.

VI – See vapor intrusion.

VOC – See volatile organic compounds.

Volatile organic compounds (VOCs) - Organic chemicals that have a high vapor pressure at ordinary room temperature (60° Fahrenheit), some of which may have short- and long-term adverse health effects.

Volatile petroleum hydrocarbons (VPH) - A group of petroleum hydrocarbons that includes the petroleum fractions typically found in gasoline and other lighter petroleum products that are not analyzed and reported as

specific compounds, like benzene. VPH is also the analytical method developed by the Massachusetts Department of Environmental Protection to determine the fractional composition of these compounds.

VPH - See volatile petroleum hydrocarbons.

Executive Summary of 2018 Changes

The Montana Department of Environmental Quality (DEQ) conducts periodic reviews of its Montana Risk-Based Corrective Action (RBCA) Guidance for Petroleum Releases to determine if changes to methods and toxicity information warrant updating the guidance. Following is a bulleted list of substantive changes made to the September 2016 version of the RBCA. The changes in RBSL calculation parameters are documented in the RBCA Appendices. Additional minor editorial changes and updates were also made.

- Updated toxicity values for benzo(a)pyrene and the other carcinogenic polycyclic aromatic hydrocarbons (PAHs) with toxicity relative to benzo(a) pyrene used to calculate direct contact risk-based screening levels (RBSLs) (EPA 2017).
- Updated the groundwater RBSLs to reflect updated Montana Circular DEQ-7 human health standards (HHSs; DEQ 2017).
- Updated the RBSL based upon leaching to groundwater to be protective of the 2017 DEQ-7 HHSs.
- Various clarifying language regarding Tier 2 procedures.
- One final thing to note regarding the 2018 changes to the RBCA is that the 2018 RBSLs for soil and water are still not designed to be protective of risks posed by the vapor intrusion (VI) pathway. In 2016, DEQ added some discussion related to VI and included a description of its Air Phase Hydrocarbon (APH) Calculator; however, if volatile compounds are present in the vicinity of habitable structures, then the VI pathway should be evaluated either qualitatively or quantitatively using the Montana Vapor Intrusion Guide (DEQ, 2011). In addition, DEQ completed a study and published a report called Typical Indoor Air Concentrations of Volatile Organic Compounds in Non-Smoking Montana Residences Not Impacted by VI (DEQ, 2012). These VI documents are guidance and are not considered regulation. At this time, DEQ has not adopted the EPA Petroleum Vapor Intrusion Guidance or the EPA Vapor Intrusion Screening Level (VISLs) Calculator.

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RISK-BASED CORRECTIVE ACTION
EVALUATION PROCESS

1.0   INTRODUCTION

1.1   Overview of Risk-Based Corrective Action

DEQ created this document to describe the risk-based corrective action (RBCA) evaluation process.   This document provides a description of the concepts and terms used in RBCA for petroleum releases in Montana and is not intended to address other chemical (non-petroleum) releases. This document is applicable to petroleum releases, suspect releases, and permits regulated by DEQ's Waste Management and Remediation Division and Enforcement Division. In addition, this guidance may be used as a screening tool for new releases at hazardous waste sites that are covered by Resource Conservation and Recovery Act (RCRA) permits or orders. For hydrocarbon compounds not specifically addressed in this document, a site-specific approach may be developed in consultation with DEQ. The appropriate regulating agency or bureau should be contacted to determine whether the RBCA evaluation process is appropriate.

1.2   RBCA Risk Evaluation

The goal of RBCA is to identify and reduce risks to public health, safety, and welfare, and the environment. RBCA uses environmental risk analysis, which incorporates elements of toxicology, hydrogeology, chemistry, and engineering to assess the existing and potential risks from a petroleum release. This information is used to develop contaminant concentration levels determined to be acceptable in the State of Montana. The risk-based screening levels (RBSLs) developed within RBCA can be used as cleanup levels at sites in Montana without the need to perform site-specific leaching evaluations or risk analysis for each release and exposure scenario.

DEQ's Tier 1 (the lowest level of complexity in the RBCA evaluation process) site evaluation process consists of assessing site conditions and maximum contaminant concentrations, and choosing the appropriate Tier 1 RBSLs to determine whether further evaluation or corrective action is needed to confirm a suspected release or address a release. Tier I RBSLs may be used in an environmental assessment or permitting process to determine whether a release has occurred or to set permit limits. The Tier 1 process involves comparing contaminant concentrations to Tier 1 RBSLs tables containing generic contaminant concentrations that represent acceptable risks to human health and the environment with very limited site-specific information (current and future land uses and depth to the water table). Sites with potential impacts to soil and groundwater from petroleum releases are initially evaluated through the RBCA Tier 1 evaluation process. Tier 1 allows sites to be screened, evaluated, and cleaned up to generic screening levels. Generic screening levels for petroleum-related compounds are the RBSLs found in Tables 1, 2 and 3. When petroleum contamination is demonstrated to be less than RBSLs, the release or suspected release might be resolved without the need to perform site-specific risk analysis or additional remediation.

A petroleum release from a petroleum storage tank (PST) is confirmed when any soil analytical data exceed levels published in this document (see Administrative Rules of Montana 17.56.506).

The administrative rule also requires any person conducting subsurface investigations, as well as any other parties, to report a suspected petroleum release to DEQ. Failure to report a suspected or confirmed release may result in enforcement actions.

For sites where chemicals exceed Tier 1 RBSLs, a Tier 2 evaluation allows screening levels to be adjusted based upon site-specific information and cleanup to site-specific screening levels for direct contact and leaching to groundwater exposure scenarios. Tier 2 involves adjusting Tier 1 RBSLs based upon site-specific information such as the number of chemicals of concern (COCs) or the characteristics of the vadose zone. Additional site-specific data or information may be necessary for a Tier 2 evaluation. Direct contact adjustments for carcinogenic compounds are based on a 1×10^{-5} excess lifetime cancer risk and non-carcinogenic compounds are based on a hazard index of 1. Leaching to groundwater adjustments may be based upon site-specific dilution and attenuation, an analysis of time for transport, or the evaluation of site-specific chemical partitioning behavior.

More complicated releases require a more extensive investigation, data collection, and analysis to fully assess the risk and address the contamination. These will typically include releases where surface water or groundwater are contaminated at concentrations above groundwater RBSLs or Circular DEQ-7 human health standards, or releases with extensive soil contamination that cannot practically be dealt with under Tier 1 or Tier 2. An example of the latter situation would be a release with gasoline-contaminated surface water or sediment. A Tier 3 analysis is appropriate for these types of sites. Tier 3 involves a full risk assessment, calculation of site-specific cleanup levels, or a site-specific modeling of contaminants leaching to groundwater, and is intended for use at more complex releases.

Vapor Intrusion (VI) cleanup levels are developed using a Tier 2 type of approach. Please refer to DEQ's Vapor Intrusion Guidance for additional information. In addition, Tier 1or Tier 2 may not be appropriate for releases where site-specific cleanup levels have already been established (e.g., there is already a Record of Decision for the site). The appropriate regulating agency or bureau should be consulted to determine whether Tier 1 or 2 may be applied at these releases.

2.0 CORRECTIVE ACTIONS UNDER RBCA

The nature and extent of contamination at petroleum releases are generally characterized through remedial investigations. During these investigations, responsible parties and their environmental professionals identify which contaminants are present at a release, determine concentrations, and horizontal and vertical distribution of the contaminants. Other site conditions, such as geology, hydrogeology (including determination of site-specific depth to groundwater), local land use, and potential receptors are also documented. This information is evaluated and analytical data are compared to RBSLs to determine RBCA site-specific screening levels for each release (described in more detail below). These site-specific screening levels are set to ensure that any COC concentrations that might remain will not pose unacceptable risks to public health, safety, and welfare, and the environment.

RBCA screening levels can be achieved by removing contaminated material from the release until remaining COC concentrations are below Tier 1 RBSLs. However, RBCA screening levels may also be reached by using combinations of other methods that reduce the potential for exposure. Acceptable methods might include excavation, in situ treatment technologies, source

control or treatment, engineered controls that reduce or restrict migration, or enhancement technologies that promote biodegradation.

Removing or reducing contamination to levels below the RBSLs does not always ensure that contamination has not already leached or migrated downward to the water table. The RBSLs listed in this document that address protection of groundwater are based on protective assumptions to minimize leaching of contaminants to groundwater. If soil contamination concentrations are reduced below RBSLs, then leaching at levels of concern should not occur in the future. However, if contamination exceeded RBSLs in the past, then the leaching process may have already taken place. This has been particularly evidenced in permeable soils and at locations where releases have been present for long periods of time. Therefore, achieving soil RBSLs does not preclude the need to investigate groundwater to determine whether groundwater has been contaminated. In some cases, contamination may have leached downward and formed a smear zone of contamination within the soil between the seasonal high and low water levels of an aquifer. A smear zone can be a secondary source of groundwater contamination. Many factors should be evaluated to determine if a groundwater investigation is necessary. These factors should include the volume and age of the release, permeability of the soil, the depth to groundwater, maximum soil contaminant concentrations originally present, and estimated mass of contamination removed or destroyed, as well as other site-specific parameters.

Risk-based evaluation and cleanup may also be conducted through a Tier 2 evaluation. Some spills can be mitigated easily and remediated to meet Tier 1 generic screening levels (Tier 1 RBSLs), but for sites with more complex issues, a Tier 2 evaluation may be warranted. The Tier 2 evaluation allows Tier 1 RBSLs to be adjusted to site-specific screening levels for direct contact exceedances and leaching to groundwater. If VI is found to be an issue at a site, a separate evaluation will be done using site-specific adjustments when appropriate. Section 4.0 discusses the VI evaluation process.

3.0   TIER 1 RBCA EVALUATION PROCESS

The Tier 1 evaluation is the lowest level of complexity of RBCA. It can be applied for initial evaluation of contaminated soil or simple releases that can be cleaned up using routine methods with limited site characterization. A Tier 1 evaluation generally includes: conducting a field investigation to determine the maximum concentrations of COCs in soil and groundwater associated with the release, developing a conceptual site model (CSM) to identify potentially complete exposure pathways and receptors, and comparing the maximum COC concentrations to the Tier 1 RBSL Tables to determine which pathways are considered complete. The Tier 1 evaluation provides information regarding the "worse-case" scenario and allows responsible parties to decide whether a release will require additional evaluation or remedial actions.

For petroleum releases from a PST system, responsible parties and their environmental professionals follow guidelines to complete forms such as a 30-Day Release Report. This provides DEQ with the information necessary to determine what corrective action is necessary, and whether a release can be resolved without further action.

3.1   Documenting Site Conditions

For releases from PSTs, initial conditions related to the release site are typically documented on the 30-Day Release Report submitted to DEQ. The DEQ Enforcement Division uses the Complaint/Spill Report to document initial information about a release. Other regulating agencies or bureaus may have their own reporting requirements.

DEQ uses information and laboratory analytical data provided by the responsible party to determine whether a release can be resolved using Tier 1, or if a more complex evaluation is needed under Tiers 2 or 3. Some site conditions, such as surface water or sediment contamination, or vapor intrusion prevent resolving a release under Tier 1. In such cases, DEQ may require a Tier 2 or a Tier 3 evaluation to gather more information and develop release cleanup and management strategies, and site-specific screening or cleanup levels.

3.2   Conceptual Site Model

Once a petroleum release has been confirmed, CSM should be developed. A complete exposure assessment is necessary to characterize a site's exposure setting, which includes the physical environment, potentially exposed populations, and current and reasonably anticipated future land uses. This allows the potential exposure pathways, points of exposure, and exposure routes to be identified to ensure that adequate data are collected for all impacted media.

The CSM begins with the source. Sources of petroleum contamination include storage tanks, piping and dispensers, and surface spills or overfills, such as from a refueling truck or other activities. A leak or release from any source can potentially contaminate the surrounding media and create an exposure pathway to a receptor. For example, petroleum leaking beneath a dispenser can enter and contaminate the soil. The petroleum can then leach through the soil to the groundwater where a nearby domestic well may pump the contaminated groundwater into a house creating a potential pathway between the petroleum contamination released from the dispenser and a resident user of the well. COCs from a leak or release can spread through various environmental media such as soil, groundwater, surface water, and air, and can accumulate in vegetation, animals, and other organisms. They are transported by many processes, including gravity, advection, dispersion, diffusion and volatilization. The spread and migration of COCs help complete the exposure pathway which can include natural or man-made processes and media, and can be direct or indirect.

Figure 1 is an example of common exposure pathways for gasoline leaking from an underground storage tank system. Vapors can migrate through the soil vertically or laterally to contribute to VI, which can cause human health impacts. Soluble fractions of gasoline dissolve into and move through groundwater and impact wells. Vapors can penetrate concrete subfloors in basements creating an explosive hazard in nearby houses or other enclosed structures.

Figure 2 provides a flowchart example of a CSM for the same type of release. Table 5 provides a template for a tabular version of a typical petroleum tank release CSM. Additional information regarding the components of a CSM is provided below. The initial CSM is developed based upon the information available for the site at the time. As the site is characterized and risks are evaluated, the CSM is adjusted and refined based upon new information. For example, if the groundwater is not known to be contaminated but COCs are later found in groundwater, additional exposure pathways and receptors may be added. The CSM provides the basis for

determining what data and analyses are necessary to assess risks and determine remediation requirements.
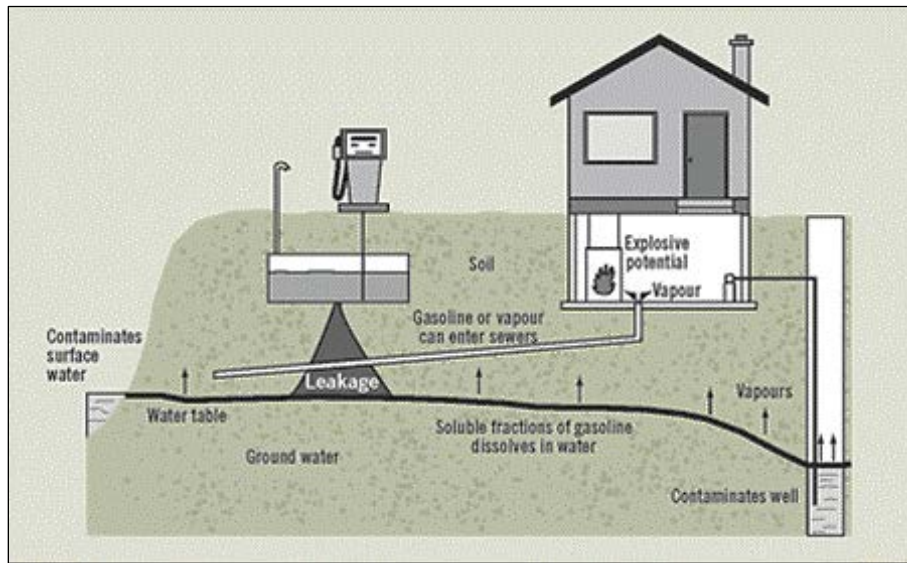
Figure 1 - Graphical depiction of conceptual site model
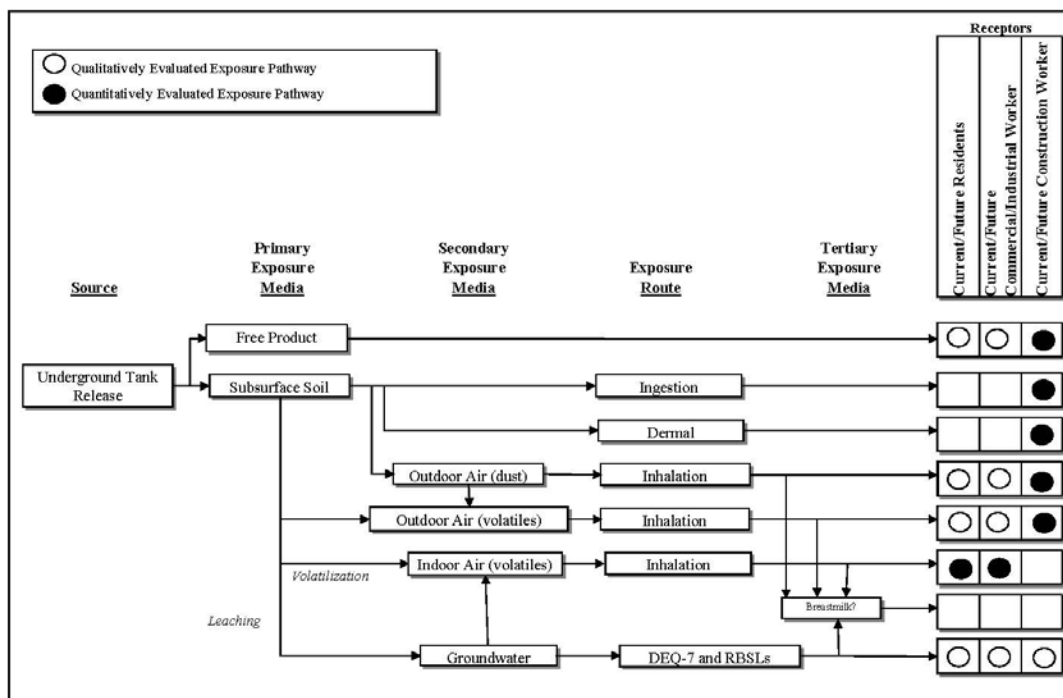
Figure 2 - Conceptual Site Model Flowchart

3.2.1 Receptors

Receptors are humans or organisms that are or may be exposed to COCs in environmental media (surface soil, groundwater, outdoor air, etc.) which can be divided into primary, secondary, and even tertiary points of exposure, each using a different route of exposure (ingestion, inhalation, etc.). Typical receptors include:

- Adults and children in a residential scenario;
- Adult workers in a commercial scenario; and
- Adults in a construction scenario (which includes residential excavations).

Both current and potential future receptors and both on-site and off-site receptors should be evaluated. Therefore, current and reasonably anticipated future land uses for a site and surrounding properties will need to be determined.

3.2.2 Exposure Pathways

Exposure pathways are ways a receptor can come into contact with a COC. Specific pathways include direct contact, leaching from soil to groundwater, runoff to surface water, dispersion of dust through the air, volatilization of COCs to indoor or outdoor air, and uptake of COCs by plants.

3.2.3 Exposure Routes

Exposure routes are the way COCs in contaminated media may come into contact with potential receptors and include:

- Ingestion;
- Dermal Contact; and
- Inhalation.

Exposure routes should be evaluated for current and future exposures. Exposure at petroleum contaminated sites occurs at an exposure point (e.g., contaminated soil or water) through an exposure route (e.g., incidental ingestion of soil, ingestion of water, inhalation of vapors or soil particles).

3.3   Chemicals of Concern

Typical petroleum products such as fuels and lubricants contain a large number of chemical constituents that may be harmful to the public health, safety, and welfare, and to the environment. DEQ has identified several common petroleum constituents as COCs generally detected in petroleum releases. Soil and water samples from petroleum release sites are analyzed for these COCs during a Tier 1 evaluation. Other COCs may be included based on site-specific activities. Any additional COCs will be identified by the appropriate regulating agency or bureau and evaluated outside the Tier 1 process.

COCs include specific compounds (such as methyl tertiary-butyl ether (MTBE), benzene, toluene, ethylbenzene, xylenes, naphthalene, lead scavengers (1,2-DCA and EDB), and PAHs) as well as groupings of compounds contained in VPH and EPH. VPH and EPH laboratory analyses are critical to evaluating risks posed by many chemicals present in typical petroleum products under the RBCA process. These analyses report groupings of chemicals, or "fractions" of the total sum of petroleum chemical present in a sample. The toxicity and behavior of a surrogate chemical have been assigned to represent each fraction in risk and fate and transport analyses. See Section 3.4.1 for further discussion of the VPH and EPH in the RBSL development process.

Data collected at each site are compared to the Tier 1 RBSL tables in order to determine site COCs. Any compounds with concentrations above Tier 1 RBSLs are considered COCs for the site. The Tier 1 process consists of three different tables located in the Tables Section of this document:

- **Table 1** applies to residential and commercial sites with contaminated surface soils from 0-2 feet below ground surface (bgs). The distance from the sample depth to groundwater is also taken into consideration. Select the screening level corresponding to the appropriate site use (residential or commercial) and select the appropriate distance to groundwater (less than 10 feet to groundwater, 10-20 feet to groundwater, or greater than 20 feet to groundwater). For VPH and EPH compounds at PST sites, the RBSLs in bold in the first column (residential, less than 10 feet to groundwater) of Table 1 are used to determine if a release has occurred at a site.

- **Table 2** applies to contaminated subsurface soil (greater than 2 feet bgs). RBSLs in this table are not differentiated for commercial and residential sites as they are for Table 1 because the exposures potentially experienced by construction workers and residents conducting excavation activities such as building structures, planting trees or shrubs, or other construction activities would be the same. The depth to groundwater is crucial when choosing the appropriate screening level. The depth used represents the distance between where the sample was collected and the shallowest water table.

- **Table 3** applies to groundwater COCs that have been derived from DEQ-7 human health standards (HHSs; DEQ 2017), where available, DEQ RBSLs for compounds without DEQ-7 HHSs, and EPA tapwater RSLs (EPA 2017).

3.4   Sampling Protocols

Table A provides useful information that should be reviewed and addressed when collecting soil samples for analysis including: holding time, preservation method, and type and number of sample containers that should be used. Sampling for volatile organic compounds (VOCs), PAHs, RCRA metals, oxygenates, and lead scavengers also have specific sampling requirements. During the initial site characterization DEQ recommends collecting additional field data, including soil characteristics (bulk density, soil moisture, pH, total organic carbon (TOC), and texture), hydrological characteristics, source characteristics, and chemical biodegradation data. Collection of this data will assist with understanding the behavior of the COCs and will save money and time if the release requires a Tier 2 or 3 evaluation.

Table A - Soil Sampling and Preservation Protocol

Parameter	Analytical Method	Sample Container/ Preservation	Holding Time
Soil Samples			
VPH	Montana Method VPH	For samples not methanol preserved: One 4 oz glass jar, cool to (4 ± 2) ℃. For samples preserved with methanol: One pre-weighed jar or 2 vials **with methanol,** plus one 4 oz glass jar without methanol for moisture analysis, cool to (4 ± 2) ℃	Without methanol preservation: 7 days to extraction and 28 days to laboratory analysis. With methanol preservation: 28 days to laboratory extraction and analysis.
EPH Screen	Montana Method EPH	One 4 oz glass jar, cool to (4 ± 2) ℃	14 days to laboratory extraction and 40 days to analysis.
EPH Fractionation with or without PAH's	Montana Method EPH (PAHs: 8270C or 8270D)	One 4 oz glass jar, cool to (4 ± 2) ℃	Following EPH Screen 14 day extraction, 40 days to analysis.
VOCs	EPA Method 8260B	One 4 oz. glass jar, cool to (4 ± 2) ℃	14 days to extraction and analysis
RCRA Metals plus zinc (Except Hg)	EPA Method 6010 or 6020	One 4 oz. plastic or glass jar, no preservation	6 months
Mercury (Hg)	EPA Method 7471	One 4 oz. plastic or glass jar, no preservation	28 days
Oxygenates	EPA Method 8260B	125 ml glass jar, cool to (4 ± 2) ℃	14 days to extraction and analysis
Lead Scavengers: EDB	EPA Method 8011	125 ml glass jar, cool to (4 ± 2) ℃	14 days to extraction and analysis
1,2-DCA	EPA Method 8260B	125 ml glass jar, cool to (4°± 2) ℃	14 days to extraction and analysis

3.4.1 Soil Sampling and Reporting Procedures

The number of soil samples collected and analyzed should delineate the extent and magnitude of the area of confirmed or suspected contamination. For RBCA analysis, soil samples should be collected from worst-case areas, surface spills or other likely sources of petroleum contamination. Samples associated with PST sites should be submitted to a laboratory capable of implementing DEQ's analytical protocol. The laboratory reporting limit should be less than DEQ screening criteria. Table B shows analyses based on product type and testing procedure. The Montana EPH and VPH analytical methods, developed by the Massachusetts Department of Environmental Protection and modified by DEQ, should be used for all RBCA evaluations in Montana.

When sample results are reported to DEQ as part of a standard reporting process for any phase of site assessment or remediation, the report should include all associated laboratory documentation including chromatograms, quality control/quality assurance data and chain of custody forms, as well as soil sample locations, sample depths, and other pertinent site history data.

Table B outlines the analytical methods necessary to apply RBCA analysis for various petroleum products in soil. VPH analysis is necessary for petroleum products that typically contain light range hydrocarbons to determine the concentrations of MTBE, benzene, toluene, ethylbenzene,

xylenes, naphthalene (collectively referred to as MBTEXN) and light end aliphatic and aromatic hydrocarbon fractions in the soil. EPH analysis is necessary in conjunction with VPH for most of the petroleum product types excluding gasoline, aviation gas, and mineral/dielectric oils. DEQ uses a two-step screening technique to evaluate soils at sites where the EPH analysis is necessary to reduce the analytical costs for the EPH analysis. The first step in the screening technique is similar to the diesel range organics (DRO) analysis and generates a total extractable hydrocarbon (TEH) concentration. If the initial screening result is 200 mg/kg or less, no additional EPH analysis is necessary. However, if the TEH concentration is greater than 200 mg/kg, then the EPH fractionation step is necessary. PAH analysis is needed on a site-specific basis if heavy hydrocarbons, refinery wastes or unknown oils/sources are present.

Table B - Testing Procedures for Soils

Petroleum Product	VPH	EPH Screen	EPH Fractionation	EPH for PAHs 8270C or 8270D	RCRA Metals + Zinc	EPA Method 8260B	Lead Scavengers
Gasoline/Aviation Gasoline	R						SS
Diesel (#1 & #2)	R	R	X	SS			
#1 - #2 Heating Oils	R	R	X	SS			
#3 - #6 Fuel Oils		R	X	X			
Used/Waste Oil	R	R	X	X	R	R	SS
Kerosene, Jet Fuel (Jet-A, JP-4, JP-5, JP-8, etc.)	R	R	X	SS			
Mineral/Dielectric Oils		R	X				
Heavier Wastes		R	X	X			
Crude Oil	R	R	X	X			
Unknown Oils/Sources	R	R	X	X	R	R	SS

R - required for RBCA analysis (DEQ technical lead will determine site-specific sampling requirements)
X - analysis to be run if the EPH screen concentration is >200 ppm TEH
SS - Site-specific determination.

3.4.1.2 Dry-Weight Reporting for Soil and Sediment Samples

Soil and sediment sample values are reported on a dry-weight basis. The initial contaminant concentration measured by a laboratory is the "as-is" or "wet weight" result. Calculations are made to wet weight contaminant concentrations to account for the moisture content of the soil (as determined by the lab) and the corrected concentrations are reported as dry weight. This eliminates the variability of contaminant concentrations as a function of moisture content.

3.4.1.3 Moisture Data Reporting for Soil and Sediment Samples

Since all soil and sediment data are reported on a dry-weight basis, moisture percentage is also determined so an adjustment can be made to the "as-is" or wet weight result. The moisture percentage should be included on the laboratory data reports so that fate and transport of COCs may be evaluated.

3.4.2 Groundwater Sampling Procedures

At some sites, it may be necessary to investigate groundwater quality to verify that contaminant concentrations are below RBSLs and DEQ-7 HHSs. MBTEXN and other lighter range hydrocarbons are commonly detected at gasoline and diesel release sites at concentrations that

exceed human health standards. The VPH method includes MBTEXN compounds but the EPH method does not. MBTEXN compounds are present in the heavier petroleum products and VPH analysis is needed in addition to the EPH method at all diesel #1, diesel #2, kerosene, jet fuel, and waste oil release sites to determine MBTEXN concentrations.

EPA Method 8270C or 8270D for PAH analysis is typically appropriate for refinery wastes and other heavy hydrocarbons regardless of the screening concentration. VPH analysis may also be necessary for some contaminants.

At sites that have used or currently use aviation fuel and those that may have had releases of leaded gasoline, analyses for the lead scavengers 1,2-DCA (1,2-dichloroethane) and EDB (also known as 1,2-dibromoethane) should be performed. Lead scavengers were added to leaded gasoline from the 1920's through the 1980's to reduce engine fouling caused by the tetra ethyl lead that was added to gasoline as an anti-knocking compound. Lead scavengers may still be present in off-road fuels such as racing gasoline and leaded aviation gasoline. Table C outlines the analytical methods for individual petroleum products in groundwater.

Table C - Testing Procedures for Groundwater

Petroleum Product	VPH	EPH Screen	EPH Fractionation	EPA Method 8270C or 8270D for PAHs	RCRA Metals + Zinc	EPA Method 8260B	Oxygenates & Lead Scavengers
Gasoline/Aviation Gasoline	R						SS
Diesel (#1 & #2)	R	R	SS	SS			
#1 - #2 Heating Oils	R	R	SS	SS			
#3 - #6 Fuel Oils		R	SS	R			
Used/Waste Oil	R	R	SS	R	SS	R	SS
Kerosene, Jet Fuels (Jet-A, JP-4, JP-5, JP-8, etc.)	R	R	SS	SS			
Mineral/Dielectric Oils		R	SS	SS			
Heavier Wastes		R	SS	R			
Crude Oil	R	R	SS	R			
Unknown Oils/Sources	R	R	SS	R	SS	R	SS

R – Analysis required for RBCA evaluation
SS – Site-Specific determination.
EPH fractionation may be necessary if the EPH screen concentration is >1000 µg/L TEH.

Table D provides useful information that should be reviewed and addressed when collecting aqueous samples for analysis including: holding time, preservation method, and type and number of sample containers that should be used. Sampling for VOCs, PAHs, RCRA metals, oxygenates, and lead scavengers also have specific sampling requirements.

Table D - Aqueous Sampling and Preservation Protocol

Parameter	Analytical Method	Sample Container/ Preservation	Holding Time
VPH	Montana Method VPH	Three 40 ml vials with zero headspace, acidify with HCl to pH <2, cool to (4 ± 2) ℃	14 days to analysis
EPH Screen	Montana Method EPH	Two 1 liter amber glass bottles, acidify with HCl or H_2SO_4 to pH <2, cool to (4 ± 2) ℃	14 days to extraction, 40 days to analysis
EPH	Montana Method EPH	Two 1 liter amber glass bottles, acidify with HCl or H_2SO_4 to pH <2, cool to (4 ± 2) ℃	14 days to EPH Screen extraction, 40 days to analysis
VOCs (Drinking Water)	EPA Method 524.2	Three 40 ml vials with zero headspace, acidify with HCl to pH <2, cool to (4 ± 2) ℃. Remove chlorine with Ascorbic Acid.	14 days to analysis
VOCs	EPA Method 8260B	Two 40 ml vials with zero headspace, acidify with HCl to pH <2, cool to (4 ± 2) ℃	14 days to analysis
PAHs (Semivolatile Organics)	EPA Method 8270C or 8270D	Two 1 liter amber glass bottles, **do not acidify**, cool to (4 ± 2) ℃. Remove chlorine with ~4 drops of 10% Sodium Thiosulfate ($Na_2S_2O_3$)	7 days to extraction, 40 days to analysis
Lead Scavengers EDB 1,2-DCA	EPA Method 8011 EPA Method 8260B	Six 40 ml vials, acidify with HCl to pH <2, cool to (4 ± 2) ℃. Remove chlorine with ~4 drops of 10% Sodium Thiosulfate ($Na_2S_2O_3$)	14 days to analysis
RCRA Metals plus zinc (except Hg)	EPA Method 6010/200.7 or 6020/200.8	One 250 ml HDPE bottle, acidify with nitric acid (HNO_3) to pH <2, cool to (4 ± 2) ℃	6 months
Mercury (Hg)	EPA Method 245.1 or 7470	One 250 ml HDPE bottle, acidify with HNO_3 to pH <2, cool to (4 ± 2) ℃	28 days

To reduce analytical costs, DEQ uses the EPH screening technique. The EPH screen approach is similar to that previously described for soils and generates a TEH concentration. If the initial screening result is 1,000 µg/L TEH or less, EPH fractionation is not necessary. If the TEH concentration exceeds 1,000 µg/L, fractionation is necessary to determine the fraction concentrations.

At least one high and one low seasonal groundwater sampling event may be needed to evaluate seasonal COC variability.

3.4.2.1 EPH Screen vs TEH

Initial groundwater samples should be submitted for the EPH screen and fractionated if the EPH screen concentration is greater than 1,000 µg/L. The EPH screen and the post-fractionation TEH concentration can have significant differences for the same sample because they are derived by two distinct analytical methods.

The EPH screen concentration is a summation of all of the compounds that are extracted from the sample and show up on the chromatogram regardless of elution time. In addition to petroleum hydrocarbons, these compounds may include naturally occurring organics and intermediate metabolites (hydrocarbon breakdown products).

The post-fractionation TEH concentration is a summation of the compounds that show up on the chromatograms after the sample has been run through a silica gel cartridge and rinsed with

hexane and methylene chloride. The silica gel removes polar petroleum hydrocarbons, such as intermediate metabolites and naturally occurring organics, so the compounds that pass through the cartridge should be the regulated petroleum hydrocarbons.

3.4.2.2 Aqueous Sample Preservation

The VPH method recommends the use of three 40 milliliter (ml) vials. The samples are to be preserved by adding hydrochloric acid (HCl) to reduce the pH to 2 or less. The vial should be checked to ensure no air bubbles are present in the vial before placing on ice. Please refer to Table D for additional sampling procedures.

Trisodium phosphate (TSP) is used as an alternative to acid preservation for fuel oxygenates. It prevents the biological degradation of the target analytes and does not cause hydrolysis of ethers to alcohols.

At sites where drinking water supplies, either water supply lines or domestic or public water supply wells, are threatened by petroleum contamination, VOC analysis by EPA Method 524.2 of the water inside the well or pipelines may be necessary. HCl is used as a preservative. If the water system is chlorinated, ascorbic acid needs to be added to prevent the formation of chlorination by-products. If the supply is not chlorinated, then only HCl is used for preserving the sample.

3.4.3 Use of Old and New Total Petroleum Hydrocarbon Data

While the use of the Montana VPH/EPH approach is a preferred means to characterize risks from petroleum products released to the environment, there are significant amounts of historical total petroleum hydrocarbon (TPH) data that have been obtained in the past for contaminated sites. For a Tier 1 evaluation, old TPH data may be converted to EPH fractional data using the guidelines discussed below. If the historical data exceeds current RBSLs, indicating that additional evaluation of a release is necessary, then the Montana VPH/EPH approach should be used.

Conservative assumptions can be made to "convert" old TPH data into EPH fractional data. Since TPH is essentially a summation of the three EPH fractions (i.e., C9-C18 aliphatics, C19-C36 aliphatics, and C11-C22 aromatics), it is possible to "convert" TPH data into the EPH fractional ranges, by making informed and reasonably conservative judgements on the chemistry of the TPH data. Compositional assumptions for soil data that are considered to be protective at most sites are provided in Table E.

Table E - Recommended TPH Compositional Assumptions in Soil

Petroleum Product	C11-C22 Aromatics	C9-C18 Aliphatics	C19-C36 Aliphatics
Diesel/#2/Crankcase Oil	60%	40%	0%
#3-#6 Fuel Oil /Bunker C	70%	30%	0%
Kerosene and Jet Fuel	30%	70%	0%
Mineral Oil Dielectric Oil	20%	40%	40%
Unknown Oil	100%	0%	0%

Source: Massachusetts Department of Environmental Protection, *Implementation of the MADEP VPH/EPH Approach*, October 2002

For old GRO soil data, consider all of the non-BTEX/MTBE hydrocarbons which have higher molecular weights than C8 to be C9-C10 Aromatics. All non-BTEX/MTBE compounds which

have lighter molecular weights than C9 are considered aliphatic hydrocarbons.

For water data, these conservative assumptions can be made:
- For TPH water data, all of the TPH should be assumed to be the most conservative EPH fractional RBSL for groundwater, although it is permissible to remove the concentrations of target PAH analytes (e.g., naphthalene), if known; and
- For GRO water data, the entire GRO concentration should be assumed to be the most conservative VPH fractional RBSL for groundwater, although it is permissible to remove the concentration of target BTEX/MTBE, if known.

3.5   Using Tier 1 Look-Up Tables

Once the field investigation is complete, the CSM has been established, and all the necessary data has been collected, data are compared to the Tier 1 RBSL look-up tables. These tables contain screening levels for surface soil, subsurface soil, and groundwater (see Tables 1, 2, and 3, respectively). They are arranged in categories that reflect different site conditions such as, current or future land use and varying depths to groundwater. The Tier 1 tables also consider both direct contact and the leaching to ground water pathways and display whichever value is lower. This ensures that the Tier 1 process is protective of human health and the environment. More information on how the RBSLs for the Tier 1 process were developed is provided in section 3.6. To determine the appropriate RBSLs, the responsible party and DEQ staff compare the soil or groundwater values to the RBSLs that correspond with the conditions present at the site.

For the purposes of a Tier 1 evaluation, "surface soil" is 0-2 feet below ground surface and "subsurface soil" is deeper than 2 feet below ground surface. Tier 1 RBSLs for contaminated surface (0-2 feet below ground surface) and subsurface (2-10 feet below ground surface) soils are divided into three categories depending on the distance to groundwater from ground surface and beneath contaminated soil:

> 1) Groundwater less than 10 feet below contamination;
> 2) Groundwater between 10 and 20 feet below contamination; and
> 3) Groundwater greater than 20 feet below contamination.

The distance to groundwater is generally determined using the difference between the depth of the soil sample location and the highest seasonal water level in a well screened in the uppermost zone of saturation within 500 feet of the release. Nearby water supply wells may not be appropriate in some cases to determine the depth to the uppermost saturated zone (first water) as they may be completed in a deeper zone. In determining which Tier 1 table is appropriate, it is necessary to know three depths:

> 1) The depth the sample was taken below the ground surface;
> 2) The depth the water table is below the ground surface; and
> 3) Known distance to groundwater below soil sample collection depth (calculated by subtracting 1 from 2).

For example, if the soil sample is collected below an underground storage tank at a depth of 10 feet below ground surface, and the water table is 25 feet below the ground surface, the depth to

the groundwater is 15 feet and data collected from this point should be compared to the RBSLs listed in the 10-20 feet to groundwater column.

When contamination is present at both surface and subsurface depths, samples with the highest concentrations in each depth zone are compared to the appropriate Tier-1 tables.

The current and reasonably anticipated future use of sites with contaminated surface soil should also be considered. The site may be designated commercial or residential by considering the reasonably anticipated future use of the site. Residential sites are those where someone resides or may reside in the future, potentially including farms and ranches and gas stations with associated residences. Commercial sites are those without residents, used only for commercial/industrial purposes. This determination is only relevant for petroleum-contaminated surface soil, including contaminated surface soil at permitted landfarm locations. When site conditions are not well defined, DEQ uses the most conservative soil RBSLs, corresponding to the shallowest depth to groundwater below contaminated soil with residential use.

If RCRA metals, including zinc are analyzed, concentrations are compared to the following background concentrations and screening levels.

Table F - RCRA Metals and Zinc Screening Levels in Soil

Metal	Screening Level	Background Threshold Value Concentrations [d]	Units
Arsenic	0.68 [a]	22.5	mg/kg
Barium	421 [c]	429	mg/kg
Cadmium	3.8 [b]	0.7	mg/kg
Chromium [e]	12,000 [a]	41.7	mg/kg
Lead	140 [b]	29.8	mg/kg
Elemental Mercury	1.0 [b]	<0.05	mg/kg
Selenium	2.6 [b]	0.7	mg/kg
Silver	8.5 [c]	0.3	mg/kg
Zinc	1,233 [c]	118	mg/kg

a. Based on the EPA RSL for residential soil (EPA, June 2016).
b. Based on the EPA November 2017 maximum contaminant level-based protection of groundwater soil screening level (multiplied by a dilution attenuation factor of 10).
c. Based on the following formula:
   (DEQ-7 HHS)/(tapwater screening level) * (RBSL) * 10
d. DEQ, *Background Concentrations of Inorganic Constituents in Montana Surface Soils.* September 2013.
e. The chromium RSL and background concentration are for chromium III as this form of chromium is the most common. If chromium VI is suspected (i.e., plated chrome is associated with the site), please consult DEQ.

For metals, if the screening level is less than the background concentration (e.g., arsenic), the background concentration is used for screening. If the background concentrations or screening levels, whichever are higher, are exceeded, further evaluation is necessary. DEQ should be contacted to determine what evaluation is appropriate.

Should COC concentrations exceed the values in the appropriate Tier 1 RBSL Lookup Table(s), the release is not ready to be resolved under the Tier 1 process. However, it may be possible to remediate a release to Tier 1 RBSLs by removing more contaminated material (e.g., through

further excavation or *in situ* remedial techniques), then resampling and following the Tier 1 evaluation process again. Releases that cannot be resolved under the Tier 1 evaluation process, including those with COCs in groundwater above the DEQ-7 HHSs or Tier 1 RBSLs (Table 3), may be addressed through further evaluation and may need additional corrective action before they can be resolved. Potential corrective actions include a Tier 2 evaluation, a Tier 3 evaluation, and/or cleanup. Please refer to Section 5.0 for details of the Tier 2 evaluation process.

3.6   Development of Tier 1 Screening Tables

DEQ calculated Tier 1 RBSLs for exposure pathways commonly associated with petroleum releases. RBSLs for surface soil were calculated for the soil leaching to groundwater pathway, and for the direct-contact pathway assuming residential and commercial land use. RBSLs for subsurface soil were calculated for the soil leaching to groundwater pathway, and for the direct contact pathway to account for exposure of receptors during any construction or excavation at a site (including residential sites). For each of the three distances to groundwater categories in Tables 1 and 2, the RBSLs in Table 1 reflect the most conservative (most protective) COC concentration calculated for any of the three Tier 1 exposure scenarios (i.e., for the soil leaching to groundwater pathway and through direct contact). Table 4 is a comprehensive soil RBSL table presenting the RBSLs calculated for direct contact and leaching to groundwater. This table is the basis for a Tier 2 evaluation. Please refer to section 5.0 for information on the Tier 2 process and the correct use of Table 4.

Tier 1 RBSLs for groundwater provided in Table 3 consist of DEQ-7 human health standards for the individual (target) COCs. For the petroleum fractions, direct contact RBSLs were calculated using parameters associated with surrogate compounds.

3.6.1 Derivation of RBSLs

Tier 1 RBSLs were calculated using chemical fate and transport modeling, exposure models, and data characterizing the mobility, toxicity, and aesthetics of petroleum compounds. The contaminant transport models simulate chemical movement from a release source to underlying groundwater, and incorporate conservative assumptions regarding soil type, the rate of water infiltration, and the behavior of the COCs. Contaminant transport modeling results were used to calculate soil target levels protective of groundwater RBSLs (including DEQ-7 human health standards). Exposure modeling was performed to characterize potential risk from direct contact with contaminated soil, including ingestion, inhalation, and dermal contact exposure routes, and contact with groundwater, including ingestion and inhalation.

Refined petroleum products are typically mixtures of organic chemicals, many of which do not have DEQ-7 HHSs. The groundwater RBSL table (Table 3) includes DEQ-7 HHSs for target COCs for which standards were available. RBSLs for the COCs that do not have a DEQ-7 standard or an RSL have been developed as described in the following paragraphs.

RBSLs for the non-target ranges of petroleum hydrocarbons were developed using a fraction-surrogate approach because DEQ-7 human health standards were not available. These petroleum constituents are divided into fractions (e.g., C5-C8 aliphatics) based on chemical behavior and toxicity. RBSLs were calculated using a chemical representative ("surrogate") for each fraction. Groundwater RBSLs were developed for each petroleum fraction based on the toxicity of each

surrogate chemical. Toxicity values were combined with exposure parameters used to estimate ingestion and inhalation exposure to the COCs in groundwater to develop RBSLs based solely on risk to human health. These exposure parameters are similar to those used to develop DEQ-7 human health standards. DEQ also considered the lowest reasonably achievable practical quantitation limit (see Table 3) in setting RBSLs for the petroleum fractions.

Soil RBSLs were calculated for each petroleum fraction using the chemical fate and transport model used for the target compounds. These soil RBSLs are designed to be protective of groundwater below releases, so that contaminants leaching from contaminated soil will not cause groundwater to exceed groundwater RBSLs.

Protective, generic estimates of physical, chemical, and exposure parameters were used to develop the Tier 1 RBSLs. These generic estimates produce RBSLs with built-in safety margins, to compensate for the limited site-specific information typically available at Tier 1. The conservative Tier 1 RBSLs were created using several generic "worst-case" assumptions for model parameters.

3.6.2 Models Used to Generate Tier 1 RBSLs

DEQ calculated Tier 1 RBSLs for the soil leaching to groundwater pathway using the "VS2DT Solute Transport in Variably Saturated Porous Media" model (United States Geological Survey, 1996), combined with the "Hydrologic Evaluation of Landfill Performance" (HELP) model, which was used to estimate water infiltration rates. Direct contact RBSLs were calculated using equations developed by the EPA and the Massachusetts Department of Environmental Protection. The specific assumptions used in DEQ's Tier 1 soil leaching to groundwater models are discussed in Appendix A. The assumptions used in the direct contact modeling, including those associated with the fraction-surrogate approach, are discussed in Appendix B. Since Tier 1 RBSLs are intended for use at a variety of releases throughout the state, the assumptions of Tier 1 provide for a wide margin of safety, and are therefore conservative.

3.7   Summary of Tier 1 Evaluation Procedures

Procedures for evaluating a release using RBCA Tier 1 are summarized as follows:

1) Document site conditions by contacting DEQ and, for underground storage tank releases, filling out the proper forms such as the 30-Day Release Report.
2) Develop a conceptual site model to characterize the site's exposure setting identifying the different exposure pathways, points of exposure, exposure routes, and receptors to ensure adequate data are collected for all impacted media.
3) Compare data to the Tier 1 RBSL Tables, using the following procedures:
   a) Determine if the soil sample represents surface or subsurface soil
      - If the sample depth is two feet or less, the sample represents surface soil and the Tier 1 Surface Soil RBSLs (Table 1) apply.
      - When samples represent surface soil, use the appropriate land use category in Table 1 (commercial or residential).
      - If anyone lives at the site or may live at the site in the future (e.g., farms and ranches), residential RBSLs apply to surface soil.
      - If the site is used as a place of business with regular employee presence and no one lives at the site and an analysis of the reasonably anticipated future uses of the site

indicates it is unlikely that people may live at the site in the future, commercial RBSLs apply to surface soil.

- ◆ If the sample depth is greater than two feet, the sample represents subsurface soil and the Tier 1 Subsurface Soil RBSLs (Table 2) apply.

b) Determine the depth to groundwater
- ◆ For both surface (Table 1) and subsurface (Table 2) soils, if the depth to groundwater is less than ten feet below the sample collection location, the first column of RBSLs apply (left hand column(s)).
- ◆ For both surface (Table 1) and subsurface (Table 2) soil, if groundwater is between ten and twenty feet below the sample collection location, the second column of RBSLs apply (middle column(s)).
- ◆ For both surface (Table 1) and subsurface (Table 2) soil, if groundwater is greater than twenty feet below the sample collection location, the third column of RBSLs apply (right hand column(s)).

4) If the worst-case soil sample results are less than the appropriate RBSL value, no further corrective action may be necessary. DEQ will discuss the results and forward progress with you.

5) If soil sampling results exceed RBSLs, corrective action identified by DEQ should be completed.

6) Following the required corrective actions, complete confirmation soil and groundwater sampling and compare the results with RBSLs on the Tier 1 Tables by repeating step 4.

7) At any point in the process, if groundwater sampling results or site conditions indicate that groundwater is impacted, compare groundwater data to the Tier 1 groundwater RBSLs (Table 3) to evaluate potential groundwater impacts. Groundwater sampling results that represent a range of hydrological scenarios (e.g. seasonal high and low) may be necessary for a complete evaluation (ARM 17.56.605(6) states two years of monitoring or another reasonable time period approved by DEQ may be required).

8) If groundwater sampling results exceed the Tier 1 groundwater RBSLs (Table 3) the release cannot be resolved under the Tier 1 RBCA process, and additional evaluation (e.g., investigation, corrective action, etc.) is necessary.

4.0 VAPOR INTRUSION TO INDOOR AIR

VI sampling assists in determining whether or not the VI exposure pathway is complete and, if so, whether it poses an unacceptable risk to human health. This section, as with the entire document, describes risk-based approaches for petroleum contamination only. A complete pathway means that humans are exposed to vapors originating from site contamination: either from volatilization from impacted soil, impacted groundwater, or both. The RBSLs for soil and water are not designed to be protective of the VI pathway. If volatile compounds are present in the vicinity of inhabitable structures, then the VI pathway should be evaluated either qualitatively or quantitatively. DEQ has developed the Montana Vapor Intrusion Guide (DEQ, 2011) to aid in the evaluation of risks posed by sub-surface concentrations of chemical contaminants, and DEQ will approve specific evaluation procedures based on this guidance. The Montana Vapor Intrusion Guide has not been adopted as a regulation but does provide guidance on conducting a proper investigation. At this time, DEQ has not adopted the EPA Petroleum Vapor Intrusion Guidance or the EPA Vapor Intrusion Screening Level (VISLs) Calculator.

The VI evaluation is conducted separately from the RBCA Tier 1 and Tier 2 soil and groundwater evaluations. When investigating VI, an initial phase of sample collection and

comparison to generic screening levels will take place and may be followed by a more in-depth investigation and development of site-specific screening levels. More than one set of samples is typically necessary to determine whether VI is occurring and to what extent. Several different types of environmental samples may be collected:

Soil vapor samples are collected to characterize the nature and extent of vapor contamination in the soil in a given area. They may be collected prior to collecting sub-slab vapor and/or indoor air samples to help identify buildings or groups of buildings that need to be sampled. Soil vapor samples are used to determine the potential for vapors to accumulate beneath buildings. Soil vapor samples are not the same as soil samples.

Sub-slab vapor samples are collected to characterize the nature and extent of vapor contamination in the soil/gravel layer immediately beneath a building with a slab or a concrete-floored basement. In buildings without a slab, crawl space air and/or soil gas samples may be collected below the building. Sub-slab vapor results are used to determine the potential for VI.

Indoor air samples are collected to characterize the nature and extent of vapors within a building. Indoor air sample results help to evaluate whether vapors are currently migrating into a building. They are also compared to sub-slab vapor and outdoor air results to help determine where volatile chemicals may be coming from (indoor sources, outdoor sources, and/or beneath the building). To best conduct this comparison/determination, indoor air and sub-slab samples should be collected simultaneously.

Outdoor air samples are collected to characterize site-specific background air conditions. Outdoor air results are used to evaluate the extent to which outdoor sources, such as automobiles, lawn mowers, oil storage tanks, gasoline stations, or commercial/industrial sites may be affecting indoor air quality. However, the presence of a contaminant in the outdoor air does not necessarily mean that the contaminant will be present in indoor air. DEQ recommends that outdoor air samples be collected upwind of the building or air intake point to be representative of ambient conditions.

4.1   Vapor Screening Levels

When indoor air and sub-slab sample data have been collected they can be compared to generic screening levels for an initial evaluation to determine whether the pathway for VI is complete and whether there is a potential for risk associated with the inhalation of vapors from contaminated subsurface media (DEQ, 2011). The screening levels used are based on potential exposure scenarios for residential and industrial (commercial) receptors. The appropriate screening levels to use for VI evaluations are discussed below. If the concentrations are less than generic screening levels, additional investigations may not be needed. In order to make this determination, the data should also indicate that the contaminant source is not increasing or migrating and should represent anticipated seasonal variations. An exceedance of generic screening levels does not necessarily mean that mitigation is necessary. However, it does mean that additional investigations or evaluations may be needed to fully assess VI.

4.1.1 Regional Screening Levels

During initial screening, indoor air concentrations should be compared to the most recent EPA RSL for residential or industrial (commercial) air. The EPA developed generic screening levels based upon typical residential or industrial exposure. The industrial RBSLs should be used when evaluating a commercial exposure scenario under RBCA. When comparing VI data at a site in

Montana, adjustments may need to be made. The EPA RSL screening levels are based upon a cancer risk representing a 1×10^{-6} (or one in one million) excess lifetime cancer risk and therefore allow for as many as 10 cancer-causing compounds to be present at their screening levels before the Montana-allowable 1×10^{-5} excess lifetime cancer risk is exceeded. In Montana, cancer risk is considered to be additive regardless of the type of cancer that may result from exposure. To determine site-specific screening levels based upon non-cancer risk, divide the screening level by 10 to account for multiple compounds that may impact the same target organs or have the same critical effects. Non-cancer risks are considered additive as exposure may affect the same organs or result in the same critical effects.

4.1.2 Typical Indoor Air Concentrations

DEQ has reported Typical Indoor Air Concentrations of Volatile Organic Compounds in Non-Smoking Montana Residences Not Impacted by Vapor Intrusion (DEQ, 2012) to aid in evaluating background indoor air concentrations of various volatile chemical compounds found in petroleum products. Where these background concentrations are higher than the RSLs or other risk-based screening levels, the background concentrations may be used in lieu of either generic or site-specific screening levels as appropriate.   This is the case for residential screening levels for 1,2-DCA, benzene, C5-C8 aliphatics, C9-C12 aliphatics, ethylbenzene, and naphthalene.

4.1.3 APH Screening Levels

DEQ developed the Air-Phase Petroleum Hydrocarbon (APH) Vapor Intrusion calculator for use at sites containing only petroleum contamination. If generic screening indicates that petroleum compounds are the only VI COCs for a site, adjustments may be made using the calculator found at http://deq.mt.gov/Land/statesuperfund/aphvicalc. The APH is based upon samples collected using the Massachusetts Air-Phase Petroleum Hydrocarbons (APH) method.   DEQ developed the screening levels using the same assumptions as those EPA used to calculate the RSLs. For non-carcinogenic COCs, DEQ adjusted the target hazard index by dividing by ten to ensure that cumulative potential health effects were addressed. The petroleum fractions were calculated by DEQ and are based on toxicological information from the EPA Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons (EPA, 2009). The remaining petroleum compounds were derived from the RSL Table (EPA, 2016) and adjusted to account for a 78-year life expectancy from the EPA Exposure Factors Handbook (EPA, 2011).

The APH Screening Level Calculator is a computer based screening tool only to be used for petroleum contamination to determine if VI concentrations exceed generic risked-based screening levels. This calculator is not meant to be used with solvent sites or mixed waste sites containing a combination of petroleum and other contaminants. This calculator adjusts RBSLs based upon the COCs present at a site above appropriate RSLs.

APH VI Screening Level Calculator

Instructions: 1. Compare your analytical results to DEQ/EPA RSL Screening value in Table 1.
2. All compounds that exceed the Table 1: DEQ/EPA RSL Screening values must be added to the to drop down boxes under "Chemical" in Table 2 to view the adjusted screening value.

Table 1

Chemical	DEQ/EPA RSL Screen (µg/m³)*	
	Residential	Industrial
1,2 Dichloroethane (DCA)	0.23	0.52
1,3 Butadiene	0.1	0.46
Aliphatic (C5-C8)	94	260
Aliphatic (C9-C12)	44	44
Aromatic (C9-C10)	10	44
Benzene	1.3	1.8
Ethylbenzene	1.2	5.5
Ethylene Dibromide (EDB)	0.0052	0.022
MTBE	12	52
Naphthalene	0.39	0.4
Toluene	520	2200
Xylenes (mix of mp & o)	10	44

Table 2

	Chemical	Adjusted RSL (µg/m³)**	
		Residential	Industrial
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			

*DEQ/EPA RSL Screening values are based on a cancer risk of 1×10^{-6} (adjusted for 78-year lifespan) and a hazard index of 0.1 for non-carcinogens.
**Adjusted RSL values are based on a cumulative cancer risk of 1×10^{-5} (adjusted for 78-year lifespan) and a cumulative hazard index of 1.0 (non-carcinogens) for only those chemicals selected.
Please see DEQ's VI APH Calculator Discussion document for additional information.

Figure 3 - Screen view of APH Calculator Without Site-Specific COCs

To use this calculator, compare the analytical results to the APH Table 1 DEQ/EPA RSLs as seen in Figure 3. Manually add those compounds that exceed the APH Table 1 screening levels to APH Table 2 shown in Figure 3 by clicking one-by-one on the drop-down tabs (this includes any compounds detected above the RSL that are J-flagged). As compounds are entered, the calculator will display the adjusted residential and industrial screening levels. If the newly adjusted screening level is below typical indoor air concentrations provided in the Typical Indoor Air Concentrations of Volatile Organic Compounds in Non-Smoking Montana Residences Not Impacted by Vapor Intrusion (DEQ, 2012), the calculator will automatically default to background screening levels. For more information about the APH calculator, please refer to the APH VI Calculator Discussion found here: http://deq.mt.gov/Land/statesuperfund/aphvicalc.

5.0   TIER 2 RBCA EVALUATION PROCESS

During the Tier 1 evaluation process, site conditions are thoroughly evaluated and data are collected to determine the site COCs and the nature and extent of contamination at the site. Soil and groundwater data are compared to the Tier 1 RBSL Tables and a decision is made as to whether a site can be closed or whether remediation or additional evaluation should be conducted. Using the conservative Tier 1 RBSLs is appropriate for initial screening to determine whether a release has occurred or for a Tier 1 analysis or cleanup. However, because the Tier 1 RBSLs are meant to be conservative, once additional information about the COCs is available for a site, the soil RBSLs may be adjusted on a site-specific basis for a Tier 2 analysis.

A Tier 1 evaluation is conducted prior to implementing the Tier 2 process. If a site has not undergone a Tier 1 evaluation, please refer to Section 3.0 and complete the Tier 1 steps before moving forward with a Tier 2 evaluation.

5.1 COC Exceedance Evaluation

The first step in the Tier 2 evaluation process is determining exceedances that may exist for direct contact and/or leaching to groundwater at the site. Table 4 is the Master Table used to evaluate potential COC exceedances. The Master Table contains RBSLs specific to leaching to groundwater (first three columns) and RBSLs specific to direct contact (last three columns). The leaching to groundwater RBSLs vary depending upon the distance between the bottom of soil contamination and the top of groundwater. The direct contact RBSLs are calculated based on sample depth and a site's use (residential, commercial, etc.). Residential RBSLs include soil samples collected from 0-2 feet bgs and have or could have persons living at the site. Commercial RBSLs include soil samples collected from 0-2 feet bgs from a site with a business where employees and/or visitors come and go, but no one is living at the site. Construction RBSLs are used for samples collected from 0-10 feet bgs and apply to both residential and commercially used properties.

If leaching to groundwater is not a concern or has otherwise been addressed in an appropriate manner (see Tier 2 Leaching to Groundwater discussion in Section 5.3), it is possible that a Tier 2 evaluation can be conducted by consulting the Master Table and verifying that the direct contact RBSLs are not exceeded. The following example presents a situation where soils exceed Tier 1 RBSLs and groundwater concentrations are now below the RBSLs.

Example 1:
There is a petroleum site with benzene, toluene, and MTBE in residential surface soil where groundwater is 6 feet below the contamination. The compounds detected in soil were previously detected in groundwater, but now samples collected during high and low groundwater conditions indicate that the groundwater meets RBSLs. During the Tier 1 evaluation, the surface soil concentrations are first compared to the Tier 1 RBSLs for direct contact found on Table 1 of the RBCA Guidance.

Compound	Cancer/Non-Cancer Basis	Tier 1 RBSL mg/kg	Site Concentration mg/kg
Benzene	Cancer	0.07	0.9
Toluene	Non-cancer	21	30
MTBE	Cancer	0.078	3

Benzene, Toluene, and MTBE all exceed the Tier 1 RBSLs and are considered COCs for the site. Next, the Master Table (Table 4) is consulted to determine the basis (direct contact or leaching to groundwater) of the Table 1 RBSL.

Compound	Cancer/Non-Cancer Basis	Leaching to Groundwater RBSL mg/kg	Direct Contact Residential RBSL mg/kg	Site Concentration mg/kg
Benzene	Cancer	0.07	1.3	0.9
Toluene	Non-cancer	21	610	30
MTBE	Cancer	0.078	52	3

By using the Master Table, the exceedances seen in the Tier 1 evaluation for all three compounds were based on leaching to groundwater. Since the groundwater data indicated that leaching of remaining contamination is not occurring, soil concentrations can be screened using the Direct

Contact Residential RBSL to determine whether a direct contact risk is present. In this example, leaching has been shown to not be a concern for the site and site concentrations do not exceed the direct contact RBSLs therefore, the site could be closed without further remediation or evaluation.

5.2 Direct Contact Exceedance

Tier 1 site screening is conducted when not much information is known about a site to ensure that any decision not to remediate the site does not leave an unacceptable risk. Because of this conservatism, it may be acceptable to adjust the Tier 1 RBSLs for a Tier 2 site-specific screening evaluation.

These adjustments are only appropriate for direct contact exposure and are NOT appropriate for screening levels (RBSLs and SSLs in the EPA RSL tables) that are based on leaching to groundwater. Section 5.3 outlines the steps that can be taken for site-specific leaching to groundwater evaluations.

Cancer-causing compounds (carcinogens) represent some risk of getting cancer even at low concentrations. In the RBCA Tier 1 or 2 evaluations all cancer risks are treated the same (e.g., there is no differentiation between skin cancer and liver cancer). The State of Montana allows an excess lifetime cancer risk level of 1 in 100,000 or 1×10^{-5}. The RBSLs based upon direct contact for carcinogens are based upon $1/10^{th}$ of that risk or 1 in 1,000,000 or 1×10^{-6}. Therefore, a site could have up to 10 carcinogenic compounds present at concentrations as high as their respective screening levels and still not have a cumulative cancer risk that exceeds the allowable risk level of 1×10^{-5}.

Carcinogens may also have non-carcinogenic effects and there are other compounds that are not known or suspected to cause cancer (non-carcinogens). Non-carcinogens have known threshold concentrations below which adverse non-cancer health effects are not expected to occur. This threshold is represented by a reference dose that may be compared to the dose associated with exposure to site concentrations. This comparison is represented by a hazard quotient. A hazard quotient of 1 or less indicates that the dose from the contaminant concentration is not greater than the threshold dose. Non-carcinogens may impact different organs or systems (e.g., liver, kidneys, and central nervous system). If there are several non-carcinogens that affect a particular organ or system, the effects are added together and the sum of the hazard quotients for those compounds is referred to as the hazard index. A hazard index greater than 1 represents a risk to a particular organ or system. Therefore, non-cancer Tier 1 RBSLs levels are adjusted to account for multiple compounds impacting the same organ or system to ensure that the hazard index does not exceed 1.

Each direct contact RBSL listed in the master table represents a hazard quotient of 0.125, since there are eight compounds in each analytical suite (VPH and EPH) that have non-cancer effects. Therefore, if as many as eight petroleum compounds or fractions are present at concentrations as high as their screening levels, and even if all the compounds impact the kidneys, there would still be no adverse health effects expected and the hazard index would not exceed 1.

Because the Tier 1 RBSLs were developed on this conservative basis, it is possible to adjust the RBSLs if all compounds or fractions are not present based upon the verified data for the site. The adjustment is made based upon the number of COCs actually present at the site. The

following are examples to illustrate the process.

Example 2:

Compound	Cancer/Non-Cancer Basis	Tier 1 RBSL (mg/kg)	Site Concentration (mg/kg)
Benzene	Cancer	0.07	1.5
Toluene	Non-cancer	21	850
Ethylbenzene	Cancer	6.4	8
C9-C12 Aliphatics	Non-cancer	77	140
Naphthalene	Cancer	4.3	6

A petroleum site contains benzene, toluene, ethylbenzene, C9-C12 aliphatics, and naphthalene in surface soil. Groundwater had previously been contaminated, but was found to meet RBSLs for the last high and low groundwater monitoring events. The concentrations are first compared to the Tier 1 RBSLs found on Table 1 of the RBCA Guidance.

Since leaching to groundwater is no longer occurring, Table 4, the Master Table, is consulted to identify the direct contact RBSLs. The following table depicts the Master Table direct contact RBSLs, as well as the cancer risk levels and hazard quotients represented by the RBSLs.

Compound	Cancer/ Non-Cancer Basis	Direct Contact Residential RBSL (mg/kg)	Cancer Risk Level	Hazard Quotient*
Benzene	Cancer	1.3	1×10^{-6}	NA
Toluene	Non-cancer	610	NA	0.125
Ethylbenzene	Cancer	6.4	1×10^{-6}	NA
C9-C12 Aliphatics	Non-cancer	77	NA	0.125
Naphthalene	Cancer	4.3	1×10^{-6}	NA
Totals	**--**	**--**	**3×10^{-6}**	**0.25**

Because the sum of the cancer risks and the total hazard index based on the direct contact RBSLs for all the compounds present at the site are less than 1×10^{-5} and 1, respectively, it is acceptable to adjust the RBSLs. The first step is to multiply the Master Table Direct Contact RBSL for each compound by 10 for carcinogens, and by 8 for the non-carcinogens. This removes the conservatism built into the Tier 1 RBSLs to account for the potential presence of all the COCs. Then the adjusted RBSLs for carcinogenic compounds are divided by the number of carcinogenic compounds at the site to divide the risks equally between the different carcinogenic compounds while ensuring that the total risk does not exceed 1×10^{-5}. The same process is conducted for the non-carcinogenic compounds, while ensuring that the combined total does not exceed a hazard index of 1. The following table depicts these adjustments.

Compound	Cancer/ Non-Cancer	Adjustment mg/kg * adj. factor	Adjusted Tier 2 RBSL mg/kg	Cancer Risk Level	Hazard Quotient
Benzene	Cancer	1.3 * 10/3	4.3	3.3×10^{-6}	NA
Toluene	Non-cancer	610 * 8/2	2440	NA	0.5
Ethylbenzene	Cancer	6.4 * 10/3	21	3.3×10^{-6}	NA
C9-C12 Aliphatics	Non-cancer	77 * 8/2	308	NA	0.5
Naphthalene	Cancer	4.3 * 10/3	14	3.3×10^{-6}	NA
Totals	**--**	**--**	**--**	**1×10^{-5}**	**1**

In this example, the adjustment results in each of the carcinogens representing a 3.3×10^{-6} or one third of the total 1×10^{-5} risk. The adjustment results in each of the non-carcinogens representing a hazard index of 0.5 or one half of the total hazard index of 1. Next the site concentrations are compared to the adjusted Tier 2 RBSLs.

Compound	Cancer/Non-Cancer Basis	Adjusted Tier 2 RBSL (mg/kg)	Site Concentration (mg/kg)
Benzene	Cancer	4.3	1.5
Toluene	Non-cancer	2440	850
Ethylbenzene	Cancer	21	8
C9-C12 Aliphatics	Non-cancer	308	140
Naphthalene	Cancer	14	6

Therefore, based upon the groundwater data indicating that leaching of remaining contamination is not occurring and that site concentrations do not exceed the adjusted Tier 2 direct contact RBSLs, the site could be closed without further remediation or evaluation.

The groundwater RBSLs may not be adjusted in the same manner as the soil RBSLs. Many of the Tier 1 RBSLs are DEQ-7 human health standards and therefore may not be adjusted. The RBSLs for the petroleum fractions are already based upon a hazard quotient of 1, similar to the DEQ-7 standards, and may not be adjusted. Finally, the RSLs for 1-methylnaphthalene and 2-methylnaphthalene included in Table 3 have also already been adjusted to be based upon a 1×10^{-5} excess lifetime cancer risk and a hazard quotient of 1. Therefore, site groundwater concentrations should be compared directly to these RBSLs and DEQ-7 human health standards. An exception exists for Class IV groundwater. If the natural condition of the groundwater, is Class IV as defined in Administrative Rules of Montana 17.30.1006, only the carcinogenic HHSs apply.

5.3   Leaching to Groundwater Exceedances

If site soil concentrations exceed leaching to groundwater RBSLs included in the Master Table, it may be possible to demonstrate via groundwater sampling that the groundwater is not or is no longer contaminated. However, it may be necessary to conduct a site-specific Tier 2 analysis. Multiple approaches can be used to calculate site-specific screening levels based on leaching. These calculations vary from simple to complex and generally site-specific soil and hydrological

data are necessary to estimate contaminant travel time through the vadose zone, calculate a site-specific dilution attenuation factor (DAF) and/or conduct fate and transport modeling.

The following sections outline the options available. One of the options below or a combination of more than one may be used to evaluate site-specific leaching to groundwater.

5.3.1 Data Needs

In order to develop site-specific screening levels for leaching to groundwater, it may be necessary to collect additional data to characterize chemical partitioning behavior and the site-specific DAF. Collecting this data during the initial site characterization phase in Tier 1 is recommended to save time and money. Site-specific data needed may include the following, depending on the complexity of the evaluation (i.e., site-specific DAF versus fate and transport modeling):

- **Soil characteristics** from the major soil types present in surface and subsurface soils, and aquifer sediments below the water table: fraction of organic carbon (foc) from uncontaminated areas of the site; dry bulk density; soil moisture; soil pH; and soil texture.
- **Hydrologic characteristics**: hydraulic conductivity; hydraulic gradient; and aquifer thickness.
- **Source characteristics**: COC source dimensions and concentrations; COC leaching characteristics; and non-aqueous phase liquids composition.
- **Chemical biodegradation**: groundwater COC concentrations and geochemical data.

DEQ's Technical Guidance "General Field Data Needs for Fate and Transport Modeling" (DEQ, 2008) identifies the information needed and describes how the data are used for fate and transport modeling. A copy of this guidance can be found under "Guidance/References" at: http://deq.mt.gov/Land/StateSuperfund/resources.

5.3.2 Calculating a Site-Specific Dilution Attenuation Factor

As precipitation moves through contaminated soil, contamination is dissolved in the water. During this movement through the soil column, contaminant concentrations in this liquid, or soil leachate, may be reduced by adsorption and degradation, and once the soil leachate reaches the groundwater, it may be diluted by the clean groundwater within the aquifer. The reduction in concentration is represented by the DAF, defined as the ratio of the contaminant concentration in soil leachate to the concentration in groundwater at the receptor point (EPA, 1996). The DAF is used to assess whether soil concentrations are likely to cause groundwater contamination above DEQ-7 standards or RBSLs for groundwater. A low DAF value indicates little to no dilution or attenuation of contaminants (soil leachate and receptor well concentrations are equal), and high DAF values correspond to a large reduction in contaminant concentration from the soil to the receptor well. The variables in the DAF calculation represent conditions and physical processes occurring at the site; therefore, the following site information is needed for a site-specific DAF assessment:

- Aquifer parameters including hydraulic conductivity, hydraulic gradient, and aquifer thickness
  - Hydraulic conductivity as determined through site-specific aquifer tests (pump or slug tests) or estimated through knowledge of local hydrogeologic conditions (EPA, 1996);

- ◆ Hydraulic gradient as measured on a map of the site's water table, or based on estimates from knowledge of local hydrogeologic conditions (EPA, 1996);
- ◆ Aquifer thickness as determined from soil boring or well logs or based on estimates from knowledge of local hydrogeologic conditions. This information will be used to calculate the mixing zone depth (see equation below). Mixing zone depth should not exceed the aquifer thickness, so if the calculation results in a number larger than the aquifer thickness, use the aquifer thickness in place of the mixing zone depth (EPA, 1996).
- Source length parallel to groundwater flow as determined through site-specific sampling data.
- Infiltration or recharge rate as determined through use of the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1984) or based on estimates of local/regional precipitation to estimate the fraction of the annual precipitation which percolates vertically through the soil column and into the aquifer.

Example Calculation of a site-specific mixing zone depth using the following equation (EPA, 1996):

$$D = [0.0112 \times L^2]^{0.5} + d_a\{1 - EXP\left[\frac{(-LI)}{(Kid_a)}\right]\}$$

Where:

D   = Mixing zone depth (ft)
L   = Length of source parallel to groundwater flow (ft)
d_a = Aquifer Thickness (ft)
I   = Infiltration rate (ft/day)
K   = Aquifer hydraulic conductivity (ft/day)
i   = Hydraulic gradient (ft/ft)

As identified above, if $D > d_a$, replace value for D with d_a in DAF equation below.

Example Calculation of a site-specific DAF using the following equation (EPA, 1996):

$$DAF = 1 + \frac{KiD}{IL}$$

Where:

DAF   = Dilution attenuation factor (unitless)
K   = Aquifer hydraulic conductivity (ft/day)
i   = Hydraulic gradient (ft/ft)
D   = Mixing zone depth (ft)
I   = Infiltration rate (ft/day)
L   = Length of source parallel to flow (ft)

In this example DAF values previously calculated using a Tier 1 soil leaching to groundwater model which incorporated Tier 1 model assumptions have been replaced with site-specific conditions.

Parameter	Tier 2 Site-Specific Values	Units
Aquifer hydraulic conductivity	165	ft/day
Hydraulic gradient	0.0057	ft/ft
Mixing zone depth	10	ft
Infiltration rate	0.00081	ft/day
Length of source parallel to flow	400	ft
Site -Specific DAF	**30**	**--**

Once a site-specific DAF is determined, it can be used in place of the default DAF of 10 built into the leaching-based RBSLs to provide a site-specific evaluation of leaching (e.g., divide the leaching-based RBSL by 10 to remove the default DAF and then multiply the number by the site-specific DAF to get the adjusted, or site-specific, leaching-based screening level). If the contaminant concentrations are less than this site-specific screening level, the leaching to groundwater pathway can be eliminated from concern. For example, assume that a site has benzene in subsurface soil at a concentration of 0.15 mg/kg. The leaching-based RBSL, from Table 4, for benzene is 0.07 mg/kg, so if the RBSL is divided by 10 to remove the generic DAF, and then multiplied by the site-specific DAF of 30 (the DAF calculated in the example above), the resulting site-specific screening level is 0.21 mg/kg. The site concentration of benzene is 0.15 mg/kg, which is less than the site-specific screening level of 0.21 mg/kg, so the benzene concentration is not a concern for the leaching to groundwater pathway.

5.3.3 Vadose Zone Travel Time

The vadose zone travel time of a contaminant is an estimate of how long it will take a COC in the vadose zone to reach groundwater. This information can be used to determine the amount of time it took or the time it will take for a compound to leach to groundwater. It is particularly useful when the date of a release is known and can be used to illustrate that contaminants have already leached and have diluted, attenuated, or degraded, when they will likely reach groundwater, or when their contaminant-specific characteristics are such that they are not likely to reach groundwater. The following steps are included in calculating a COC's travel time:

Step 1 - Calculate vertical pore water velocity though the vadose zone

   (a) Estimate infiltration rate based on precipitation and any water application at the site;
   (b) Estimate representative water filled porosity of vadose zone soils based on measured soil moisture content;
   (c) Divide infiltration rate by water filled porosity = vertical pore water velocity.

Step 2 - Calculate chemical partitioning coefficient K_d – Two Options

   • Option 1 - Calculate using EPA equations in the Soil Screening Guidance Document: Technical Background Document - Part 2: Development Of Pathway-Specific Soil Screening Levels (EPA, 1996; available at https://www.epa.gov/superfund/superfund-

soil-screening-guidance) and site-measured foc:

    (a) **If dealing with pentachlorophenol or other ionizing organic chemicals not addressed under RBCA** use Equation 27 on Page 39 to calculate K_{oc} values as a function of pH. Otherwise, use the EPA-tabulated value for K_{oc}.
    (b) For organics use Equation 23 on Page 37 to calculate $K_d = K_{oc}f_{oc}$; for inorganics use the EPA-tabulated value for K_d.

- Option 2 - **If Synthetic Precipitation Leaching Procedure** (**SPLP) analysis has been conducted**: calculate site-specific K_d using Equation 22 on Page 36 of the Soil Screening Guidance – Part 2 (see Option 1 above for link). Use the measured SPLP water concentration for C_w, and the measured chemical concentration in the soil concentration for C_t.

Step 3 Calculate chemical retardation coefficient in vadose zone soils

Use Equation (3) in the Simple Derivation of the Retardation Equation and Application to Preferential Flow and Macrodispersion (Bouwer, 1991; available at http://info.ngwa.org/gwol/pdf/910655328.PDF) to calculate the chemical retardation coefficient.

Step 4 Calculate chemical velocity in vadose zone soils

Chemical velocity in vadose zone = (vertical pore water velocity) / (retardation coefficient)

Step 5 Solve for chemical travel time to water table

Chemical travel time to water table = (distance between contamination and groundwater) / (chemical velocity in vadose zone)

The following discussion provides an example of a situation where this approach may be used to evaluate the leaching potential at a site.

The following compounds are present in the silty clay soil at a site at concentrations above the leaching-based Tier 1 RBSLs: benzene, naphthalene, benzo(a)anthracene, and benzo(a)pyrene. The calculations show that benzene would have leached in approximately two years, naphthalene in 24 years, benzo(a)anthracene in 7,100 years, and benzo(a)pyrene in 19,000 years. The release was documented to have occurred 22 years previously and groundwater has been sampled periodically since the release. Evaluation of the groundwater data shows that benzene has routinely been detected at concentrations above the DEQ-7 standard/RBSL, naphthalene was detected in samples historically, but is no longer seen at concentrations above the DEQ-7 standard/RBSL, and benzo(a)anthracene and benzo(a)pyrene have never been detected in groundwater at the site. As a result of this exercise, benzene remains the only compound of concern. Naphthalene, while a problem historically, has leached and concentrations are now reduced below the DEQ-7 standard/RBSL and the PAH compounds are unlikely to ever reach groundwater given their relative immobility in this setting, as determined through the calculations.

5.3.4 Synthetic Precipitation Leaching Procedure

SPLP is a sample preparation method developed by the EPA to model an acid rain leaching environment. It is designed to predict the mobility of organic and inorganic compounds and determine the potential for leaching to ground and surface waters. SPLP data can be used to quantify contaminant partitioning in soils but should not be used by directly comparing to DEQ-7 standards. Soil samples need to be collected from the same interval and analyzed for the COC using the normal soil analytical methods and SPLP (which will result in a leachate (liquid - µg/L) concentration). Once collected, the data can be used to develop a site-specific leaching to groundwater screening level. This can be done in the following ways:

- To define site-specific partitioning behavior (i.e., calculate the soil water partitioning coefficient or K_d). The ratio between the total soil concentration and the reported COC SPLP concentration can be used to define the partitioning behavior. This can be used in fate and transport modeling in place of literature values and is discussed in DEQ's Technical Guidance "General Field Data Needs for Fate and Transport Modeling" (DEQ, 2008). A copy of this guidance can be found under "Guidance/References" at: http://deq.mt.gov/Land/StateSuperfund/resources.
- To develop a site-specific leaching to groundwater screening level. There are several ways to do this, as described in New Jersey Department of Environmental Protection's "Development of Site-Specific Impact to Ground Water Soil Remediation Standards Using the Synthetic Precipitation Leaching Procedure" (NJDEP, 2013).

5.4   Summary of Tier 2 Evaluation Procedures

Procedures for evaluating a release using RBCA Tier 2 are summarized as follows:

1) Complete a RBCA Tier 1 evaluation. If groundwater has been impacted or direct contact/leaching to groundwater COCs cannot easily be cleaned up to meet Tier 1 RBSLs, it may be appropriate to proceed with the following steps.
2) Conduct a Tier 2 COC Exceedance Evaluation:
   a) Determine both direct contact and leaching to groundwater COCs based on the Master Table, Table 4.
      - Leaching to groundwater RBSLs are based on the sample depth and distance to groundwater. Distance to groundwater is the distance between the sample depth and the depth to high groundwater.
      - For both surface (0-2 feet bgs) and subsurface (>2 feet bgs) soils, if groundwater at the site is less than ten feet below the sample location, the first column of RBSLs apply.
      - For both surface (0-2 feet bgs) and subsurface (>2 feet bgs) soil, if groundwater at the site is between ten and twenty feet below the bottom of soil contamination location, the second column of RBSLs apply.
      - For both surface (0-2 feet bgs) and subsurface (>2 feet bgs) soil, if groundwater at the site is greater than twenty feet below the bottom of soil contamination location, the third column of RBSLs apply.
      - Direct contact RBSLs for surface soils (0.-2 ft. bgs) are based on a site's use (residential or commercial). Both current and future use of the site should be evaluated.

- If anyone lives at the site or may live at the site in the future, residential RBSLs apply to surface soil.
- If the site is used as a place of business with employees present regularly and no one lives at the site or may live there in the future, commercial RBSLs apply to surface soil.
- Construction RBSLs are used for samples collected from 0-10 ft. bgs and apply to both residential and commercially used properties.

b) If leaching to groundwater is not a concern or has been previously addressed then soil data may be compared to the Master Table direct contact RBSLs. If no Tier 2 direct contact exceedances are present the site may be considered for closure.

c) If Tier 2 direct contact or leaching to groundwater RBSLs are exceeded, then remediation or further evaluation outlined in the following steps may be appropriate.

3) Direct Contact Evaluation - RBSL Adjustments:
   a) If soil sampling results, following the Tier 2 COC exceedance evaluation, exceed direct contact RBSLs, site-specific screening levels may be calculated following the steps in Section 5.2.
   b) If site COC concentrations are below site-specific screening levels, the site may be evaluated for closure.
   c) If site COC concentrations are above site-specific screening levels, additional remediation or evaluation may need to be implemented.

4) Leaching to Groundwater Evaluation:
   a) If site soil concentrations exceed Tier 2 leaching to groundwater RBSLs (Table 4), a site-specific leaching to groundwater analysis may be appropriate.
   b) If soil sampling results, following the Tier 2 COC exceedance evaluation, exceed leaching to groundwater RBSLs, site-specific screening levels should be calculated.
   c) Collection of site-specific soil and hydrologic data may be needed prior to completing the steps below.
   d) The site-specific leaching to groundwater evaluation may include calculating a site-specific DAF, modeling vadose zone travel time of COCs, or calculating a site-specific screening level using the SPLP method. See Section 5.3 for details on each option.
   e) If site COC concentrations are below site-specific screening levels, the site may be evaluated for closure.
   f) If site COC concentrations are above site-specific screening levels, additional remediation or evaluation may need to be completed.

6.0 TIER 3 RBCA EVALUATION

The amount of contamination at some sites or the complexity of the site may warrant a thorough site-specific risk-based analysis, or Tier 3 RBCA evaluation. For these sites, a baseline human health and possibly even a baseline ecological risk assessment may be appropriate. These analyses may take into account recreational or other land uses, may evaluate risks to surface water, may take into account climate or soil temperature data, and may include analyses of target organs, among other things. Please refer to DEQ's Frequently Asked Questions at http://deq.mt.gov/Land/StateSuperfund/FrequentlyAskedQuestions for additional information on these types of risk assessments.

Computer modeling programs may be appropriate to support a detailed assessment (or Tier 3 evaluation) of chemicals leaching to groundwater. Complexity should only be added when

compelling reasons exist to warrant detailed modeling of chemical behavior or site characteristics. Several well documented computer programs have been developed to model chemical leaching to groundwater, including, but not limited to, VS2DI and HYDRUS. Tier 3 computer modeling should be coordinated with DEQ during the design, execution, and evaluation of modeling results.

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Tables

TABLE 1
TIER 1 SURFACE SOIL (0-2 ft) RBSLs (mg/kg)
(includes default RBSLs)

This table applies to contaminated surface soil from 0-2 feet below ground surface. Distance to water is from the sample depth to the water table. **For VPH compounds at UST sites, default RBSLs (bold) are used to determine if a release has occurred at a site. Default RBSLs apply to the entire soil column and always apply in the absence of adequate information. For EPH compounds, the 200 ppm EPH screen concentration is used to determine if additional analysis (fractionation) is needed.**

Distance to groundwater		< 10 feet to groundwater				10-20 feet to groundwater				> 20 feet to groundwater			
Chemical units (mg/kg = ppm)	E	Residential RBSL (mg/kg)	B	Commercial RBSL (mg/kg)	B	Residential RBSL (mg/kg)	B	Commercial RBSL (mg/kg)	B	Residential RBSL (mg/kg)	B	Commercial RBSL (mg/kg)	B
For Gasoline and Light Hydrocarbons measured using the Massachusetts Method for Volatile Petroleum Hydrocarbons (VPH)													
C5-C8 Aliphatics	n	**52**	dc	220	1	52	dc	290	dc	52	dc	290	dc
C9-C12 Aliphatics	n	**77**	dc	360	dc	77	dc	360	dc	77	dc	360	dc
C9-C10 Aromatics	n	**130**	l/dc	130	1	130	dc	470	1	130	dc	720	1
MTBE	c	**0.078***	1	0.078*	1	0.16	1	0.16	1	0.25	1	0.25	1
Benzene	c	**0.07**	1	0.07	1	0.21	1	0.21	1	0.33	1	0.33	1
Toluene	n	**21**	1	21	1	65	1	65	1	100	1	100	1
Ethylbenzene	c	**6.4**	dc	26	1	6.4	dc	28	dc	6.4	dc	28	dc
Xylenes	n	**72**	dc	310	dc	72	dc	310	dc	72	dc	310	dc
Naphthalene	c	**4.3**	dc	12	1	4.3	dc	19	dc	4.3	dc	19	dc
Lead Scavengers													
1,2-Dibromoethane (EDB)	c	**0.000086***	1	0.000086*	1	0.00022*	1	0.00022*	1	0.00033*	1	0.00033*	1
1,2-Dichloroethane (DCA)	c	**0.019**	1	0.019	1	0.052	1	0.052	1	0.079	1	0.079	1
For Diesel and Heavy Hydrocarbons measured using the Massachusetts Method for Extractable Petroleum Hydrocarbons (EPH)													
EPH Screen, Fractionate		**200**		200		200		200		200		200	
C9-C18 Aliphatics	n	**110**	dc	540	dc	110	dc	540	dc	110	dc	540	dc
C19-C36 Aliphatics	n	**24,000**	dc	200,000	dc	24,000	dc	200,000	dc	24,000	dc	200,000	dc
C11-C22 Aromatics	n	**370**	1	370	1	490	1	1,300	1	490	1	2,000	1
Acenaphthene	n	**27**	1	27	1	91	1	91	1	140	1	140	1
Anthracene	n	**2,200**	dc	2,600	1	2,200	dc	8,800	1	2,200	dc	14,000	1
Benz(a)anthracene	c	**1.3**	dc	6.8	1	1.3	dc	23	1	1.3	dc	24	dc
Benzo(a)pyrene	c	**0.13****	dc	2.3	1	0.13**	dc	2.4	dc	0.13**	dc	2.4	dc
Benzo(b)fluoranthene	c	**1.3**	dc	23	1	1.3	dc	24	dc	1.3	dc	24	dc
Benzo(k)fluoranthene	c	**13**	dc	230	1	13	dc	240	dc	13	dc	240	dc
Chrysene	c	**130**	dc	690	1	130	dc	2,300	1	130	dc	2,400	dc
Dibenzo(a,h)anthracene	c	**0.13****	dc	2.4	dc	0.13**	dc	2.4	dc	0.13**	dc	2.4	dc
Fluoranthene	n	**85**	1	85	1	280	1	280	1	300	dc	440	1
Fluorene	n	**35**	1	35	1	120	1	120	1	180	1	180	1
Indeno(1,2,3-cd)pyrene	c	**1.3**	dc	24	dc	1.3	dc	24	dc	1.3	dc	24	dc
Naphthalene	c	**4.3**	dc	12	1	4.3	dc	19	dc	4.3	dc	19	dc
Pyrene	n	**83**	1	83	1	220	dc	280	1	220	dc	430	1
1-Methylnaphthalene	c	**2.1**	1	2.1	1	7.1	1	7.1	1	11	1	11	1
2-Methylnaphthalene	n	**6.9**	1	6.9	1	23	1	23	1	30	dc	35	1

Notes:

E = Effect is either: n = non-carcinogenic and direct contact RBSLs are based on a hazard quotient of 0.125 for a total hazard index which does not exceed 1, or

c = carcinogenic and direct contact RBSLs are based on a cancer risk of 1×10^{-6} for a total cancer risk which does not exceed 1×10^{-5}.

RBSLs for residential and commercial exposure to naphthalene are based upon carcinogenic inhalation risk.

B = Basis is the most conservative of: l = leaching from soil to groundwater;

dc = residential direct contact including ingestion, inhalation, and dermal; or

bu = adversely affects beneficial uses (foul odor or taste).

If the leaching pathway is not the most conservative basis, residential or commercial RBSLs apply to surface soil.

* = The best achievable practical quantitation limit (0.20) is greater than the RBSL; therefore, if the compound is detected, additional evaluation may be necessary.

** = The best achievable practical quantitation limit (0.33) is greater than the RBSL; therefore, if the compound is detected, additional evaluation may be necessary.

For information regarding odor considerations, please refer to the Odors as a Significant Risk to Public Welfare/Nuisance Condition Section of the Montana Tier 1 Risk-Based Corrective Action Guidance for Petroleum Releases.

The RBSLs for soil and water are not designed to be protective of the vapor intrusion (VI) pathway. Please refer to the Vapor Intrusion to Indoor Air Section of the Montana Tier 1 Risk-Based Corrective Action Guidance for Petroleum Releases.

TABLE 2
TIER 1 SUBSURFACE SOIL (>2 ft) RBSLs (mg/kg)

This table applies to contaminated subsurface soil (>2 feet below the ground surface).   Distance to water is from the sample depth to the water table. **For VPH compounds at UST sites, default RBSLs, provided in bold on Table 1, are used to determine if a release has occurred at a site. Default RBSLs apply to the entire soil column and always apply in the absence of adequate information. For EPH compounds the 200 ppm screen concentration is used to determine if additional analysis (fractionation) of the soil sample is needed.**

Distance to groundwater		< 10 feet to ground water		10-20 feet to ground water		> 20 feet to ground water	
Chemical units (mg/kg = ppm)	E	>2 ft Construction RBSL (mg/kg)	B	>2 ft Construction RBSL (mg/kg)	B	>2 ft Construction RBSL (mg/kg)	B
For Gasoline and Light Hydrocarbons measured using the Massachusetts Method for Volatile Petroleum Hydrocarbons (VPH)							
C5-C8 Aliphatics	n	220	l	410	dc	410	dc
C9-C12 Aliphatics	n	640	dc	640	dc	640	dc
C9-C10 Aromatics	n	130	l	470	l	720	l
MTBE	c	0.078*	l	0.16	l	0.25	l
Benzene	c	0.07	l	0.21	l	0.33	l
Toluene	n	21	l	65	l	100	l
Ethylbenzene	c	26	l	84	l	130	l
Xylenes	n	320	l	610	dc	610	dc
Naphthalene	n	12	l	40	l	62	l
Lead Scavengers							
1,2-Dibromoethane (EDB)	c	0.000086*	l	0.00022*	l	0.00033*	l
1,2-Dichloroethane (DCA)	c	0.019	l	0.052	l	0.079	l
For Diesel and Heavy Hydrocarbons measured using the Massachusetts Method for Extractable Petroleum Hydrocarbons (EPH)							
EPH Screen, Fractionate		200		200		200	
C9-C18 Aliphatics	n	900	dc	900	dc	900	dc
C19-C36 Aliphatics	n	200,000	dc	200,000	dc	200,000	dc
C11-C22 Aromatics	n	370	l	1,300	l	2,000	l
Acenaphthene	n	27	l	91	l	140	l
Anthracene	n	2,600	l	8,800	l	14,000	l
Benz(a)anthracene	c	6.8	l	23	l	35	l
Benzo(a)pyrene	c	2.3	l	7.5	l	12	l
Benzo(b)fluoranthene	c	23	l	76	l	120	l
Benzo(k)fluoranthene	c	230	l	750	l	1,200	l
Chrysene	c	690	l	2,300	l	3,500	l
Dibenzo(a,h)anthracene	c	7.5	l	24	l	38	l
Fluoranthene	n	85	l	280	l	440	l
Fluorene	n	35	l	120	l	180	l
Indeno(1,2,3-cd)pyrene	c	77	l	250	l	380	l
Naphthalene	n	12	l	40	l	62	l
Pyrene	n	83	l	280	l	430	l
1-Methylnaphthalene	c	2.1	l	7.1	l	11	l
2-Methylnaphthalene	n	6.9	l	23	l	35	l

Notes:

E = Effect is either: n = non-carcinogenic and direct contact RBSLs are based on a hazard quotient of 0.125 for a total hazard index which does not exceed 1, or

c = carcinogenic and direct contact RBSLs are based on a cancer risk of $1X10^{-6}$ for a total cancer risk which does not exceed $1X10^{-5}$.

RBSLs for construction work are based upon noncarcinogenic risk, including ingestion, dermal, and inhalation.

B = Basis is the most conservative of:
l = leaching from soil to groundwater;
dc = residential direct contact including ingestion, inhalation, and dermal; or
bu = adversely affects beneficial uses (foul odor or taste).

If the leaching pathway is not the most conservative basis, excavation RBSLs apply to subsurface soil.

* = The best achievable practical quantitation limit (0.20) is greater than the RBSL; therefore, if the compound is detected, additional evaluation may be necessary.

For information regarding odor considerations, please refer to the Odors as a Significant Risk to Public Welfare/Nuisance Condition Section of the Montana Tier 1 Risk-Based Corrective Action Guidance for Petroleum Releases.

The RBSLs for soil and water are not designed to be protective of the vapor intrusion (VI) pathway. Please refer to the Vapor Intrusion to Indoor Air Section of the Montana Tier 1 Risk-Based Corrective Action Guidance for Petroleum Releases.

TABLE 3
TIER 1 GROUNDWATER RBSLs AND STANDARDS

This table applies to groundwater and consists of DEQ-7 Human Health Standards (HHSs; DEQ 2012), where available. For compounds without DEQ-7 HHSs, DEQ has developed RBSLs and included them in the table. For EPH compounds, a total extractable hydrocarbon (TEH) concentration of 1,000 µg/L is used to determine if additional analysis (fractionation) is needed. Surface water impacts require a minimum of a Tier 2 evaluation.

Chemical	Effect	Basis	Groundwater Standard or RBSL (µg/l)
For Gasoline and Light Hydrocarbons measured using the Massachusetts Method for Volatile Petroleum Hydrocarbons (VPH)			
C5-C8 Aliphatics [(b)]	n	rb	650
C9-C12 Aliphatics [(b)]	n	rb	1,400
C9-C10 Aromatics [(b)]	n	rb	1,100
MTBE	n	hhs	30
Benzene	c	hhs	5
Toluene	n	hhs	1,000
Ethylbenzene	n	hhs	700
Xylenes	n	hhs	10,000
Naphthalene	c	hhs	100
Lead Scavengers			
Ethylene dibromide (EDB)	c	hhs	0.017
1,2-Dichloroethane (DCA)	c	hhs	4
For Diesel and Heavy Hydrocarbons measured using the Massachusetts Method for Extractable Petroleum Hydrocarbons (EPH)			
EPH / TEH Screen fractionation required [(a)]			1,000
C9-C18 Aliphatics [(b)]	n	rb	1,400
C19-C36 Aliphatics	n	bu	1,000
C11-C22 Aromatics [(b)]	n	rb	1,100
Acenaphthene	n	hhs	70
Anthracene	n	hhs	2,100
Benz(a)anthracene	c	hhs	0.5
Benzo(a)pyrene	c	hhs	0.05*
Benzo(b)fluoranthene	c	hhs	0.5
Benzo(k)fluoranthene	c	hhs	5
Chrysene	c	hhs	50
Dibenzo(a,h)anthracene	c	hhs	0.05*
Fluoranthene	n	hhs	20
Fluorene	n	hhs	50
Indeno(1,2,3-cd)pyrene	c	hhs	0.5
Naphthalene	c	hhs	100
Pyrene	n	hhs	20
1-Methylnaphthalene	c	rsl	11
2-Methylnaphthalene	n	rsl	36

Notes:
(a) = An exceedance of the 1,000 µg/l EPH/TEH screen value indicates only that fractionation is required. If none of the fractions exceed, then the EPH/TEH value does not need to be identified as a COPC exceeding RBSLs.

(b) = The fraction surrogate (for modeling purposes) uses a representative compound with a mid range Equivalent Carbon Number (Massachusetts DEP 2002 Table 4-14). This number doesn't take into account the higher molecular weight compounds that have higher solubilities than the fraction surrogate therefore underestimating the overall solubility of the fraction.

Effect is either: n = non-carcinogenic RBSLs and RSLs are based on a hazard quotient of 1, or
c = carcinogenic RBSLs and RSLs are based on a cancer risk $1X10^{-5}$.

Basis is: rb = risk-based screening level;
hhs = DEQ-7 Human Health Standard (DEQ, October 2012. Circular DEQ-7 Montana Numeric Water Quality Standards); or
rsl = tapwater risk-based screening level based upon TR of 1E-05 and THQ of 1.0 consistent with DEQ-7
bu = adversely affects beneficial uses (foul taste or odor).
* = The best achievable practical quantitation limit (0.1 µg/L) may be greater than the human health standard; therefore, if the compound is detected, additional evaluation may be necessary.

The RBSLs for soil and water are not designed to be protective of the vapor intrusion (VI) pathway. Please refer to the Vapor Intrusion to Indoor Air Section of the Montana Risk-Based Corrective Action Guidance for Petroleum Releases.

TABLE 4 - MASTER TABLE
ALL POTENTIAL TIER 1 RBSLs FOR SOIL (mg/kg)
Leaching RBSLs are based on the distance from the bottom of the contamination to the groundwater.

Chemical	Leaching 0-10 feet	Leaching 10-20 feet	Leaching >20 feet	Direct Contact Residential	Direct Contact Commercial*	Direct Contact Construction
For Gasoline and Light Hydrocarbons measured using the Montana Method for Volatile Petroleum Hydrocarbons (VPH)						
C5-C8 Aliphatics	220	770	1,200	52	290	410
C9-C12 Aliphatics	11,000	40,000	60,000	77	360	640
C9-C10 Aromatics	130	470	720	130	1,000	1,000
MTBE	0.078	0.16	0.25	52	230	8,900
Benzene	0.07	0.21	0.33	1.3	5.7	240
Toluene	21	65	100	610	5,500	5,500
Ethylbenzene	26	84	130	6.4	28	1,300
Xylenes	320	1,000	1,600	72	310	610
Naphthalene**	12	40	62	4.3^c	19^c	140^n
Lead Scavengers						
1,2-Dibromoethane (EDB)	0.000086	0.00022	0.00033	0.04	0.18	7.8
1,2-Dichloroethane (DCA)	0.019	0.052	0.079	0.52	2.3	110
For Diesel and Heavy Hydrocarbons measured using the Montana Method for Extractable Petroleum Hydrocarbons (EPH)						
C9-C18 Aliphatics	53,000	170,000	270,000	110	540	900
C19-C36 Aliphatics	Considered Immobile			24,000	200,000	200,000
C11-C22 Aromatics	370	1,300	2,000	490	3,900	3,900
Acenaphthene	27	91	140	450	3,800	3,800
Anthracene	2,600	8,800	14,000	2,200	19,000	19,000
Benz(a)anthracene	6.8	23	35	1.3	24	390
Benzo(a)pyrene	2.3	7.5	12	0.13	2.4	39
Benzo(b)fluoranthene	23	76	120	1.3	24	390
Benzo(k)fluoranthene	230	750	1,200	13	240	3,900
Chrysene	690	2,300	3,500	130	2400	39,000
Dibenzo(a,h)anthracene	7.5	24	38	0.13	2.4	39
Fluoranthene	85	280	440	300	2,500	2,500
Fluorene	35	120	180	300	2,500	2,500
Indeno(1,2,3-cd)pyrene	77	250	380	1.3	24	390
Naphthalene**	12	40	62	4.3^c	19^c	140^n
Pyrene	83	280	430	220	1,900	1,900
1-Methylnaphthalene	2.1	7.1	11	20	81	1,400
2-Methylnaphthalene	6.9	23	35	30	250	250

* = Construction workers are exposed to both surface and subsurface soil. The lower of construction or commercial RBSLs are provided here.

** = Naphthalene has both carcinogenic (^{c}) and non-carcinogenic effects (^{n}). For residential and commerial receptors the carcinogenic RBSLs are lower. For construction workers the non-carcinogenic RBSL are lower. Please use the appropriate adjustment for Tier 2 analysis (see Section 5.2).

Table 5: Conceptual Site Model (CSM) - Evaluation of Exposure Pathways (MT DEQ PTCS 03/22/2018)

Consultant:			Date:		DEQ PM:		
Facility Name:							
Facility ID:			**Release:**		**WP ID:**		Describe for each Receptor: contaminant(s) and whether a non-threat, threat or impact
Petroleum Source(s)	**Affected Medium**	**Exposure Medium / Point**		**Exposure Route**		**Receptor**	

Required: Complete Description of the Source(s) of Petroleum or other Contaminants

Affected Medium	Exposure Medium / Point	Exposure Route	Receptor	Describe
Surface Soil (0 - 2 ft bgs)	Soil	Ingestion Dermal	Resident and/or Worker	
	Soil	Leaching	Groundwater	
	Dust/Vapors	Inhalation	Resident and/or Worker	
	Surface Erosion to Surface Water and Sediment	Ingestion Dermal	Recreator, Ecological Receptor [1]	
Sub-Surface Soil (> 2 ft bgs)	Soil	Ingestion Dermal	Construction Worker [2]	
	Soil	Leaching	Groundwater	
	Indoor Air	Inhalation	Commercial or Residential Indoor Air	
	Dust/Vapors	Inhalation	Construction Worker	
	Buried Water Line	Ingestion Dermal	Resident and/or Worker	
	Buried Utility Line	Inhalation of Indoor Air	Indoor Resident and/or Worker	
Groundwater	Groundwater		State water [3]	
	Indoor Air [4]	Inhalation of Indoor Air	Resident and/or Worker	
	Groundwater and Vapors	Ingestion Dermal Inhalation	Construction Worker [2]	
	Drinking Water	Ingestion Dermal	Resident and/or Worker	
	Surface Water and/or Sediment	Ingestion Dermal Inhalation	Recreator, Ecological Receptor	
	Buried Water Line	Ingestion Dermal	Resident and/or Worker	
	Buried Utility Line	Inhalation of Indoor Air	Indoor Resident and/or Worker	

Data Gaps:	
Recommendations:	

Footnotes:
1. Ecological Receptors (e.g. plants and animals) can be added as a separate line associated with surface soil but it is not common for PTC sites.
2. Construction worker covers excavations conducted for building construction, utility installation and repair, as well as residents planting trees, etc.
3. Standard or RBSL exceedence are a complete pathway to a receptor, which is state water (or groundwater).
4. Indoor Air is the exposure medium for a potential or known vapor intrusion setting where a resident or an employee of a business may breathe petroleum vapor from the release.

Appendix A

VADOSE ZONE MODELING TECHNICAL SUPPORT DOCUMENT

SOIL LEACHING TO GROUNDWATER MODELING

This appendix describes the methods the Montana Department of Environmental Quality (DEQ) used to develop Tier 1 soil leaching to groundwater risk-based screening levels (RBSLs). The soil leaching to groundwater RBSLs were calculated using two computer codes and the EPA soil-water partition equation for organic contaminants (*Soil Screening Guidance Technical Support Document*, EPA, 1996). The EPA partitioning equation was used to relate chemical of concern (COC) concentrations in soil moisture to the total concentration detected in a soil sample, assuming linear partitioning and equilibrium conditions. Dilution/Attenuation Factors (DAFs), representing the ratio of COC concentration in soil leachate at the source area to the COC concentration at the down gradient edge (DGE) were calculated using the VS2DT Solute Transport in Variably Saturated Porous Media code developed by the USGS. The DGE was established as a monitoring well constructed at the downgradient edge of the contaminated source zone, with a well screen extending 1 meter into the water table. The Hydrologic Evaluation of Landfill Performance (HELP) code (U.S. Army Engineer Waterways Experiment Station) was used to generate a generic water budget, including estimates of water infiltration, runoff, evapotranspiration, and soil moisture percolation rates into the contaminated source area. The percolation rates generated by the HELP code were incorporated into the VS2DT modeling.

Physical processes simulated by the DEQ Tier 1 soil leaching to groundwater model include COC adsorption and desorption onto vadose zone soils and the aquifer matrix, advection and hydrodynamic dispersion of COCs in the vadose and saturated zones, and dilution due to mixing of soil leachate and groundwater. The model setup includes a finite contaminant source zone. Biological degradation of the COCs is not considered in the model.

Three scenarios were simulated. In the most conservative scenario, the contaminated source was assumed to be located 0.1 meter above the water table. In the second scenario, the distance between the source and the water table was 3.1 meters. The final scenario incorporated a 6.1-meter layer of unimpacted soil between the source and the water table. DEQ-7 human health standards were used as the groundwater target for individual COCs. Groundwater targets for petroleum fractions were developed based on the toxicity and aesthetics of surrogate chemicals representative of each fraction. In all cases, the soil RBSL represents a COC concentration that, based on the results of the modeling effort, would produce a maximum groundwater concentration equal to the groundwater target at the DGE.

Generic application of the RBSLs to petroleum release sites throughout Montana dictated the use of several conservative assumptions in the soil leaching to groundwater model. Conservative elements included the use of sandy soil as the default soil type, incorporation of an upper end estimate of the water percolation rate, and the assumption that no biodegradation of COCs in the vadose or saturated zones occurs. A description the VS2DT and HELP codes, model input parameters, and results of the modeling efforts are presented below.

Model Description: VS2DT

VS2DT simulates the movement of water in variably saturated porous media under isothermal and isohaline conditions. The governing equation describing the movement and occurrence of water combines the principle of conservation of mass with equations for fluid flux and storage. A thorough discussion of the derivation of VS2D, the USGS code prior to the addition of a solute transport module, is presented in *Documentation of Computer Program VS2D to Solve the Equations of Fluid Flow in Variably Saturated Porous Media*, USGS, 1987. The code uses finite differences to discretize spatial and temporal domains. Non-linear conductance and storage terms and unsaturated hydraulic conductivities are calculated using equations developed by Brooks and Corey, van Genuchten, or Haverkamp.

The code was modified in 1990 to simulate solute transport, using a governing equation accounting for advective transport, hydrodynamic dispersion, and solute sources and sinks. The hydrodynamic dispersion term includes mechanical dispersion and molecular diffusion in water. The code does not simulate volatilization or COC movement in soil vapor. A discussion regarding the addition of the solute transport module is presented in *Simulation of Solute Transport in Variably Saturated Porous Media With Supplemental Information on Modifications to the U.S. Geological Survey's Computer Program VS2D*, USGS, 1990.

Model Description: HELP

The HELP code was written to simulate water movement through landfills. The model accepts weather, soil, and design data and accounts for surface water and snow storage, snowmelt, runoff, infiltration, evapotranspiration, vegetative growth, soil moisture storage, and unsaturated vertical drainage. The HELP code uses many routines previously developed and used in other hydrologic models, including the WGEN synthetic weather generator (U.S. Department of Agriculture) and Soil Conservation Service (SCS) runoff curves. Snowmelt modeling is based on the National Weather Service River Forecast System Snow Accumulation and Ablation Model, and frozen soils are simulated using a subroutine from the Chemicals, Runoff, and Erosion from Agricultural Management System (CREAMS) code. Vertical drainage is simulated using Darcy□s law using unsaturated hydraulic conductivity based on the Brooks and Corey relationship. Results are expressed as daily, monthly, and annual water budgets. Documentations of the HELP Model include the *HELP Model User's Guide for Version 3*, EPA, 1994 and the *HELP Model Engineering Documentation for Version 3*, EPA, 1994.

DEQ Soil Leaching Model Setup

The conceptual model for the soil leaching to groundwater pathway was developed as a two-dimensional cross-section consisting of a vadose zone of varying thickness overlying a water table aquifer two meters in thickness. Soil properties were homogeneous and isotropic throughout the model domain. The vertical profile consisted of 1.4 meters of unimpacted soil, overlying 1.5 meters of contaminated soils, overlying a 2-meter saturated zone located 0.1 meter, 3.1 meters, and 6.1 meters below the bottom of the contaminated soils.

The HELP modeling was performed to simulate water movement through the top 1.5-meter layer of soil and generate a soil moisture flux rate for the top boundary of the VS2DT model domain. The HELP code was selected based on its widespread use, flexibility, and thorough documentation. Necessary soil data included porosity, field capacity, wilting point, saturated hydraulic conductivity, initial moisture storage, and SCS runoff curve number. Design specifications included vegetative cover, soil layer thickness and areal dimensions, surface slope and slope length, and evaporative zone depth. Daily precipitation for six Montana cities (Billings, Great Falls, Havre, Helena, Kalispell, and Miles City) was simulated by the HELP code for a 30-year period based on statistical qualities of 5 years of daily field data recorded in these cities. In the same manner, 30 years of synthetic daily temperature and solar radiation data were generated by the code.

The top of the soil column was modeled as bare ground with a surface slope of 1 percent, with 95 percent of the surface area available for runoff. Default soil properties for a well-graded sand (soil texture #3) were used in the HELP model. This soil series was selected primarily due to its saturated hydraulic conductivity value, which was approximately one-half the value used in the VS2DT simulation. This reduction in conductivity was included to reflect a moderate degree of compaction expected in surface soils and/or the presence of a semi-permeable cover at many sites. HELP model results indicated that percolation through the bottom of the 1.5-meter layer ranged from 8.3 cm/yr (Kalispell) to 3.8 cm/yr (Helena).

VS2DT Boundary Conditions

The VS2DT model domain was 13 meters in the horizontal direction and 5, 8, and 11 meters in the vertical direction, depending on the depth to groundwater. The top horizontal boundary of the VS2DT model domain was set as a constant flux boundary, and a percolation rate of 2.5×10^{-4} meters per day, corresponding to the Kalispell percolation rate, was used. A water saturated zone was established using constant head boundaries extending 2 meters up from the bottom of the model domain, and were set with a total head difference of 0.06 meters from the left side to the right side of the model domain, resulting in a groundwater gradient of 0.005 m/m. The bottom of the model domain was set 2 meters below and parallel to the water table, and the bottom boundary of the domain and side boundaries of the vadose zone were set as no flow boundaries. The source zone dimensions were set to 9 meters wide (parallel to the groundwater flow direction) and 1.5 meters in thickness. The contaminated source was bordered by two meters of unimpacted soils on each side.

VS2DT Initial Conditions

The VS2DT code requires that initial values of total head, moisture content, or pressure heads be specified everywhere in the model domain. For each distance to groundwater scenario, a preliminary model run was performed to compute an equilibrium pressure head profile for all nodes in the domain based on the boundary conditions and soil textural parameters. The equilibrium pressure head matrices generated by the preliminary runs were subsequently used in

the VS2DT simulations for each distance to groundwater scenario. Figure 1 presents the steady-state moisture content profile for the 0.1-meter (most conservative) distance to groundwater scenario.

Unfortunately, the VS2DT code will not accept total COC concentrations in soils as an initial condition.   Instead, COC concentrations in soil moisture were set to a constant value (typically $10 \ g/m^3$). An average soil moisture content was calculated for the source zone using the soil moisture profile generated by VS2DT. The total soil concentration in equilibrium with the target soil moisture concentration (back calculated for each COC using the groundwater target multiplied by the DAF) was estimated using the EPA soil-water partitioning equation.

VS2DT Finite Difference Parameters

Rapid changes in pressure heads and moisture content near the capillary fringe dictated relatively fine vertical discretization. Maximum grid spacing in the vertical direction was 0.1 meters in the vadose zone and 0.25 meters in the saturated zone. Minimum grid spacing was 0.01 meters in the vicinity of the water table. Maximum changes in grid spacing ranged from a factor of 1.5 to 2.0. Grid spacing in the horizontal direction was 0.5 meters, and was reduced to 0.25 meters in the vicinity of the compliance monitoring well.   Time discretization was set using a maximum time step of 1 day. At the beginning of the simulation, the time step was set to 0.01 day and was subsequently increased by a factor of 1.5 until the 1 day time step was achieved.

Closure criteria for total heads was set to $1.0x10^{-4}$ meters, and closure criteria for the solute transport equation was set to $1.0x10^{-5} \ g/m^3$ (g/m^3 units convert to mg/L).   The strongly implicit procedure (SIP) was used in calculating total head values, and central differencing in space and time was used for the solute transport equation. The arithmetic mean of adjacent cells was used to calculate intercell conductivities.

Physical and Chemical Parameters

Physical parameters for vadose and saturated zone soils, including hydraulic conductivity, specific storage, porosity, residual moisture content, and van Genuchten non-linear parameters were estimated using the *Subtitle D Landfill Application Manual for the Multimedia Exposure Assessment Model Final Report,* US EPA, 1995. The values selected for these parameters were consistent with a well-sorted sand. Chemical-specific parameters, including the molecular diffusion coefficient in water and the organic carbon-water partitioning coefficient were estimated using the EPA Soil Screening Guidance Technical Support Document. Organic carbon content of vadose and saturated zone soils was estimated as 0.006 g/g and 0.001 g/g, respectively. Longitudinal dispersivity for COCs in the vadose zone was estimated using the equation $D_l = 0.02 + 0.022*L$ where D_l is the longitudinal dispersivity, and L is the vertical distance between the center of the contaminated source area and the top of the water table. For the saturated zone dispersivities, the longitudinal dispersivity was estimated as one tenth the horizontal distance between the center of the contaminated source and the down gradient edge monitoring well, and the transverse dispersivity (in the vertical direction) was estimated as one

tenth of the value of the longitudinal dispersivity. For the vadose zone, the transverse dispersivity was set equal to the longitudinal dispersivity as the flow of soil moisture perpendicular to bedding planes is expected to result in greater transverse spreading of COCs compared to saturated zone flow parallel to bedding planes. Physical and chemical input parameters incorporated in the leaching to groundwater model are presented in Tables 1 and 2.

Down Gradient Edge

Conceptually, the down gradient edge (DGE) was set as a monitoring well constructed with a screened interval extending one meter from the top of the water table. As implemented in the VS2DT code, COC concentrations at five adjacent cell nodes in a vertical line, corresponding to the DGE location, were reported for each time step. The uppermost cell was located 10 centimeters below the top of the water table, under the downgradient edge of the vadose zone source. The vertical dimensions of the cells were 0.1, 0.15, 0.25, and 0.25 meters, respectively. In order to generate an average DGE well concentration accounting for the differences in cell dimensions, the concentration in each cell was multiplied the cell vertical dimension, the values for all five cells were totaled, and divided by the total vertical length of the five cells (1 meter). This calculation was performed on the output from each time step, and the highest average of the five nodes was recorded.

RBSL Calculation

Back-calculation of RBSLs incorporated the COC-specific DAF generated by the VS2DT modeling and the EPA soil-water partitioning equation. Table 3 presents the EPA partitioning equation and the parameters required for the calculation of the Tier 1 soil targets. DAFs for the most conservative scenario, with the contaminated source located immediately above the water table (0.1-meter scenario), ranged from 20.4 (MTBE) to 12.6 (Acenaphthalene and Anthracene). The majority of the PAHs have very high soil-water partitioning coefficients and correspondingly high retardation factors, resulting in exceedingly long travel times between the source and the DGE well. As a result, the DAFs for some PAH COCs were estimated using for DAFs computed for Dibenzo(a, h)Anthracene (Table 3).

Mass Balance Results

Use of fine spatial and temporal discretization combined with the steady-state flow of soil moisture and groundwater incorporated in the simulations resulted in low water and COC mass balance errors. Percent mass balance for water was calculated as the ratio between the reported fluid volume balance and the total fluid flux. Similarly, the percent mass balance error for the COCs was the ratio between the reported solute mass balance and the initial starting mass. All simulations assumed linear COC partitioning between soil and water. The VS2DT code calculates an initial mass of COC sorbed to soil as the initial water concentration multiplied by the partitioning coefficient, soil bulk density, and dimensions of the source area.

Sensitivity Analysis Results

Analysis of sensitivity of model output to selected input parameters was performed for the VS2DT and HELP codes. Sensitivity of VS2DT was measured using the benzene/0.1-meter scenario. Sensitivity analysis model runs were performed using expected minimum and maximum values of selected input parameters. Parameter sensitivity was reported as the ratio of predicted DGE concentrations for the minimum and maximum case for each input parameter. Sensitivity results for VS2DT indicated that the benzene/0.1-meter distance to groundwater scenario was most sensitive to the saturated hydraulic conductivity, source width, groundwater gradient, and soil moisture percolation rate. With the exception of the source width, these parameters affect the water balance between percolating soil moisture and the underlying saturated zone. Increasing the saturated zone hydraulic conductivity from 1 meter per day to 15 meters per day resulted in a reduction in the maximum DGE concentration by a factor of 5.3. Sensitivity results for the HELP code indicated that simulation was most sensitive to the soil type, site location, and maximum depth of evapotranspiration.

Table 1
Leaching Model Physical Parameters

Model Setup Parameters	0.1m simulations Sand	3.1m simulations Sand	6.1m simulations Sand
Maximum no. of Time Steps	1,000,000	1,000,000	1,000,000
units	meter day gram	meter day gram	meter day gram
Initial Hydraulic Condition	Steady state	Steady state	Steady state
Intercell Relative Hydraulic Conductivity	Arithmetic mean	Arithmetic mean	Arithmetic mean
Hydraulic Characteristic Function	Van Genuchten	Van Genuchten	Van Genuchten
Differencing Scheme for Transport Equation	Centered	Centered	Centered
Adsorption	Linear Isotherm	Linear Isotherm	Linear Isotherm
Relaxation Parameter	0.7	0.7	0.7
Minimum Iterations per Time Step	2	2	2
Maximum Iterations per Time Step	80	80	80
Closure criteria for head [m]	1.00E-04	1.00E-04	1.00E-04
Closure criteria for concentration [g/m^3]	1.00E-05	1.00E-05	1.00E-05
Grid spacing - rows (m)	0.01-0.1	0.01-0.1	0.01-0.1
Grid spacing - columns (m)	0.25-0.5	0.25-0.5	0.25-0.5
Domain width [m]	13	13	13
Domain thickness [m]	5.0	8.0	11.0
Source Area width [m]	9.0	9.0	9.0
Source Area thickness [m]	1.5	1.5	1.5
Vadose zone thickness [m]	3.0	6.0	9.0
Saturated zone thickness [m]	2.0	2.0	2.0
Initial concentration 1.4-2.9m, [g/m^3]	10.0	10.0	10.0
Vadose/Saturated Zone Soil Parameters			
Kz/Kh	1.0	1.0	1.0
Saturated Kh [m/d]	7.0	7.0	7.0
Specific Storage	0	0	0
Porosity	0.4	0.4	0.4
Residual Moisture Content	0.045	0.045	0.045
VG alpha parameter [1/m]	-14.5	-14.5	-14.5
VG beta parameter	2.68	2.68	2.68
Soil density [g/m^3]	1.50E+06	1.50E+06	1.50E+06
Vadose Zone Solute Parameters			
Longitudinal dispersivity [m]	0.05	0.1	0.15
Transverse dispersivity [m]	0.05	0.1	0.15
Decay coefficient [1/d]	0	0	0
Fraction organic carbon (included in Kd value)	0.006	0.006	0.006
Partitioning coefficient, Kd [m^3/g]	EPA values	EPA values	EPA values
Molecular Diffusion Coefficient [m^2/d]	EPA values	EPA values	EPA values
Saturated Zone Soil Parameters			
Kz/Kh	1.0	1.0	1.0
Saturated Kh [m/d]	7.0	7.0	7.0
Porosity	0.4	0.4	0.4
Residual Moisture Content	0.045	0.045	0.045
VG alpha parameter [1/m]	-14.5	-14.5	-14.5
VG beta parameter	2.68	2.68	2.68
Soil density [g/m^3]	1.50E+06	1.50E+06	1.50E+06
Specific Storage	0	0	0
Hydro Parameters			
Number of recharge periods	1	1	1
Recharge period length [d]	varies	varies	varies
Initial Time step [d]	0.01	0.01	0.01
Time step multiplier	1.5	1.5	1.5
Maximum Time step [d]	1	1	1
Minimum Time step [d]	0.01	0.01	0.01
Depth to water [m]	3	6	9
Time step reduction factor	0.1	0.1	0.1
Maximum head change [m]	0.05	0.05	0.05
Steady-state head criterion [m]	0	0	0
Maximum height of ponding [m]	0	0	0
Specified flux boundary [m/d]	2.50E-04	2.50E-04	2.50E-04
Groundwater gradient [m/m]	0.005	0.005	0.005
Specified total head boundary-upgradient [m]	-2.97	-5.97	-8.97
Specified total head boundary-downgradient [m]	-3.03	-6.03	-9.03

HELP Input Parameters	
Parameter	**value**
No. of soil layers	1
Thickness [m]	1.5
Porosity	0.457
Field Capacity	0.083
Wilting Point	0.033
Initial Moisture Content	0.166
Saturated Hydraulic Conductivity [m/d]	2.67
SCS Runoff Curve Number [%]	81.3
Fraction of Area Allowing Runoff	95
Horizontal Area [Hectares]	0.09
Evaporative Zone Depth [m]	0.15

Table 2
VS2DT Chemical Parameters

Constituent	Hd	Koc L/Kg	Di,w cm^2/s	DEQ-7 ug/L
Methyl t-Butyl Ether	2.40E-02	1.2E+01	8.6E-06	30
Benzene	2.28E-01	1.5E+02	1.0E-05	5
Toluene	2.72E-01	2.3E+02	9.2E-06	1000
Ethylbenzene	3.23E-01	4.5E+02	8.5E-06	700
Xylenes	2.76E-01	3.8E+02	8.5E-06	10000
Naphthalene	1.98E-02	1.5E+03	8.4E-06	100
1,2-Dibromoethane	3.04E-02	4.0E+01	1.0E-05	0
1-2-Dichloroethane	4.00E-02	4.0E+01	1.1E-05	4
Acenaphthene	6.36E-03	5.0E+03	8.3E-06	670
Anthracene	2.67E-03	1.6E+04	7.9E-06	2100
Benz(a)Anthracene	1.37E-04	1.8E+05	6.7E-06	0.50
Benzo(a)Pyrene	4.63E-05	5.9E+05	5.6E-06	0.05
Benzo (b)Fluoranthene	4.55E-03	6.0E+05	5.6E-06	0.50
Benzo (k) Fluoranthene	3.40E-05	5.9E+05	5.6E-06	5
Chrysene	3.88E-03	1.8E+05	6.7E-06	50
Dibenzo(a,h) Anthracene	6.03E-07	1.9E+06	5.2E-06	0.05
Fluoranthene	6.60E-04	5.5E+04	7.2E-06	130
Fluorene	2.61E-03	9.2E+03	7.9E-06	1100
Indeno(1,2,3-cd)Pyrene	6.56E-05	2.0E+06	5.2E-06	0.50
Pyrene	4.51E-04	5.43E+04	7.2E-06	830
Methylnaphthalene, 1-	2.1E-02	2.53E+03	7.8E-06	11
Methylnaphthalene, 2-	2.1E-02	2.48E+03	7.8E-06	36

*EPA 2016 RSLs https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables-may-2016

Conversions Constituent	Koc L/Kg	Koc M^3/g	foc 0.006 Kd-sand	foc 0.001 Saturated	Di,w cm^2/s	Di,w m^2/d
Methyl t-Butyl Ether	1.2E+01	1.2E-05	6.94E-08	1.16E-08	8.6E-06	7.42E-05
Benzene	1.5E+02	1.5E-04	8.70E-07	1.50E-07	1.0E-05	8.90E-05
Toluene	2.3E+02	2.3E-04	1.40E-06	2.30E-07	9.2E-06	8.00E-05
Ethylbenzene	4.5E+02	4.5E-04	2.70E-06	4.50E-07	8.5E-06	7.30E-05
Xylenes	3.8E+02	3.8E-04	2.30E-06	3.80E-07	8.5E-06	7.30E-05
Naphthalene	1.5E+03	1.5E-03	9.30E-06	1.50E-06	8.4E-06	7.20E-05
1,2-Dibromoethane	4.0E+01	4.0E-05	2.40E-07	4.00E-08	1.0E-05	9.00E-05
1-2-Dichloroethane	4.0E+01	4.0E-05	2.40E-07	4.00E-08	1.1E-05	9.50E-05
Acenaphthene	5.0E+03	5.0E-03	3.00E-05	5.00E-06	8.3E-06	7.20E-05
Anthracene	1.6E+04	1.6E-02	9.80E-05	1.60E-05	7.9E-06	6.80E-05
Benz(a)Anthracene	1.8E+05	1.8E-01	1.10E-03	1.80E-04	6.7E-06	5.80E-05
Benzo(a)Pyrene	5.9E+05	5.9E-01	3.50E-03	5.90E-04	5.6E-06	4.80E-05
Benzo (b)Fluoranthene	6.0E+05	6.0E-01	3.60E-03	6.00E-04	5.6E-06	4.80E-05
Benzo (k) Fluoranthene	5.9E+05	5.9E-01	3.50E-03	5.90E-04	5.6E-06	4.80E-05
Chrysene	1.8E+05	1.8E-01	1.10E-03	1.80E-04	6.7E-06	5.80E-05
Dibenzo(a,h) Anthracene	1.9E+06	1.9E+00	1.10E-02	1.90E-03	5.2E-06	4.50E-05
Fluoranthene	5.5E+04	5.5E-02	3.30E-04	5.50E-05	7.2E-06	6.20E-05
Fluorene	9.2E+03	9.2E-03	5.50E-05	9.20E-06	7.9E-06	6.80E-05

EPA SSL soil/water partitioning equation
Use the new excel rounding formula
May 2017
Ct = Cw*[(koc*foc)+(Pw+(Pa*Hd))/Pb]

Ct = soil concentration [mg/kg]
Cw = leachate concentration [mg/L]
koc = soil organic carbon-water partition coefficient [L/kg]
foc = fraction organic carbon [kg/kg]
Pw = water-filled soil porosity
Pa = air filled soil porosity
Pb = dry soil bulk density [kg/L]
Hd = dimensionless Henry's Law

Key:

(yellow)	parameter not modeled; estimated DAF
(grey)	2016 entries
na	not applicable
100	DEQ-7/Raw Leaching Soil Target updated

Sand 0.1m scenario chemical	DEQ-7 (mg/L)	koc	koc 2016	Hd	Predicted attenuation source/POC	Predicted attenuation source/POC	Target source (mg/L)	Target source (mg/L)	soil	foc	Pt	Pw	Pa	Pb	Raw Leaching Soil Target	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	12.6	12.4	8.84E+00	8.68E+00	sand	0.006	0.4	0.079	0.321	1.5	2.23E+02	200	2.19E+02	220
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	12.6	12.3	1.26E+01	1.23E+01							1.15E+04	10,000	1.12E+04	11,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	12.6	12.5	1.26E+01	1.25E+01							1.36E+02	100	1.35E+02	130
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.16E+01	2.40E-02	20.1	20.4	6.03E-01	6.12E-01							7.84E-02	0.08	7.78E-02	0.078
Benzene	5.00E-03	6.17E+01	1.46E+02	2.28E-01	16.1	14.3	8.04E-02	7.15E-02							3.79E-02	0.04	6.98E-02	0.070
Toluene	1.00E+00	1.40E+02	2.34E+02	2.72E-01	14.6	13.7	1.46E+01	1.37E+01							1.39E+01	10	2.07E+01	21
Ethylbenzene	7.00E-01	2.04E+02	4.46E+02	3.23E-01	14.1	13.3	9.90E+00	9.31E+00							1.33E+01	10	2.61E+01	26
Xylenes	1.00E+01	2.45E+02	3.83E+02	2.76E-01	13.4	13.4	1.34E+02	1.34E+02							2.12E+02	200	3.23E+02	320
Naphthalene	1.00E-01	1.19E+03	1.54E+03	1.98E-02	12.9	12.7	1.29E+00	1.27E+00							9.32E+00	9	1.18E+01	12
1,2-Dibromoethane	**1.70E-05**	2.50E+01	3.96E+01	3.04E-02	18.03	17.1	3.07E-04	2.91E-04							6.41E-05	0.000064	**8.63E-05**	**0.000086**
1-2-Dichloroethane	4.00E-03	1.74E+01	3.96E+01	4.00E-02	19.23	16.6	7.69E-02	6.64E-02							1.27E-02	0.01	1.98E-02	0.020
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	12.6	13.0	1.26E+01	1.30E+01							5.17E+04	50,000	5.32E+04	53,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							immobile	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	12.6	12.3	1.26E+01	1.23E+01							3.80E+02	400	3.70E+02	370
Acenaphthene	**7.00E-02**	4.90E+03	5.0E+03	6.36E-03	12.6	12.6	8.84E-01	8.82E-01							2.60E+01	30	**2.67E+01**	**27**
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	12.6	12.6	2.65E+01	2.65E+01							3.74E+03	4,000	2.60E+03	2,600
Benz(a)Anthracene	5.00E-04	3.58E+05	1.37E+05	1.37E-04	12.6	12.8	6.32E-03	6.40E-03							1.36E+01	10	6.79E+00	6.8
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	12.6	13.0	6.32E-04	6.50E-04							3.67E+00	4	2.29E+00	2.3
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	12.6	13.0	6.32E-03	6.50E-03							4.66E+01	50	2.34E+01	23
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	12.6	13.0	6.32E-02	6.50E-02							4.66E+01	500	2.29E+02	230
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	12.6	12.8	6.32E-01	6.40E-01							1.51E+03	2,000	6.93E+02	690
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	12.6	13.1	6.32E-04	6.55E-04							6.78E+00	7	7.51E+00	7.5
Fluoranthene	**2.00E-02**	4.91E+04	5.5E+04	6.60E-04	12.6	12.7	2.53E-01	2.54E-01							7.44E+01	70	**8.45E+01**	**85**
Fluorene	**5.00E-02**	7.71E+03	9.2E+03	2.61E-03	12.6	12.7	6.32E-01	6.35E-01							2.92E+01	30	**3.49E+01**	**35**
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	12.6	13.1	6.32E-03	6.55E-03							1.32E+02	100	7.67E+01	77
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	12.9	12.7	1.29E+00	1.27E+00							9.32E+00	9	1.18E+01	12
Pyrene	**2.00E-02**	6.80E+04	5.43E+04	4.51E-04	12.6	12.7	2.53E-01	2.54E-01							1.03E+02	100	**8.28E+01**	**83**
Methylnaphthalene, 1-	1.10E-02	na	2.53E+03	2.1E-02	na	12.8	na	1.41E-01							na		2.14E+00	2.1
Methylnaphthalene, 2-	3.60E-02	na	2.48E+03	2.1E-02	na	12.8	na	4.61E-01							na		6.88E+00	6.9

Sand 3.1m scenario / chemical	DEQ-7 (mg/L)	koc	koc 2016	Hd	Predicted attenuation source/POC	Predicted attenuation source/POC	Target source (mg/L)	Target source (mg/L)	soil	foc	Pt	Pw	Pa	Pb	Raw Leaching Soil Target	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	42.6	43.4	2.98E+01	3.04E+01	sand	0.006	0.4	0.073	0.327	1.5	7.57E+02	800	7.72E+02	770
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	42.6	43.4	4.26E+01	4.34E+01							3.89E+04	40,000	3.97E+04	40,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	42.6	43.4	4.26E+01	4.34E+01							4.59E+02	500	4.68E+02	470
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.2E+01	2.40E-02	43.3	43.1	1.30E+00	1.29E+00							1.64E-01	0	1.59E-01	0.16
Benzene	5.00E-03	6.17E+01	1.5E+02	2.28E-01	43.3	43.5	2.17E-01	2.18E-01							1.01E-01	0	2.12E-01	0.21
Toluene	1.00E+00	1.40E+02	2.3E+02	2.72E-01	42.9	43.2	4.29E+01	4.32E+01							4.07E+01	40	6.53E+01	65
Ethylbenzene	7.00E-01	2.04E+02	4.5E+02	3.23E-01	42.7	42.9	2.99E+01	3.00E+01							4.01E+01	40	8.40E+01	84
Xylenes	1.00E+01	2.45E+02	3.8E+02	2.76E-01	43.0	42.9	4.30E+02	4.29E+02							6.79E+02	700	1.03E+03	1,000
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	42.6	42.9	4.26E+00	4.29E+00							3.06E+01	30	4.00E+01	40
1,2-Dibromoethane	1.70E-05	2.50E+01	4.0E+01	3.04E-02	44.01	43.5	7.48E-04	7.40E-04							1.54E-04	0	2.17E-04	0.00022
1-2-Dichloroethane	4.00E-03	1.74E+01	4.0E+01	4.00E-02	43.42	43.7	1.74E-01	1.75E-01							2.81E-02	0	5.16E-02	0.052
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	42.6	42.4	4.26E+01	4.24E+01							1.74E+05	200,000	1.74E+05	170,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							none	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	42.6	43.4	4.26E+01	4.34E+01							1.28E+03	1,000	1.30E+03	1,300
Acenaphthene	7.00E-02	4.90E+03	5.0E+03	6.36E-03	42.6	42.9	2.98E+00	3.00E+00							8.77E+01	90	9.07E+01	91
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	42.6	42.7	8.94E+01	8.97E+01							1.26E+04	10,000	8.81E+03	8,800
Benz(a)Anthracene	5.00E-04	3.58E+05	1.8E+05	1.37E-04	42.6	42.4	2.13E-02	2.12E-02							4.57E+01	50	2.25E+01	23
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	42.6	42.4	2.13E-03	2.12E-03							1.24E+01	10	7.47E+00	7.5
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	42.6	42.4	2.13E-02	2.12E-02							1.57E+02	200	7.62E+01	76
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	42.6	42.4	2.13E-01	2.12E-01							1.57E+03	2,000	7.47E+02	750
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	42.6	42.4	2.13E+00	2.12E+00							5.08E+03	5,000	2.30E+03	2,300
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	42.6	42.4	2.13E-03	2.12E-03							2.28E+01	20	2.43E+01	24
Fluoranthene	2.00E-02	4.91E+04	5.5E+04	6.60E-04	42.6	42.5	8.51E-01	8.50E-01							2.51E+02	300	2.83E+02	280
Fluorene	5.00E-02	7.71E+03	9.2E+03	2.61E-03	42.6	42.7	2.13E+00	2.14E+00							9.85E+01	100	1.17E+02	120
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	42.6	42.4	2.13E-02	2.12E-02							4.43E+02	400	2.48E+02	250
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	42.6	42.9	4.26E+00	4.29E+00							3.06E+01	30	4.00E+01	40
Pyrene	2.00E-02	6.80E+04	5.4E+04	4.51E-04	42.6	42.6	8.51E-01	8.52E-01							3.47E+02	300	2.78E+02	280
Methylnaphthalene, 1-	1.10E-02	na	2.5E+03	2.1E-02	na	42.7	na	4.70E-01								na	7.15E+00	7.1
Methylnaphthalene, 2-	3.60E-02	na	2.5E+03	2.1E-02	na	42.7	na	1.54E+00								na	2.29E+01	23

Sand 6.1m scenario / chemical	DEQ-7 (mg/L)	koc	koc 2016	Hd	Predicted attenuation source/POC	Predicted attenuation source/POC	Target source (mg/L)	Target source (mg/L)	soil	foc	Pt	Pw	Pa	Pb	Raw Leaching Soil Target	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)	Raw Leaching Soil Target (mg/kg)
C5-C8 Aliphatics	7.00E-01	2.27E+03	2.27E+03	5.40E+01	65.8	66.9	4.60E+01	4.68E+01	sand	0.006	0.4	0.073	0.327	1.5	1.17E+03	1,000	1.19E+03	1,200
C9-C12 Aliphatics	1.00E+00	1.50E+05	1.50E+05	6.50E+01	65.8	65.5	6.58E+01	6.55E+01							6.01E+04	60,000	5.99E+04	60,000
C9-C10 Aromatics	1.00E+00	1.78E+03	1.78E+03	3.30E-01	65.8	66.9	6.58E+01	6.69E+01							7.10E+02	700	7.22E+02	720
Methyl t-Butyl Ether	3.00E-02	1.20E+01	1.2E+01	2.40E-02	66.7	66.3	2.00E+00	1.99E+00							2.52E-01	0	2.45E-01	0.25
Benzene	5.00E-03	6.17E+01	1.5E+02	2.28E-01	66.8	67.1	3.34E-01	3.36E-01							1.56E-01	0	3.26E-01	0.33
Toluene	1.00E+00	1.40E+02	2.3E+02	2.72E-01	66.3	66.6	6.63E+01	6.66E+01							6.28E+01	60	1.01E+02	100
Ethylbenzene	7.00E-01	2.04E+02	4.5E+02	3.23E-01	65.9	66.3	4.62E+01	4.64E+01							6.20E+01	60	1.30E+02	130
Xylenes	1.00E+01	2.45E+02	3.8E+02	2.76E-01	66.3	66.3	6.63E+02	6.63E+02							1.05E+03	1,000	1.60E+03	1,600
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	65.8	66.2	6.58E+00	6.62E+00							4.74E+01	50	6.17E+01	62
1,2-Dibromoethane	1.70E-05	2.50E+01	4.0E+01	3.04E-02	67.7	67.1	1.15E-03	1.14E-03							2.36E-04	0	3.34E-04	0.00033
1-2-Dichloroethane	4.00E-03	1.74E+01	4.0E+01	4.00E-02	66.9	67.3	2.67E-01	2.69E-01							4.33E-02	0	7.94E-02	0.079
C9-C18 Aliphatics	1.00E+00	6.80E+05	6.80E+05	6.90E+01	65.8	65.5	6.58E+01	6.55E+01							2.69E+05	300,000	2.68E+05	270,000
C19-C36 Aliphatics	1.00E+00	immobile	immobile	immobile	immobile	immobile	immobile	immobile							none	immobile	immobile	immobile
C11-C22 Aromatics	1.00E+00	5.00E+03	5.00E+03	3.00E-02	65.8	66.9	6.58E+01	6.69E+01							1.98E+03	2,000	2.01E+03	2,000
Acenaphthene	7.00E-02	4.90E+03	5.0E+03	6.36E-03	65.8	66.2	4.60E+00	4.63E+00							1.36E+02	100	1.40E+02	140
Anthracene	2.10E+00	2.35E+04	1.6E+04	2.67E-03	65.8	66.0	1.38E+02	1.39E+02							1.95E+04	20,000	1.36E+04	14,000
Benzo(a)Anthracene	5.00E-04	3.58E+05	1.8E+05	1.37E-04	65.8	65.5	3.29E-02	3.28E-02							7.06E+01	70	3.48E+01	35
Benzo(a)Pyrene	5.00E-05	9.69E+05	5.9E+05	4.63E-05	65.8	65.5	3.29E-03	3.28E-03							1.91E+01	20	1.15E+01	12
Benzo (b)Fluoranthene	5.00E-04	1.23E+06	6.0E+05	4.55E-03	65.8	65.5	3.29E-02	3.28E-02							2.43E+02	200	1.18E+02	120
Benzo (k) Fluoranthene	5.00E-03	1.23E+06	5.9E+05	3.40E-05	65.8	65.5	3.29E-01	3.28E-01							2.43E+03	2,000	1.15E+03	1,200
Chrysene	5.00E-02	3.98E+05	1.8E+05	3.88E-03	65.8	65.5	3.29E+00	3.28E+00							7.85E+03	8,000	3.55E+03	3,500
Dibenzo(a,h) Anthracene	5.00E-05	1.79E+06	1.9E+06	6.03E-07	65.8	65.5	3.29E-03	3.28E-03							3.53E+01	40	3.76E+01	38
Fluoranthene	2.00E-02	4.91E+04	5.5E+04	6.60E-04	65.8	65.7	1.32E+00	1.31E+00							3.88E+02	400	4.37E+02	440
Fluorene	5.00E-02	7.71E+03	9.2E+03	2.61E-03	65.8	66.0	3.29E+00	3.30E+00							1.52E+02	200	1.82E+02	180
Indeno(1,2,3-cd)Pyrene	5.00E-04	3.47E+06	2.0E+06	6.56E-05	65.8	65.5	3.29E-02	3.28E-02							6.85E+02	700	3.83E+02	380
Naphthalene	1.00E-01	1.19E+03	1.5E+03	1.98E-02	65.8	66.2	6.58E+00	6.62E+00							4.74E+01	50	6.17E+01	62
Pyrene	2.00E-02	6.80E+04	5.4E+04	4.51E-04	65.8	65.8	1.32E+00	1.32E+00							5.37E+02	500	4.29E+02	430
Methylnaphthalene, 1-	1.10E-02	na	2.5E+03	2.1E-02	na	66.0	na	7.26E-01							na	na	1.11E+01	11
Methylnaphthalene, 2-	3.60E-02	na	2.5E+03	2.1E-02	na	66.0	na	2.38E+00							na	na	3.55E+01	35

Appendix B

DIRECT CONTACT TECHNICAL SUPPORT DOCUMENT

DIRECT CONTACT

This portion of Appendix B explains the methods Montana Department of Environmental Quality (DEQ) used to develop direct contact risk-based screening levels (RBSLs) for Tier 1 of the risk-based corrective action (RBCA) process. The appendix is made up of tables and spreadsheets used to develop the RBSLs. The following is a brief explanation of these tables and spreadsheets. Data sources are provided in the spreadsheets and a reference list is provided at the end of this appendix. DEQ chose conservative parameters to develop RBSLs applicable to a wide variety of sites.

Table 1 provides a compilation of the chemical specific information used to develop the RBSLs and the actual direct contact RBSLs calculated for each compound. DEQ chose toxicity values based upon the December 5, 2003 EPA OSWER Directive 9285.7-53, which provides a hierarchy of human health values recommended for risk assessments (EPA, December 2003). For the petroleum fractions, DEQ obtained toxicity values for ingestion and dermal exposure from the Massachusetts Department of Environmental Protection (MADEP) November 2003 Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH /APH Methodology. (Volatile Petroleum Hydrocarbons = VPH, Extractable Petroleum Hydrocarbons = EPH, and Air-Phase Hydrocarbons). For petroleum fraction toxicity via inhalation, DEQ uses the EPA September 2009 Provisional Peer-Reviewed Toxicity Values for Complex Mixtures of Aliphatic and Aromatic Hydrocarbons (EPA, September 2009).

The columns in Table 1 that depict the oral reference dose (RfDo)/oral slope factor (SFo) and the reference concentration (RfC)/inhalation unit risk (IUR) depict either the non-cancer or the cancer value depending upon which provides for the more conservative RBSL. DEQ relied upon the United States Environmental Protection Agency (EPA) Regional Screening Levels (RSL) Tables (EPA, November 2017) for this determination. For naphthalene, both the RfC and the IUR are provided. RBSLs for residential and commercial exposure are based upon naphthalene carcinogenicity via inhalation. The RBSL for construction exposure is based upon non-carcinogenic risk via ingestion, inhalation, and dermal exposure.

The Volatilization Factors spreadsheet was used to calculate volatilization factor for the volatile fraction using the method provided in the EPA RSL User's Guide (EPA, November 2017). Volatile chemicals are defined as those chemicals having a Henry's Law constant greater than 10^{-5} (atm-m^3/mol) and a molecular weight less than 200 g/mole as defined in EPA, November 2017. Data sources are provided at the end of the spreadsheets. DEQ used the EPA RSL Calculator (EPA, November 2017) as the source of the volatilization factors for the target analytes, like benzene.

The Age-Adjusted Factors spreadsheet was used to calculate age-adjusted factors for the soil ingestion and dermal contact exposure routes using the method provided in the EPA, November 2017. These age-adjusted factors, as well as the other exposure parameters included in the spreadsheets are based upon those included in the EPA February 2014 Human Health Evaluation Manual Supplemental Guidance: Update of Standard Default Exposure Factors (EPA, February 2014) and in some cases the EPA October 2011 Exposure Factors Handbook.

The Residential Scenario: Carcinogens spreadsheet was used to calculate RBSLs for residential exposure to carcinogens using the methods provided in EPA, November 2017. These RBSLs are

based on a target risk of $1X10^{-6}$, providing some assurance that overall site risks will not exceed $1X10^{-5}$, and are applied to the top 2 feet of soil at sites where the current and reasonably expected future usage is residential.

The Residential Scenario: Non-carcinogens spreadsheet was used to calculate RBSLs for residential exposure to non-carcinogens using the methods provided in EPA, November 2017, EPA, September 2008, the MADEP Characterizing Risks Posed by Petroleum Contaminated Sites: Implementation of the MADEP VPH/EPH Approach, Final Policy (October 31, 2002). These RBSLs are based on a target hazard quotient of 0.125 for each compound. There are eight possible non-carcinogens, including the non-target fractions, present in either gasoline or diesel. Therefore, a hazard quotient of 0.125 provides some assurance that the overall hazard index for a site will not exceed 1.   These RBSLs are applied to the top 2 feet of soil at sites where the current and reasonably expected future usage is residential.

The Commercial Scenario: Carcinogens spreadsheet was used to calculate RBSLs for a commercial worker's exposure to carcinogens using the methods provided in EPA, November 2017. These RBSLs are based on a target risk of $1X10^{-6}$, providing some assurance that overall site risks will not exceed $1X10^{-5}$, and are applied to the top 2 feet of soil at sites where the current and reasonably expected future usage is commercial or industrial.

The Commercial Scenario: Non-carcinogens spreadsheet was used to calculate RBSLs for a commercial worker's exposure to non-carcinogens using the methods provided in EPA, November 2017 and MADEP, October 2002. These RBSLs are based on a target hazard quotient of 0.125 for each compound. There are eight possible non-carcinogens, including the non-target fractions, present in either gasoline or diesel. Therefore, a hazard quotient of 0.125 provides some assurance that the overall hazard index for a site will not exceed 1. The RBSLs are applied to the top 2 feet of soil at sites where the current and reasonably expected future usage is commercial or industrial.

The Construction Scenario: Carcinogens spreadsheet was used to calculate RBSLs for an construction worker's exposure to carcinogens using the methods provided in EPA, November 2017. These RBSLs are based on a target risk of $1X10^{-6}$, providing some assurance that overall site risks will not exceed $1X10^{-5}$ and are applied to soil greater than 2 feet below the ground surface at all sites where there is a potential for utility installation, pipe repair, or other excavation in the future.

The Construction Scenario: Non-carcinogens spreadsheet was used to calculate RBSLs for a construction worker's exposure to non-carcinogens using the methods provided in EPA, November 2017 and MADEP, October 2002. These RBSLs are based on a target hazard quotient of 0.125 for each compound. There are eight possible non-carcinogens, including the non-target fractions, present in either gasoline or diesel. Therefore, a hazard quotient of 0.125 provides some assurance that the overall hazard index for a site will not exceed 1. The RBSLs may be applied to soil greater than 2 feet below the ground surface at all sites where there is a potential for utility installation, pipe repair, or other excavation in the future.

The Water Quality Guidelines for Non-Target Analytes spreadsheet was used to calculate RBSLs for non-target analytes in water using the methods provided in the EPA Drinking Water Regulations and Health Advisories (EPA, October 1996) and MADEP, October 2002.

REFERENCES

United States Environmental Protection Agency (EPA), October 1996. Drinking Water Regulations and Health Advisories.

EPA, December 2002. Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.

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EPA, October 2011. Exposure Factors Handbook.

EPA, February 2014. Human Health Evaluation Manual Supplemental Guidance: Update of Standard Default Exposure Factors.

EPA, November 2017. Regional Screening Levels User's Guide, Calculator, and Tables.

Integrated Risk Information System (IRIS) EPA, January 2017. EPA's Integrated Risk Information System (IRIS) – January 2017 search for current toxicity values.

Massachusetts Department of Environmental Protection (MADEP), October 2002. Characterizing Risks Posed by Petroleum Contaminated Sites: Implementation of MADEP VPH/EPH Approach Public Comment Draft.

Massachusetts Department of Environmental Protection (MADEP), November 2003. Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH/APH Methodology.

TABLE 1: Chemicals Included in RBCA

Compound	MW (g/mol)	Henry's Law Constant (dimensionless)	VF (m³/kg)	RAF oral (unitless)	RAF dermal (unitless)	RAF water (unitless)	Effect*	RfDo mg/kg-d or SFo kg-d/mg	Oral Toxicity Reference	RfC mg/m³ or IUR m³/µg	Inhalation Toxicity Reference
For Gasoline											
C5-C8 Aliphatics	93	54	1,189	1	1	1	n	4.0E-02	MADEP 2003	6.0E-01	PPRTV 2009
C9-C12 Aliphatics	149	65	7,176	1	0.5	1	n	1.0E-01	MADEP 2003	1.0E-01	PPRTV 2009
C9-C10 Aromatics	120	69	NA	1	0.5	0.91	n	3.0E-02	MADEP 2003	1.0E-01	PPRTV 2009
MTBE	88.15	0.02	4,900	1	0	1	c	1.8E-03	EPA 2017	2.6E-07	EPA 2017
Benzene	78.1	0.23	3,540	1	0	1	c	5.5E-02	IRIS 2018	7.8E-06	IRIS 2018
Toluene	92.14	0.27	4,290	1	0	1	n	8.0E-02	IRIS 2018	5.0E+00	IRIS 2018
Ethylbenzene	106.16	0.32	5,670	1	0	1	c	1.1E-02	EPA 2017	2.5E-06	IRIS 2018
Xylenes	106.16	0.27	5,740	1	0	1	n	2.0E-01	IRIS 2018	1.0E-01	IRIS 2018
Naphthalene**	128.16	0.02	46,300	1	0.13	1	n/c	2.0E-02	IRIS 2018	3E-03/3.4E-05	EPA 2017
Lead Scavengers											
1,2-Dibromoethane (EDB)	187.88	0.03	8,640	1	0	1	c	2.0E+00	IRIS 2018	6.0E-04	IRIS 2018
1,2-Dichloroethane (DCA)	98.96	0.05	4,570	1	0	1	c	9.1E-02	IRIS 2018	2.6E-05	IRIS 2018
For Diesel and Heavy Compounds											
C9-C18 Aliphatics	170	0.33	11,092	1	0.5	1	n	1.0E-01	MADEP 2003	1.0E-01	PPRTV 2009
C19-C36 Aliphatics	NA	NA	NA	1	0.1	1	n	3.0E+00	PPRTV 2009	NA	PPRTV 2009
C11-C22 Aromatics	150	0.03	NA	0.36	0.1	0.91	n	3.0E-02	MADEP 2003	1.0E-01	PPRTV 2009
Acenaphthene	152.2	7.50E-03	141,000	1	0.13	1	n	6.0E-02	IRIS 2018	NA	IRIS 2018
Anthracene	178.24	2.30E-03	523,000	1	0.13	1	n	3.0E-01	IRIS 2018	NA	IRIS 2018
Benzo(a)anthracene	228.3	4.90E-04	4,410,000	1	0.13	1	c	1.0E-01	EPA 2017	6.0E-05	EPA 2017
Benzo(a)pyrene	252.32	1.90E-05	NA	1	0.13	1	c	1.0E+00	IRIS 2018	6.0E-04	EPA 2017
Benzo(b)fluoranthene	252.32	2.70E-05	NA	1	0.13	1	c	1.0E-01	EPA 2017	6.0E-05	EPA 2017
Benzo(k)fluoranthene	252.32	2.40E-05	NA	1	0.13	1	c	1.0E-02	EPA 2017	6.0E-06	EPA 2017
Chrysene	228.3	2.10E-04	NA	1	0.13	1	c	1.0E-03	EPA 2017	6.0E-07	EPA 2017
Dibenzo(a,h)anthracene	278.35	5.80E-06	NA	1	0.13	1	c	1.0E+00	EPA 2017	6.0E-04	EPA 2017
Fluoranthene	202.26	3.60E-04	NA	1	0.13	1	n	4.0E-02	IRIS 2018	NA	IRIS 2018
Fluorene	166.22	3.90E-03	281,000	1	0.13	1	n	4.0E-02	IRIS 2018	NA	IRIS 2018
Indeno(1,2,3-cd)pyrene	276.34	1.40E-05	NA	1	0.13	1	c	1.0E-01	EPA 2017	6.0E-05	EPA 2017
Naphthalene**	128.16	0.02	46,300	1	0.13	1	n/c	2.0E-02	IRIS 2018	3E-03/3.4E-05	EPA 2017
1-Methylnaphthalene	142.2	0.021	58,600	1	0.13	1	c	2.9E-02	PPRTV 2008	NA	EPA 2017
2-Methylnaphthalene	142.2	0.021	58,000	1	0.13	1	n	4.0E-03	IRIS 2018	NA	EPA 2017
Pyrene	202.25	4.90E-04	2,380,000	1	0.13	1	n	3.0E-02	IRIS 2018	NA	IRIS 2018

Particulate Emission Factor (PEF) = 1.36E+09 (1359344438) m3/kg (EPA, May 2016)

*For compounds with both non-carcinogenic and carcinogenic effects, the more conservative of the two was chosen.

**The inhalation unit risk and the reference concentration are provided for naphthalene. RBSLs for residential and commercial exposure are based upon naphthalene carcinogenicity via inhalatio

construction exposure is based upon non-carcinogenic risk via ingestion, dermal, and inhalation.

MW = molecular weight
g/mol = grams per mole
VF = volatilization factor
m^3/kg = cubic meter per kilogram
RAF = relative absorption factor
RfDo = oral reference dose
mg/kg-d = milligram per kilogram-day
SFo = oral slope factor
kg-d/mg = kilogram-day per milligram
RfC = reference concentration
mg/m^3 = milligrams per cubic meter
IUR = inhalation unit risk
m^3/µg = cubic meter per microgram
Res. = residential
Comm. = commercial/industrial
Cons. = construction
MADEP = Massachusetts Department of Environmental Quality
EPA = U.S. Environmental Protection Agency
PPRTV = Provisional Peer Reviewed Toxicity Value
IRIS = Integrated Risk Information System

EPA Volatilization Factor (EPA, May 2016)	
VF = [(Q/C) * ((3.14*Da*T)^(1/2))/(2*db*Da)*10^-4]	
Da = ((Pa^(10/3)*Di*H+Pw^(10/3)*Dw)/n^2)/(db*Kd+Pw+Pa*H)	
C5-C8 ALIPHATICS	
VF = volatilization factor (m^3/kg) calculated	1189
Q/C = inverse of the mean conc. at center of square source (g/m^2-s per kg/m^3)	68.18
pi = 3.14	3.14
Da = apparent diffusivity (cm^2/s) calculated	0.0094
Pa = air-filled soil porosity (Lair/Lsoil)	0.28
Di = diffusivity in air (cm^2/s) chemical specific	0.08
H = dimensionless Henry's law constant chemical specific	54
Pw = water-filled soil porosity (Lwater/Lsoil)	0.15
Dw = diffusivity in water (cm^2/s) chemical specific	1.00E-05
n = total soil porosity (Lpore/Lsoil)	0.43
db = dry soil bulk density (g/cm^3)	1.50E+00
Kd = soil-water partition coefficient (Koc*foc; cm^3/g) calculated	13.59
Koc = soil organic carbon-water partition coefficient (cm^3/g) chemical specific	2265
foc = organic carbon content of soil (g/g)	0.006
T = exposure interval (s)	8.20E+08
10^-4 = conversion factor (m^2/cm^2)	1.00E-04
C9-C12 ALIPHATICS	
VF = volatilization factor (m^3/kg) calculated	7176
Q/C = inverse of the mean conc. at center of square source (g/m^2-s per kg/m^3)	68.18
pi = 3.14	3.14
Da = apparent diffusivity (cm^2/s) calculated	0.00026
Pa = air-filled soil porosity (Lair/Lsoil)	0.28
Di = diffusivity in air (cm^2/s) chemical specific	0.07
H = dimensionless Henry's law constant chemical specific	65
Pw = water-filled soil porosity (Lwater/Lsoil)	0.15
Dw = diffusivity in water (cm^2/s) chemical specific	1.00E-05
n = total soil porosity (Lpore/Lsoil)	0.43
db = dry soil bulk density (g/cm^3)	1.5
Kd = soil-water partition coefficient (Koc*foc; cm^3/g) calculated	900
Koc = soil organic carbon-water partition coefficient (cm^3/g) chemical specific	1.50E+05
foc = organic carbon content of soil (g/g)	0.006
T = exposure interval (s)	8.20E+08
10^-4 = conversion factor (m^2/cm^2)	1.00E-04
C9-C18 ALIPHATICS	
VF = volatilization factor (m^3/kg) calculated	11092
Q/C = inverse of the mean conc. at center of square source (g/m^2-s per kg/m^3)	68.18
pi = 3.14	3.14
Da = apparent diffusivity (cm^2/s) calculated	0.000035
Pa = air-filled soil porosity (Lair/Lsoil)	0.28
Di = diffusivity in air (cm^2/s) chemical specific	0.07
H = dimensionless Henry's law constant chemical specific	69
Pw = water-filled soil porosity (Lwater/Lsoil)	0.15
Dw = diffusivity in water (cm^2/s) chemical specific	5.00E-06
n = total soil porosity (Lpore/Lsoil)	0.43
db = dry soil bulk density (g/cm^3)	1.5
Kd = soil-water partition coefficient (Koc*foc; cm^3/g) calculated	4080
Koc = soil organic carbon-water partition coefficient (cm^3/g) chemical specific	6.80E+05
foc = organic carbon content of soil (g/g)	0.006
T = exposure interval (s)	
10^-4 = conversion factor (m^2/cm^2)	1.00E-04
* The following are the sources of the data used to calculate the volatilization factors:	
All non-chemical specific data and the chemical specific data for the target analytes: EPA, May 2016	
Chemical specific data for the non-target analytes except for Dw: MADEP, October 2002	

Soil Ingestion Factor (EPA Regional Screening Levels tables)

$IFSadj = EDc*IRSc/BWc + (EDtot-EDc)*IRSa/BWa$

Parameters	Values
IFSadj (Age-adjusted soil ingestion factor - mg*yr/kg*day)	105
EDc (Child exposure duration - yr; EPA, February 2014)	6
IRSc (Child soil ingestion rate - mg/day; EPA, February 2014)	200
BWc (Child body weight - kg; EPA, February 2014)	15
EDtot (Total exposure duration - yr; EPA, February 2014)	26
IRSa (Adult soil ingestion rate - mg/day; EPA, February 2014)	100
BWa (Adult body weight - kg; EPA, February 2014)	80

Mutagenic Soil Ingestion Factor (EPA Regional Screening Levels tables)

$IFSMadj = ED0\text{-}2*IRSc*10/BWc + ED2\text{-}6*IRSc*3/BWc + ED6\text{-}16*IRSa*3/BWa + ED16\text{-}30*IRSa*1/BWa$

Parameters	Values
IFSadj (Mutagenic age-adjusted soil ingestion factor - mg*yr/kg*day)	477
ED0-2 (0-2 year exposure duration - yr; EPA, November 2012)	2
ED2-6 (2-6 year exposure duration - yr; EPA, November 2012)	4
ED6-16 (6-16 year exposure duration - yr; EPA, November 2012)	10
ED16-26 (16-26 year exposure duration - yr; EPA, February 2014)	10
IRSc (Child soil ingestion rate - mg/day; EPA, February 2014)	200
BWc (Child body weight - kg; EPA, February 2014)	15
IRSa (Adult soil ingestion rate - mg/day; EPA, February 2014)	100
BWa (Adult body weight - kg; EPA, February 2014)	80

Mutagenic Soil Inhalation Factor (EPA Regional Screening Levels tables)

$MIFadj = (ED0\text{-}2*10) + (ED2\text{-}6*3) + (ED6\text{-}16*3) + (ED16\text{-}30*1)$

Parameters	Values
MIFadj (Mutagenic age-adjusted inhaltion factor - yr)	72
ED0-2 (0-2 year exposure duration - yr; EPA, November 2012)	2
ED2-6 (2-6 year exposure duration - yr; EPA, November 2012)	4
ED6-16 (6-16 year exposure duration - yr; EPA, November 2012)	10
ED16-26 (16-26 year exposure duration - yr; EPA, February 2014)	10

Dermal Factor (EPA Regional Screening Levels tables)

$DFSadj = EDc*Sac*AFc/BWc + (EDtot-EDc)*Saa*AFa/BWa$

Parameters	Values
DFSadj (Age-adjusted dermal factor - mg*yr/kg*day)	295
EDc (Child exposure duration - yr; EPA, February 2014)	6
SAc (Child surface area - cm2/day; EPA, February 2014)	2373
AFc (Child adherence factor - mg/cm2; EPA, February 2014)	0.2
BWc (Child body weight - kg; EPA, February 2014)	15
EDtot (Total exposure duration - yr; EPA, February 2014)	26
SAa (Adult surface area - cm2/day; EPA, February 2014)	6032
AFa (Adult adherence factor - mg/cm2; EPA, February 2014)	0.07
BWa (Adult body weight - kg; EPA, February 2014)	80

Mutagenic Dermal Factor (EPA Regional Screening Levels tables)

$DFSMadj = ED0\text{-}2*AFc*SAc*10/BWc + ED2\text{-}6*AFc*SAc*3/BWc$
$+ ED16\text{-}30*AFa*SAa*1/BWa$

Parameters	Values
DFSMadj (Age-adjusted soil ingestion factor - mg*yr/kg*day)	1224
ED0-2 (0-2 year exposure duration - yr; EPA, November 2012)	2
ED2-6 (2-6 year exposure duration - yr; EPA, November 2012)	4
ED6-16 (6-16 year exposure duration - yr; EPA, November 2012)	10
ED16-26 (16-26 year exposure duration - yr; EPA, February 2014)	10
SAc (Child surface area - cm2/day; EPA, February 2014)	2373
AFc (Child adherence factor - mg/cm2; EPA, February 2014)	0.2
BWc (Child body weight - kg; EPA, February 2014)	15
SAa (Adult surface area - cm2/day; EPA, February 2014)	6032
AFa (Adult adherence factor - mg/cm2; EPA, February 2014)	0.07
BWa (Adult body weight - kg; EPA, February 2014)	80

Cancer Risk Formula (with volatilization factor):

$$Cs = [(TR*AT)/(EF*((SFo*RAFo*CF*IFSadj)+(IUR*CFi*(1/VF+1/PEF)*ED*ETres)+(SFo*RAFd*CF*DFSadj)))]$$

BENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1.3
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	5.50E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
IUR (Chemical specific - kg-day/mg; IRIS, EPA, January 2018)	7.80E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	3540
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

ETHYLBENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	6.4
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
IUR (Chemical specific - kg-day/mg; IRIS, EPA, November 2017)	2.50E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5670
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

MTBE	
Parameters	Values
Cs (Soil concentration - mg/kg)	52
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.80E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	2.60E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4900
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

1,2-DIBROMOETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	0.040
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	2.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
IUR (Chemical specific - kg-day/mg; IRIS, EPA, January 2018)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	8640
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

1,2-DICHLOROETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	0.52
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	9.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.60E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4570
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	4.3
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	3.40E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	46300
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; EPA, November 2017)	26
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1

Mutagenic Mode of Action Cancer Risk Formula (without volatilization factor):

$$Cs = [(TR*AT)/(EF*((SFo*RAFo*CF*IFSMadj)+(IUR*CFi*(1/PEF)*MIFadj*ETres)+(SFo*RAFd*CF*DFMadj)))]$$

BENZ(A)ANTHRACENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1.28
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

BENZO(A)PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	0.128
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

BENZO(B)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1.28
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

BENZO(K)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	12.8
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

DIBENZO(A,H)ANTHRACENE

Parameters	Values
Cs (Soil concentration - mg/kg)	0.128
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

CHRYSENE

Parameters	Values
Cs (Soil concentration - mg/kg)	128
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

INDENO(1,2,3-CD)PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	1.28
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSMadj (Mutagenic age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	477
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0.E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
MIFadj (Mutagenic age-adjusted inhalation factor - yr; EPA, February 2014)	72
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSMadj (Mutagenic age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	1224

Cancer Risk Formula (without inhalation):

Cs = [(TR*AT)/(EF*((SFo*RAFo*CF*IFSadj)+(SFo*RAFd*CF*DFSadj)))]

1-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	20
TR (Target cancer risk - Arsenic example representing total risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	350
SFo (Chemical specific oral cancer slope factor - kg-day/mg; PPRTV, 2008)	2.90E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0.E-06
IFSadj (Age-adjusted soil ingestion factor - mg-yr/kg-day; EPA, February 2014)	105
ED (Exposure duration - yr; EPA, November 2017)	26
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
DFSadj (Age-adjusted soil dermal factor - mg-yr/kg-day; EPA, February 2014)	295

Non-cancer Risk Formula (with volatilization factor):

$$Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSc)/BWc)+(1/RfC*ETres*(1/PEF+1/VF))+((1/RfDo*CF*R$$

C5-C8 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	52
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2003)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	6.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	1189
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	1
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

C9-C12 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	77
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2003)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.00E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	7176
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	0.5
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	16
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	3.00E-03
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	46300
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

C9-C18 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	109
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2003)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	11092
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	0.5
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

TOLUENE

Parameters	Values
Cs (Soil concentration - mg/kg)	611
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	8.00E-02
CF (Conversion factor - kg/mg; EPA, December 1991)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, August 1997)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	5.00E+00
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4290
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAc (Child surface area - cm^2/day; EPA, February 2015)	2373
AFc (Child adherence factor - mg/cm^2; EPA, February 2015)	0.2

XYLENES

Parameters	Values
Cs (Soil concentration - mg/kg)	72
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	1.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5740
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

Non-cancer Risk Formula (with inhalation but without volatilization factor):

Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSc)/BWc)+(1/RfC*ETres*(1/PEF))+((1/RfDo*CF*RAFd*S

C9-C10 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	134
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2003)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	0.5
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

C11-C22 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	491
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2003)	0.36
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	0.1
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

BENZO(A)PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	2
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-04
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	2.00E-06
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2003)	0.1
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

ANTHRACENE

Parameters	Values
Cs (Soil concentration - mg/kg)	2242
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July, 2004)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

ACENAPHTHENE

Parameters	Values
Cs (Soil concentration - mg/kg)	448
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	6.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

FLUORENE

Parameters	Values
Cs (Soil concentration - mg/kg)	299
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, Feruary 2014)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

FLUORANTHENE

Parameters	Values
Cs (Soil concentration - mg/kg)	299
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	224
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

2-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	30
THQ (Target hazard quotient)	0.125
BWc (Child body weight - kg; EPA, November 2017)	15
AT (Averaging time - day; EPA, November 2017)	2190
ED (Exposure duration - yr; EPA, November 2017)	6
EF (Exposure frequency - day/yr; EPA, November 2017)	350
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-03
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSc (Child soil ingestion rate - mg soil/day; EPA, November 2017)	200
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAc (Child surface area - cm^2/day; EPA, November 2017)	2373
AFc (Child adherence factor - mg/cm^2; EPA, November 2017)	0.2

Cancer Risk Formula (with volatilization factor):

$$Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+(IUR*CFi*(1/VF+1/PEF)*ETcom)+((SFo*RAFd*CF*S$$

BENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	5.7
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	5.50E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	7.80E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	3,540
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

ETHYLBENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	28
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.50E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5,670
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

MTBE	
Parameters	Values
Cs (Soil concentration - mg/kg)	228
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.80E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.60E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4,900
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

1,2-DIBROMOETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	0.18
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	2.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	8,640
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

1,2-DICHLOROETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2.3
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	9.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.60E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4,570
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA,November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	19
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; EPA, November 2017)	250
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	3.40E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	46,300
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Total exposure duration - yr; EPA, November 2017)	25
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33

Cancer Risk Formula (without volatilization factor):

Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+(IUR*CFi*(1/PEF)*ETcom)+((SFo*RAFd*CF*SAa*Al

BENZ(A)ANTHRACENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	23.5
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - μg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

BENZO(A)PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2.35
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	6.00E-04
CFi (Inhalation conversion factor - μg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36.E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

BENZO(B)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	23.5
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

BENZO(K)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	235
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

DIBENZO(A,H)ANTHRACENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2.35
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

CHRYSENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2351
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

INDENO(1,2,3-CD)PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	23.5
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
ED (Exposure duration - yr; EPA, November 2017)	25
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

Cancer Risk Formula (without inhalation):

$$Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+((SFo*RAFd*CF*SAa*AFa)/BWa))]$$

1-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	81
TR (Target cancer risk - Arsenic example representing total risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; EPA, November 2017)	250
SFo (Chemical specific oral cancer slope factor - kg-day/mg; PPRTV, 2008)	2.90E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
ED (Exposure duration - yr; EPA, November 2017)	25
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

Non-cancer Risk Formula (with volatilization factor):

Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSa)/BWa)+(1/RfC*ETcom*(1/PEF+1/VF))+((1/RfDo*CF*

C5-C8 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	289
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV, 2009)	6.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	1189
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	1
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

C9-C12 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	362
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV, 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	7176
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	73
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	3.00E-03
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	46300
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

C9-C18 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	538
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV, 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	11092
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

TOLUENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	5856
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	8.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	5.00E+00
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4290
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

XYLENES	
Parameters	Values
Cs (Soil concentration - mg/kg)	311
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5740
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

Non-cancer Risk Formula (with inhalation but without volatilization factor):

Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSa)/BWa)+(1/RfC*ETcom*(1/PEF))+((1/RfDo*CF*RAFd

C9-C10 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	1406
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV, 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

C11-C22 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	5592
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	0.36
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV, 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.1
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

BENZO(A)PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	28
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-04
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	2.00E-06
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

ANTHRACENE

Parameters	Values
Cs (Soil concentration - mg/kg)	28254
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

ACENAPHTHENE

Parameters	Values
Cs (Soil concentration - mg/kg)	5651
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	6.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

FLUORENE

Parameters	Values
Cs (Soil concentration - mg/kg)	3767
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

FLUORANTHENE

Parameters	Values
Cs (Soil concentration - mg/kg)	3,767
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	2,825
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

2-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	377
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	9125
ED (Exposure duration - yr; EPA, November 2017)	25
EF (Exposure frequency - day/yr; EPA, November 2017)	250
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-03
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	100
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.12

Cancer Risk Formula (with volatilization factor):

$$Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+(IUR*CFi*(1/VF+1/PEF)*ETcom)+((SFo*RAFd*CF*SAa*AFa)/BWa))]$$

BENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	239
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	5.50E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	7.80E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	3540
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

ETHYLBENZENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1323
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.50E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	6500
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

MTBE	
Parameters	Values
Cs (Soil concentration - mg/kg)	8877
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.80E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.60E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4700
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

1,2-DIBROMOETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	7.8
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	2.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	9500
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

1,2-DICHLOROETHANE	
Parameters	Values
Cs (Soil concentration - mg/kg)	111
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	9.10E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	2.60E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5100
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1094
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
EF (Exposure frequency - day/yr; DEQ 2015)	124
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	3.40E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
VF (Volatilization factor - m^3/kg; EPA, November 2017)	54000
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ED (Exposure duration - yr; DEQ 2015)	1
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33

Cancer Risk Formula (without volatilization factor):

$$Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+(IUR*CFi*(1/PEF)*ETcom)+((SFo*RAFd*CF*SAa*AFa)/BWa))]$$

BENZ(A)ANTHRACENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	393
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

BENZO(A)PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	39.3
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; IRIS, January 2018)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, January 2018)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

BENZO(B)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	393
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

BENZO(K)FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	3928
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; IRIS, November 2017)	6.00E-06
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

DIBENZO(A,H)ANTHRACENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	39.3
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E+00
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-04
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

CHRYSENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	39284
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-03
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-07
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

INDENO(1,2,3-CD)PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	393
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; EPA, November 2017)	1.00E-01
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
IUR (Chemical specific - kg-day/mg; EPA, November 2017)	6.00E-05
CFi (Inhalation conversion factor - µg/mg; EPA, November 2017)	1.0E+03
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

Cancer Risk Formula (without Inhalation):

$$Cs = [(TR*AT)/(EF*ED*(((SFo*RAFo*CF*IRSa)/BWa)+((SFo*RAFd*CF*SAa*AFa)/BWa))]$$

1-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1355
TR (Target cancer risk)	1.E-06
AT (Averaging time - day; EPA, October 2011)	28470
BWa (Adult body weight - kg; EPA, November 2017)	80
EF (Exposure frequency - day/yr; DEQ 2015)	124
ED (Exposure duration - yr; DEQ 2015)	1
SFo (Chemical specific oral cancer slope factor - kg-day/mg; PPRTV, 2008)	2.90E-02
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

Non-cancer Risk Formula (with volatilization factor):

$$Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSa)/BWa)+(1/RfC*ETcom*(1/PEF+1/VF))+((1/RfDo*CF*RAF$$

C5-C8 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	408
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	6.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	1189
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	1
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

C9-C12 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	643
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	7,176
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

NAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	137
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; IRIS, January 2018)	3.00E-03
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	46,300
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

C9-C18 ALIPHATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	902
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	1.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	11,092
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

TOLUENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	5483
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	8.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3;IRIS, January 2018)	5.00E+00
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	4,290
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

XYLENES	
Parameters	Values
Cs (Soil concentration - mg/kg)	612
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	2.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3;IRIS, January 2018)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
VF (Volatilization factor - m^3/kg; EPA, November 2017)	5,740
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, July 2004)	0
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

Non-cancer Risk Formula (with inhalation but without volatilization factor):

$$Cs = [(THQ*AT)/(ED*EF*(((1/RfDo*RAFo*CF*IRSa)/BWa)+(1/RfC*ETcom*(1/PEF))+((1/RfDo*CF*RAFd*SAa$$

C9-C10 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	1028
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.5
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

C11-C22 AROMATICS	
Parameters	Values
Cs (Soil concentration - mg/kg)	3931
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	0.36
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	1.00E-01
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; MADEP, October 2002)	0.1
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

BENZO(A)PYRENE

Parameters	Values
Cs (Soil concentration - mg/kg)	34
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; MADEP, October 2002)	0.36
RfDo (Chemical specific oral reference dose - mg/kg-day; MADEP, November 2003)	3.00E-04
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RfC (Chemical specific inhalation reference concentration - mg/m^3; PPRTV 2009)	2.00E-06
ETcom (Commercial exposure time - 8 hr/day*1 day/24 hr; EPA, November 2017)	0.33
PEF (Particulate emission factor - m^3/kg; EPA, November 2017)	1.36E+09
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

ANTHRACENE

Parameters	Values
Cs (Soil concentration - mg/kg)	18887
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-01
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

ACENAPHTHENE

Parameters	Values
Cs (Soil concentration - mg/kg)	3777
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	6.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

FLUORENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2518
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

FLUORANTHENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	2,518
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

PYRENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	1,898
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	3.00E-02
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3470
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

2-METHYLNAPHTHALENE	
Parameters	Values
Cs (Soil concentration - mg/kg)	252
THQ (Target hazard quotient)	0.125
BWa (Adult body weight - kg; EPA, November 2017)	80
AT (Averaging time - day; EPA, November 2017)	365
ED (Exposure duration - yr; DEQ 2015)	1
EF (Exposure frequency - day/yr; DEQ 2015)	124
RAFo (Chemical specific oral relative absorption factor - unitless; EPA, November 2017)	1
RfDo (Chemical specific oral reference dose - mg/kg-day; IRIS, January 2018)	4.00E-03
CF (Conversion factor - kg/mg; EPA, November 2017)	1.0E-06
IRSa (Adult soil ingestion rate - mg soil/day; EPA, November 2017)	330
RAFd (Chemical specific dermal relative absorption factor - unitless; EPA, November 2017)	0.13
SAa (Adult surface area - cm^2/day; EPA, November 2017)	3527
AFa (Adult adherence factor - mg/cm^2; EPA, November 2017)	0.3

WATER QUALITY GUIDELINES FOR NON-TARGET ANALYTES

This spreadsheet calculates the concentrations of non-target petroleum compounds in water which result in a hazard quotient of 1 based on ingestion &, for volatile fractions, inhalation.

Non-Carcinogenic Risk Formula (EPA, November 2017):

$$Cw = [(THQ*AT*CF)/(ED*EF*(((RAFw*IRw/RfDo)/BWa)+(VF*ETres/RfC)))]$$

C5-C8 ALIPHATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	646
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	350
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	1
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (MADEP, November 2003))	0.04
VF (Andelman volatilization factor - L/m^3 (EPA, November 2017)	0.5
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	1
RfC (Inhalation reference concentration - mg/m^3 (IRIS, PPRTV, 2009))	0.6

C9-C12 ALIPHATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	1,391
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	365
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	1
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (MADEP, November 2003))	0.1
VF (Volatilization factor - L/m^3 (EPA, November 2017 (K*0.5 L/m^3))	0.5
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	13
RfC (Inhalation reference concentration - mg/m^3 (IRIS, PPRTV, 2009))	0.2

C9-C18 ALIPHATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	1,391
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	365
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	1
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (MADEP, November 2003))	0.1
VF (Volatilization factor - L/m^3 (EPA, November 2017 (K*0.5 L/m^3))	0.5
ETres (Residential exposure time - 24 hr/day*1 day/24 hr; EPA, November 2017)	13
RfC (Inhalation reference concentration - mg/m^3 (IRIS, PPRTV, 2009))	0.2

C9-C10 AROMATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	1,055
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	365
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	0.91
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (MADEP, November 2003))	0.03

C11-C22 AROMATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	1,055
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	365
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	0.91
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (MADEP, November 2003))	0.03

C19-C36 ALIPHATICS	
Parameters	**Values**
Cw (Water concentration - µg/L)	~~96,000~~
Beneficial use ceiling (µg/L)	1,000
THQ (Target hazard quotient - unitless)	1
BW (Body weight - kg; (EPA, November 2017))	80
AT (Averaging time - day (DEQ, May 2017))	10950
CF (Conversion factor - µg/mg; November 2017)	1000
ED (Exposure duration - yr (DEQ, May 2017))	30
EF (Exposure frequency - day/yr (EPA, November 2017))	365
RAFw (Chemical specific water relative absorption factor - unitless; MADEP, October 2002)	1
IRw (Ingestion rate - L/day; (EPA, November 2017))	2.5
RfDo (Oral reference dose - mg/kg/day (PPRTV, September 2009))	3

DEQ, May 2017; Montana Circular DEQ-7

EPA, November 2017; EPA Regional Screening Levels User's Guide and Tables

MADEP, October 2002; Characterizing Risks Posed by Petroleum Contaminated Sites: Implementation of MADEP VPH/EPH Approach

MADEP, November 2003; Updated Petroleum Hydrocarbon Fraction Toxicity Values for the VPH/EPH/APH Methodology

Appendix C

MONTANA METHOD

Montana Method for Volatile Petroleum Hydrocarbons (VPH) and Extractable Petroleum Hydrocarbons (EPH)

The Montana Method is based on the Massachusetts Department of Environmental Protection (MADEP) Method for the Determination of Volatile Petroleum Hydrocarbons (MADEP May 2004, Revision 1.1) and The Method for the Determination of Extractable Petroleum Hydrocarbons Extractable Petroleum Hydrocarbons (MADEP May 2004, Revision 1.1).

Montana Volatile Petroleum Hydrocarbons Method

The Montana Volatile Petroleum Hydrocarbons (VPH) Method adopts the Massachusetts VPH Method but with the following modifications and/or clarifications:

Sample Preservation and Holding Times

Soil/Sediment Samples
Soil/sediment samples may be collected in 4 oz. (120 mL) wide-mouth glass jars with Teflon-lined screw caps. Soil/sediment samples may be preserved in the field with methanol as described in the Massachusetts VPH Method, however it is not required at this time. All soil/sediment samples must be immediately cooled and maintained at a temperature of 4°C ±2°C. Soil/sediment samples must be extracted by the laboratory within 7 days of sample collection and must be analyzed within 28 days of sample extraction.

If soil/sediment samples are preserved in the field with methanol, a sample containing no methanol must also be submitted for determining moisture percentage. Otherwise, soil moisture can be obtained from the same 4 oz. sample jar used for collecting the soil/sediment sample submitted for VPH analysis.

Aqueous Samples
Aqueous samples should be collected in 40-ml glass volatile organic analyte (VOA) vials with Teflon lined septa screw caps. Samples must have zero headspace remaining when filled and must be acidified to pH of 2.0 or less at the time of collection. The pH can be adjusted to the appropriate level by adding 3 or 4 (up to 10 drops HCl may be added) drops of 1:1 HCl to each 40-ml sample vial. All aqueous samples must be immediately cooled and maintained at a temperature of 4°C ±2°C immediately after collection. Aqueous samples must be analyzed within 14 days of sample collection.

If groundwater conditions are such that the addition of acid preservative causes the sample to effervesce, the sample may be submitted without a field pH adjustment. The aqueous sample must be immediately cooled and maintained at a temperature of 4°C ±2°C immediately after collection. Aqueous samples without a field pH adjustment must be analyzed within 7 days of sample collection.

Reporting

Moisture content of soil/sediment samples must be reported and analytical results are to be reported on a dry-weight basis.

For comparison to Risk Based Screening Levels (RBSL), the concentrations of VPH fractions in soil/sediment and aqueous samples are adjusted to remove target compound concentrations that are specifically reported (e.g., benzene, toluene, etc.). VPH fractions include: C5-C8 aliphatics, C9-C12 aliphatics, and C9-C10 aromatics. C5-C8 aliphatics value is corrected for target aromatic compounds benzene and toluene. C9-C12 aliphatics value is corrected for aromatic target compounds ethylbenzene, m, p, & o- xylenes and C9-C10 aromatics. No adjustments are made to the C9-C10 aromatics.

In addition to the target analytes and hydrocarbon fractions, laboratories must generate a Total Purgeable Hydrocarbons (TPH) results for soil/sediment and aqueous samples. The TPH value should include all Flame Ionization Detector (FID) hydrocarbon response, regardless of elution time. Quantify the response using the FID average response factor for all of the VPH calibration mix constituents (do not include surrogates).

Analytical data packages should include a summary report that cross references the sample identification with the laboratory identification and identifies variations from standard operating procedures; laboratory analytical results; quality control data, which may include but is not limited to: surrogate recoveries, initial and continuing calibration blanks and spikes, method blanks, laboratory control blanks and spikes, and matrix spike and matrix spike duplicates; FID and photoionization (PID) chromatograms; chain of custody form(s); and a sample receipt checklist.

Second Column or Second Method Confirmation of MTBE and Naphthalene

DEQ is requiring a second column or second method confirmation of naphthalene and MTBE for soil/sediment and groundwater samples if concentrations of MTBE or naphthalene (reported via VPH analyses) are greater than one-half of the default RBCA Tier 1 RBSLs. Additional compounds elute at approximately the same times as naphthalene and MTBE, making it difficult for analysts to distinguish the target compounds from non-target compounds. Second column confirmation will aid in identifying the target compounds.

MTBE was legislatively banned in Montana in 2005. MTBE should be analyzed at any gasoline release that could have begun before 2005. Gasoline releases that are known to have started after the 2005 Montana MTBE ban do not need to sample for MTBE unless other circumstances are believed to exist. Second column confirmation may be warranted at sites on a case by case basis where MTBE has been reported at low concentrations and determining its presence or absence is important in evaluating the source of the contamination. Work directly with your DEQ technical contact for site-specific requirements.

Montana Extractable Petroleum Hydrocarbons Method

The Montana EPH Method adopts the Massachusetts EPH Method with the following modifications and/or clarifications.

Sample Preservation and Holding Times

Soil/Sediment Samples
Soil/sediment samples are collected in 4 oz. (120 mL) wide-mouth amber glass jars with Teflon-lined screw caps. All soil/sediment samples must be immediately cooled and maintained at a temperature of 4°C ±2°C. Soil/sediment samples must be extracted by the laboratory within 14 days of sample collection and must be analyzed within 40 days of sample extraction.

Aqueous Samples
Aqueous samples should be collected in 1 liter amber glass bottles with Teflon lined screw caps. Samples must be preserved at the time of sampling by adding a suitable acid to reduce the pH to less than 2.0. The pH can be adjusted to the appropriate level by adding 5 ml of 1:1 HCl or other suitable acid to each bottle. All aqueous samples must be immediately cooled and maintained at a temperature of 4°C ±2°C immediately after collection. Aqueous samples must be extracted within 14 days of sample collection and analyzed within 40 days.

Screening Level

The EPH method can be broken down into a two-step process. The first step, referred to as an EPH screen, is an extraction and analysis of hydrocarbons from the sample that generates a total extractable hydrocarbon (TEH) value. The TEH number should include all FID hydrocarbon response regardless of elution time. Quantify the screening concentration using the average response factor for all FID calibrated EPH aliphatic constituents (do not include surrogates). Further fractionation and analysis is not required for samples that do not exceed the screening limit. The screening step may be omitted for samples that, based upon appearance and/or odor, will exceed the screening limit.

Soil/Sediment Samples

Soil/sediment sample with results that exceed screening limit of 200 parts per million (ppm) require the silica gel cleanup and EPH fractionation step to determine the aliphatic (C9-C18 aliphatics and C19-C36 aliphatics) and aromatic (C11-C22 aromatics) fractions.

Aqueous Samples

Groundwater samples reporting TEH concentrations at or above the screening limit of 1,000 parts per billion (ppb) require fractionation. If the sample is fractionated, labs are required to report the EPH screen concentration, the C9-C18 aliphatics, C19-C36 aliphatics, C11-C22 aromatic fraction concentrations, along with the post-fractionation TEH concentration.

PAH analysis

The necessity of the PAH analysis for soil/sediment and aqueous samples will be determined on a case by case basis by the DEQ technical contact. With the exception of naphthalene, which in

included in VPH analyses, PAHs are typically not found in diesel or jet fuel. A release of waste oil, heavy-end hydrocarbons such as Bunker C, and/or unknown wastes should be analyzed for PAHs. The requisite sampling parameters will be supplied to the lab by the case manager prior to submitting the samples to the lab. Work with your DEQ technical contact for advice on how to proceed.

PAHs are to be analyzed using EPA Method 8270C or 8270D. 1-Methylnaphthalene and 2-methylnaphthalene were added to the 13 target PAHs listed in the 2009 version of RBCA. The concentrations of 1-methylnaphthalene and 2-methylnaphthalene, plus the other 13 target PAHs, are only subtracted from the C11-C22 aromatic fractions when the combined PAH concentration is three percent of the C11-C22 aromatic concentration or greater.

Reporting:

The C11-C22 aromatic fractions are adjusted for target compounds only when the combined target PAH concentration is three percent or greater of the C11-C22 aromatic concentration. The C11-C22 aromatic adjustment is accomplished by subtracting the combined target PAH concentrations from the C11-C22 aromatic fractions concentration.

Analytical data packages should include a summary report that cross references the sample identification with the laboratory identification and identifies variations from standard operating procedures; laboratory analytical results; quality control data, which may include but is not limited to: surrogate recoveries, initial and continuing calibration blanks and spikes, method blanks, laboratory control blanks and spikes, and matrix spike and matrix spike duplicates; FID chromatograms; chain of custody form(s); and a sample receipt checklist.