UNITED STATES ENVIRONMENTAL
PROTECTION AGENCY - REGION 5
UNDERGROUND STORAGE TANK SECTION

CONDUCTING RISK-BASED CORRECTIVE ACTION FOR FEDERALLY REGULATED UST PETROLEUM RELEASES

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LIST OF TERMS USED IN THIS DOCUMENT

- Active Remediation - Actions taken to reduce the concentrations of Chemical of Concern (COC).
- Attenuation - The reduction in concentrations of COC in the environment with distance and time due to processes such as diffusion, dispersion, absorption, chemical degradation, biodegradation, etc.
- Chemical of Concern (COC) - Specific constituent that is identified for evaluation in the risk assessment process.
- Corrective Action - Activities conducted to protect human health, safety, and the environment. These activities include recovery of free-product, evaluating risks, making site action decisions, implementing institutional controls, designing and operating cleanup actions and equipment, and monitoring of progress.
- Corrective Action Plan (CAP) - A document outlining proposed corrective actions.
- Direct Exposure Pathway - An exposure pathway where the point of exposure is at the source, without a release to any other medium.
- Engineering Controls - Modifications to a site or facility (e.g., capping, point of use water treatment, etc.) to reduce or eliminate the potential for exposure to COCs.
- Exposure - Contact of a person, plant or animal with a COC.
- Exposure Assessment - The determination or estimation (qualitative or quantitative) of the magnitude, frequency, duration, and route of exposure.
- Exposure Pathway - The course COCs take from the source area(s) to an exposed organism. An exposure pathway describes a unique mechanism by which an individual or population is exposed to COC. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route. If the exposure point differs from the source a transport/exposure media (e.g., ground water) is included.
- Exposure Point - The point at which it is assumed that a receptor, either actual or potential, can come into contact, either now or in the future, with the COC.
- Exposure Route - The manner in which COCs come in contact with an organism (i.e., ingestion, inhalation, dermal contact).
- Free Product - "Free product" refers to a regulated substance (40 CFR 280) that is present as a non aqueous phase liquid (e.g., liquid not dissolved in water).
- Gas Chromatograph (GC) - An instrument used to analyze soil and ground-water samples.
- Indirect Exposure Pathways - An exposure pathway with at least one intermediate release to any media between the source and the point of exposure (e.g., leaching of COCs from soil to ground water and subsequent ingestion of ground water).
- Institutional Controls - The restriction on use or access (e.g., fences, deed restrictions, restrictive

zoning, conditions for a site action decision) to a site or facility to eliminate or minimize potential exposure to COCs.

- Interim Corrective Actions - The course of action to mitigate fire and safety hazards and to prevent further migration of hydrocarbons in their vapor, dissolved, or liquid phase. Also, any action taken to reduce risk prior to implementation of a final remedy.

- Intrinsic Remediation - The verifiable reduction of COCs through naturally occurring microbial activity and/or other attenuation mechanisms.

- Maximum Contaminant Level (MCL) - A standard for drinking water established by USEPA under the Safe Drinking Water Act which is the maximum permissible level of COC in water which is used as a drinking water supply.

- Organic Vapor Analyzer (OVA) - A field instrument used to measure the organic vapors present in a sample of soil or ground water. A Photo Ionization Detector (PID) is a type of OVA.

- Point(s) of Compliance - A location(s) selected between the source area and the exposure point(s) where COCs must be at or below the determined target levels in media (e.g., soil, ground water, air).

- Reasonably Anticipated Future Use - Future use of a property or adjacent property which can be predicted with a high degree of certainty given current use, local government planning, and zoning.

- Receptors - Persons, structures, utilities, surface water, sensitive habitats, and water supply wells that are, or may be, affected by a release.

- Region - The United States Environmental Protection Agency, Region 5 Office of Underground Storage Tanks/Leaking Underground Storage Tanks

- Risk Assessment - An analysis of the potential for adverse health effects caused by COCs to determine the need for corrective action. Also used to develop target levels where corrective action is required.

- Risk Reduction - The lowering or elimination of the level of risk posed to human health or the environment through initial response action, corrective action, or institutional or engineering controls.

- Risk-Based Screening Levels (RBSL) - Risk-based, non-site-specific, corrective action target levels for a COC associated with a Tier 1 evaluation.

- Sensitive Environmental Receptor - Includes human and ecological receptors such as fisheries, wetlands and habitats of threatened or endangered species.

- Site Action - A decision to be made by the Region impacting the regulatory outcome of the site being evaluated under this guidance document. NOTE: The Region is currently revising the definition of "site action" to provide clarification on the wording of a final letter. It is similar to a "no further action" but it is not to be interpreted as such at this time. When completed, the revised "site action" will be made available. Example wording of a site action letter is included in Section III.

- Site Assessment - The collection of data on ground-water quality and potential receptors, subsurface geology, hydrology, and site characteristics to determine the levels of the COCs, and extent of the migration of the COCs to support corrective action decisions.

- Site Classification - A qualitative evaluation of a site based on known or readily available information. Associated with site classifications are initial response actions that are to be implemented simultaneously with the RBCA process. Sites should be re-classified as actions are taken to resolve concerns or as better information becomes available.

- Site-Specific Target Level (SSTL) - Risk-based corrective action target level for a COC developed for a particular site under the Tier 2 and Tier 3 evaluations.

- Source Area - defined as either the location of free-phase hydrocarbons or the location of highest soil and ground-water concentration of the COCs.

- Tier 1 Evaluation - A risk-based analysis where non-site-specific values based on conservative exposure factors (RBSL), potential exposure pathways, and land use are evaluated to determine appropriate actions.

- Tier 2 Evaluation - A risk-based analysis applying the RBSL at the exposure point, development of SSTL for potential indirect exposure pathways based on site-specific conditions, and establishment of points of compliance.

- Tier 3 Evaluation - A risk-based analysis to develop values for potential direct and indirect exposure pathways at the exposure point based on site-specific conditions.

PREAMBLE

The United States Environmental Protection Agency (U.S. EPA) Region 5 Underground Storage Tank Section (USTS) is issuing the following technical guidance to assist responsible parties and their contractors in the federally regulated (40 CFR Parts 280 & 281) leaking underground storage tank corrective action process. Release reporting and Corrective Action requirements for LUST sites can be found under Subpart E and F of the technical Standards. Subpart E - "Release Reporting, Investigation and Confirmation Section" and Subpart F - "Release Response and Corrective Action for UST systems containing Petroleum and Hazardous Substances Section" can be referenced under 40 CFR Parts 280.50-53 and 280.60-67, respectively. This document was designed to provide a methodology for making risk-based decisions concerning corrective action for releases of petroleum and petroleum products (not hazardous substances as defined in the technical standards), for those sites that will fall under federal regulatory jurisdiction. The document should be considered final, however, it may be subject to future revisions. **If this guidance document is used in other jurisdictions, please substitute the words "Region" where ever they appear with the term "implementing agency".**

The policy decisions illustrated in the accompanying text represent the views of Region 5 USTS. Throughout the document, the Region has decided to rely on a target risk range of 10^{-6} (1 in 1,000,000) for a residential scenario and 10^{-5} (1 in 100,000) for a commercial/industrial scenario. There may be instances when a risk of 10^{-4} (1 in 10,000) for an industrial scenario also will be appropriate. Accompanying tables and Risk Based Screening Levels reflect this policy decision. The Hazard Quotient is $\leq$ 1 for non-carcinogens. The decisions reflected herein are the result of a review of existing Risk Based Corrective Action (RBCA) policy decision making documents, knowledge gained during RBCA training seminars attended by Regional personnel and experience in managing risk at Federal-Lead LUST sites since federal regulations were promulgated in 1988. Where applicable, risk equations used were derived from the American Society for Testing and Materials ES-38 Guide for Risk Based Corrective Action Applied at Petroleum Release Sites, including those for the inhalation exposure based on vapor intrusion from groundwater.

The Tier 1 soil and ground water look up tables included in this guidance document reflect cancer risks of 10^{-6} for a residential scenario, and 10^{-5} for commercial/industrial scenarios. Users will note that the soil risk based screening levels are categorized into clay and sand environments. Also, because the specific input parameters used within the soil leachability model in Appendix B produced results for PAHs (naphthalene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)flouranthene, benzo(a)pyrene, chrysene, and dibenz(a-h)anthracene) greater than $1X10^{6}$ mg/kg, there are no corresponding values for these COCs within Tables 5 and 6. However, Region 5 will review all COC levels, including PAHs, on a site specific basis. If site conditions indicate potential risks from these COCs via any of the pathways covered by this guidance document, additional investigation may be necessary as part of a Tier 2 evaluation. Users will also note that soil RBSLs become less stringent with respect to depth of the COC from the measured water table. This policy choice was made by Region 5 to consider varying geologic conditions across the Region, and to account for other effects on COC migration.

Ground water look up tables were developed for ingestion of ground water, under both a Residential and Commercial/Industrial scenario. Vapor inhalation pathways were included to cover those sites where inhalation of vapors from soil poses a more realistic risk than ingestion of COC contaminated soil or ground water.

Although vapors could migrate to both ambient air and to air inside a building under certain conditions, RBSLs associated with inhalation of indoor air are not included in this guidance document. This is consistent with the U.S. EPA's Soil Screening Guidance (1994). At this time, the potential for migration of contaminants into basements cannot be quantitatively estimated in a reliable manner without a great deal of uncertainty. The existing models for vapor intrusion into buildings have not as yet been validated. In addition, the parameters used in these models (such as the number and size of cracks in basement walls) are extremely site specific and are not easily characterized by generic standard assumptions.

Because the ASTM models that were used to calculate the outdoor air RBSLs incorporate very conservative assumptions, these Tier 1 soil and ground water RBSLs are expected to also be protective of the indoor air pathway. For example, the models assume that there is an infinite source of contamination in the soil and ground water (i.e., no depletion, dilution or degradation occurs), that the contamination is spread evenly across the width of the entire affected area and extends all the way to the ground water table, and that vapors will be continuously emitted from an unpaved soil surface for the entire exposure duration (30 years for residents, 25 years for commercial/industrial workers). In addition, the vapor RBSL equations use a conservative box model to estimate dispersion in the ambient air instead of the Gaussian dispersion model used in EPA's Soil Screening Guidance.

Although soil and ground water RBSLs associated with indoor air inhalation are not included in this guidance document, the indoor air pathway should be evaluated on a case-by-case basis. If site conditions indicate potential risks via this pathway (e.g., vapors have been detected inside a building), additional investigation may be necessary as part of a Tier 2 evaluation.

Soil RBSLs based on dermal exposure also have not been included in this guidance document. This is also consistent with EPA's Soil Screening Guidance. The evaluation of this pathway is very uncertain due to the lack of data regarding the absorption of chemicals from the soil matrix through skin. Dermal exposures to contaminants in soil should also be evaluated on a case-by-case basis if site conditions indicate potential risks via this pathway.

It is expected that responsible parties required to apply this guidance document will retain qualified consultants to complete each of the steps and worksheets included within. Based on results obtained by the Region on a case by case basis, sites will be classified according to risk and kept in a Regional database. A site following the classification scheme outlined in Step 2, will receive a priority rating. This rating will represent its relative priority for Regional review and decision making.

Regarding site assessment guidance, this document references the American Society for Testing and Materials (ASTM) provisional guidance document PS 3 - Provisional Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases. The ASTM ASC Guide may be obtained (after 2/9/96) by contacting ASTM at 100 Bar Harbor Drive, West Conshohocken, PA., 19428 or at (610) 832-9500. The Region 5 RBCA document does not include a specific reference which explicitly lists which parameters to investigate or sample collection methods to be used. Instead, we rely on the knowledge and expertise of the consulting community (as defined in the ASTM Guide) to determine the proper information needed to complete either of the Tiers 1, 2 or 3 processes. A general list of necessary information for a Tier 1 evaluation can be found under Step 1 "Initial Site Assessment". There is also a reference document included (Appendix C) which lists possible parameters to be collected as part of an intrinsic remediation evaluation. Decisions as to the adequacy of site characterizations will be made by Region 5.

Regarding free product, it is the Region's policy that responsible parties will be required to remove, to the extent practicable, any free product located at a site, regardless of the classification. Free product removal requirements can be referenced in 40 CFR 280.64. To the extent practicable can mean removal of all free product, removal of a portion taking into consideration site specific constraints, or some other combination.

Unless otherwise indicated, information required to be maintained or submitted pursuant to a responsible party following this guidance document, is not subject to the approval requirements of the Paperwork Reduction Act, 44 U.S.C. 3501, et. seq. The Office of Management and Budget (OMB) has approved the information collection requirements contained in Subpart E -- "Release Reporting, Investigation, and Confirmation[1]" and Subpart F -- "Release Response and Corrective Action for UST Systems Containing Petroleum or Hazardous Substances[2]", under the provisions of the Paperwork Reduction Act, 44 U.S.C. 3501 et. seq. and has assigned OMB Control Number 2050-0068. The authority for corrective action requirements under the Federal Underground Storage Tank program (Subtitle I) can be found under Section 9003(h)(4) of the Resource Conservation and Recovery Act of 1976 as amended, 42 United States Code §6991 et. seq.

[1] Specifically 40 CFR §280.50 and §280.53
[2] Specifically 40 CFR §280.61-67, §280.71 and §280.74

NOTE: This guidance document is based on the RBCA guidance prepared by the South Carolina Department of Health and Environmental Control's LUST Program. It was modified for use by Region 5 by Gilberto Alvarez of the Underground Storage Tank Section, under the direction of Andrew Tschampa, Chief and Gerald W. Phillips (former Chief). The Region would like to acknowledge the assistance provided by Read Minor of SCDHEC, Shawn Sager of Geraghty and Miller, as well as Steve Washburn, Wesley Go & Steve Song of Environ. The Region also acknowledges the assistance provided by various peer reviewers. Comments, questions and concerns can be directed to the Region 5 USTS at 312 886 6159 or by writing to U.S. EPA; DRU-7J; 77 W. Jackson; Chicago, Il, 60604.

I. RISK-BASED DECISION MAKING FOR PETROLEUM RELEASES

The following technical criteria should be used to assist responsible parties and their contractors in the federally regulated leaking underground storage tank corrective action process. This document was designed to provide a methodology for making risk-based decisions concerning corrective action for releases of petroleum and petroleum products.

Where risk-based decision making is incorporated into the corrective action process, the result is called risk-based corrective action (RBCA). The risk-based decision process takes into account the current and potential future risk posed by releases. The risk is defined by using site-specific data on receptors, exposure potential, site hydrogeology, and the type, amount, and toxicity of the COCs. The objective of this process is to ensure that corrective actions are protective of human health and the environment.

This document is based on the ASTM Guide for Risk-Based Corrective Action at Petroleum Release Sites (ES38-94) and focuses on evaluation of the potential risk of exposure to the COCs: direct exposure due to ingestion of ground water, indirect exposure due to leaching from soil to ground water, vapor inhalation, vapor/explosive levels in buildings, structures, or utilities, and direct contact with soil. The ASTM RBCA Guide may be obtained by contacting ASTM at 100 Bar Harbor Drive, West Conshohocken, PA., 19428 or at (610) 832-9500. Outlined in the this document is a three-tiered approach for the evaluation of a petroleum release integrating risk assessment, risk management, site assessment, monitoring and corrective action selection (see accompanying flow chart) for petroleum releases in the Region.

Responsible parties must take certain initial steps, including action to prevent further releases, control fire and explosion hazards, and remove free product pursuant to the Federal Requirements for USTs, 40 CFR Part 280.64. Investigation reports, RBCA evaluations and CAPs must be approved by the Region in accordance with applicable guidance.

insert page 2 and 3 (2 page flow chart) here

II. RISK-BASED CORRECTIVE ACTION PROCEDURES

STEP 1 - INITIAL SITE ASSESSMENT

The information necessary for determining if interim corrective action is appropriate and for comparing concentrations of the COCs to the RBSL (i.e., a Tier 1 evaluation) must be obtained. An Accelerated Site Characterization (ASC) approach as outlined in the American Society of Testing and Materials provisional guidance document PS 3 "Provisional Standard Guide for Accelerated Site Characterization for Confirmed or Suspected Petroleum Releases" can be used to collect the necessary information. In general, the information to be obtained during the initial site assessment includes:

! A review of historical records of site activities and past releases;

! Quantification of the COCs. For petroleum releases, based on toxicity, mobility, persistence, and presence in material released, selected COCs are:

    For gasoline: benzene, toluene, ethylbenzene, xylenes (BTEX) and MTBE

    For leaded gasoline, add: Lead, EDB

    For diesel & kerosene: BTEX, PAHs: naphthalene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)flouranthene, benzo(a)pyrene, chrysene, and dibenz(a-h)anthracene

    For used oil, add: arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver

    As the toxicity of Total Petroleum Hydrocarbon (TPH) analyses cannot be quantified, it cannot be used in the risk decision making process.

! Additional parameters to use soil leachability model. One background soil sample for Total Organic Carbon (EPA method 415.1) and one soil sample taken from the source area for grain size analysis.

! Location of primary source(s) of COCs;
- USTs, product lines, dispensers, service bays, etc.

! Location of secondary source(s) of COCs;
- free-product, soil with concentrations above RBSL, etc.

! Location of maximum concentrations of COCs in soil and ground water;

! Determination of regional or site-specific hydrogeologic conditions (e.g., depth to ground water, flow direction, gradient, ambient ground water quality, ground-water flow velocity);

! Determine if the COCs in the soil will leach to ground water (a soil leachability model is provided in Appendix B - NOTE: The soil leachability model in Appendix B must be used for Tier 1 evaluations, additional models can be used for further tier analysis);

! Location of current and reasonable potential future receptors (including well searches);

! Identification of potential significant transport and exposure pathways. A complete exposure pathway requires: 1) a source and mechanism for COC release into the environment, 2) a transport medium (e.g., air, soil, ground water, vapor migration through soil and utilities) for the COC to move from the source to the receptor, 3) a point of potential contact of the receptor with the medium (points of exposure such as drinking water wells), and 4) an exposure route or means for taking the COC into the body (e.g., ingestion, inhalation, dermal contact);

- Determination of current and reasonably anticipated future use of the property, ground water, surface water, and sensitive environmental receptors where the release has occurred <u>and</u> the surrounding property. Land use zoning (commercial, industrial, or residential) should be considered when evaluating reasonably anticipated future use.
- If available, changes in concentrations of the COCs over time (i.e., stable, increasing, decreasing); and,
- If appropriate, concentrations of COCs measured at point(s) of exposure (e.g., concentrations of COCs in a nearby drinking water well, vapor concentrations of COCs in nearby utilities).

STEP 2 - SITE PRIORITY CLASSIFICATION

Based on initial release information, and subsequently upon completion of each tier evaluation, the release is classified into categories based on the current and projected degree of risk to human health and the environment. The highest priority classification is for those releases which pose an emergency. The second priority classification is for those releases which pose a significant near term (0 to 1 year) threat, the third priority classification is for those releases where there is a short term (1 to 2 years) threat, the fourth priority classification is for those releases where there is a long term (> 2 years) threat to human health or the environment. The fifth priority classification is for releases which: 1) do not meet any of the characteristics of the earlier priorities, or 2) where currently there is no demonstrable threat to human health or the environment but where the data indicate COCs are above the RBSL and further assessment is needed. Travel times are calculated from the monitoring well closest to the receptor that contains concentrations of COCs above the RBSL.

Prioritization is an on-going process and is based on available information. Releases may be re-classified subsequent to interim remedial actions, further assessment information, and corrective action. Please see Appendix A for the detailed priority classification system. If the site becomes a confirmed release as a result of a tank removal operation, every attempt must be made to address the most contaminated soil in and around the tank pit area. An interim action such as a limited excavation of the most heavily contaminated soils will reduce the future risk associated with the site.

Some release scenarios and proper response actions to eliminate any immediate threat are provided in Table 1. Interim remedial action to eliminate actual exposure is required - depending upon the State or local jurisdiction of the release, contact with the appropriate emergency management agency is required. Regarding free product, it is the Region's policy that responsible parties will be required to remove, to the extent practicable, any free product located at a site, regardless of the classification. Free product removal requirements can be referenced in 40 CFR 280.64. To the extent practicable can mean removal of all free product, removal of a portion taking into consideration site specific constraints, or some other combination.

STEP 3 - TIER 1 EVALUATION

Conducting a Tier 1 evaluation requires two sub-steps: (1) develop an exposure pathway analysis and (2) compare the site specific data to appropriate RBSLs. A complete exposure pathway exists where a mechanism allows a receptor to be exposed to the COC.

(1) EXPOSURE PATHWAY ANALYSIS

An exposure pathway analysis identifies all complete exposure pathways using information about the facility's operations, types of sources, and the release. Information required to develop this analysis includes the source of the COCs, current and expected site conditions/land use, proximity to receptors (receptor survey), current and expected use of ground water and human & sensitive environmental receptors. The following potential exposure pathways should be considered for evaluation: NOTE: The media described below (Air, Ground Water, Surficial (0-1 foot) and Subsurface Soil represent the transport media for the exposure pathway)

- Air
    - inhalation of ambient vapors (particulate or volatile)
- Ground Water
    - ingestion
- Surficial Soil
    - incidental ingestion
    - inhalation (particulate or volatile)
- Subsurface Soil
    - ambient (outdoor) inhalation (particulate or volatile)
    - leaching to ground water

For current conditions (and for reasonably anticipated future use if different from the current use), prepare a summary of complete exposure pathways at a site, based on the factors described above. For example, drinking water wells may not currently exist but ground water may reasonably become a source of drinking water. The potentially exposed population could include: on-site resident, off-site resident, worker, and visitor depending on current or projected land use (e.g., commercial or residential). Examples of an exposure pathway summarization are provided in Tables 2 and 3.

(2) COMPARISON TO RBSL

A key input parameter is the COC concentration at the exposure point (e.g., concentration in the water that a current or potential future receptor may drink, or concentration in the air that a receptor may breathe). The RBSL for the COC must be met at the exposure point. For the ground-water ingestion, soil leaching to ground water, vapor inhalation, and soil ingestion pathways, COC concentrations measured at the source areas should be compared with the values provided in the RBSL Look-up Tables 4 through 10. **Important Assumption:** In Tier 1, the exposure point(s) and point(s) of compliance are assumed to be located within the source area or the area containing the highest concentrations of the COC.

So that data obtained in the assessment can be consistently evaluated, representative concentrations of COC in affected media are determined by the following:

- Ground Water: the maximum COC concentration obtained from last sampling event. Historical sampling events can be used to establish trends, for consideration of a Tier 1 action.

- Soil: the maximum COC concentration obtained in the last sampling event for the ingestion, inhalation, and dermal contact pathway, the average COC concentration in the source area for the soil leaching to ground water pathway. To determine an areally representative COC concentration in the soil to be used in a leachability model, the three soil samples with the highest concentration of COC should be averaged. For the purposes of this guidance, COC concentration refers to the 95 percent upper confidence limit (UCL) on the average or mean. NOTE: Do not consider analyses of soils which have been excavated.

- Vapor: the maximum COC concentration obtained in last sampling event. Historical sampling events can be used to establish trends, for consideration of a Tier 1 action.

STEP 4 - TIER 1 ACTION

A decision as to the appropriate action must be made based on the comparison of data in step 3. Four options are available:

1) **Site Action** - If the concentrations of the COCs are below the RBSL, a site action decision will be considered by the Region (for example, further assessment and/or cleanup is not necessary). For the RBSL comparisons to be valid, it must be acceptable to the Region that the sample locations are representative of the source area(s).

2) **Interim Remedial Action** - If the concentrations of the COCs are above the RBSL, partial source removal or other actions may be necessary to reduce the risk. Free-product must be removed to the extent practicable, as described in 40 CFR 280.64.

3) **Further Tier Evaluation** - If the concentrations of the COCs are above the RBSL, further tier evaluation is warranted under the following conditions:

   - ! If the SSTL developed under further tier evaluation will be significantly different than the Tier 1 RBSL (concentrations of COCs exceed the RBSL but it is predicted that the use of site-specific data will allow different site-specific cleanup goals to be determined consistent with the same risk goals).

   - ! If the cost of corrective action to RBSL likely will be greater than further tier evaluation (data collection, analysis, review, etc.) and subsequent corrective action.

   - ! The approach, or assumptions, used to derive the current tier's goals are not representative of conditions at the site.

4) **Corrective Action** - If the concentrations of the COCs are above the RBSL and interim remedial actions or further tier evaluation are not considered appropriate options, a CAP for active cleanup and/or intrinsic remediation (to collect sufficient data to conclude that concentrations of the COCs will not present a risk to human health or the environment using natural biodegradation and/or other natural attenuation mechanisms) should be submitted. See Appendix C for further information on demonstrating intrinsic remediation.

STEP 5 - TIER 2 ASSESSMENT

If additional tier evaluation is warranted as outlined in step 4, the responsible party should submit a letter or a plan to conduct a Tier 2 assessment. NOTE: A written plan is not required for sites which use Tier 1 methods, but insert site specific data for some of the parameter values, calculating reasonable exposure scenarios and exposure point concentrations, and using statistical methods for determining source area concentrations. Additional site assessment for a Tier 2 evaluation should include:

- Determination of site-specific hydrogeologic conditions (for example, conducting a pumping test to obtain more accurate data);
- Determination of horizontal and vertical extent of COC relative to the RBSL, as appropriate;
- Determination of changes in concentrations of COC over time (i.e., stable, increasing, decreasing); and,
- Determination of concentrations of COC measured at exposure points (e.g., in a nearby drinking water well, vapor concentrations of COC in nearby utilities). Also, verification that COC contaminated ground water is hydraulically connected to potable aquifer. NOTE: See the next section for a more detailed discussion of exposure points.

Additional site assessment and fate and transport evaluation may be required to fully evaluate exposure pathways and scenarios identified during Tier 1. Again, an Accelerated Site Characterization (ASC) approach can be used to collect the more comprehensive information necessary for a Tier 2 evaluation.

STEP 6 - TIER 2 EVALUATION

Conducting a Tier 2 evaluation requires three sub-steps: (1) establish an exposure point(s), (2) establish site-specific point(s) of compliance, and (3) calculate the corresponding SSTL for the COC applicable at the point(s) of compliance and source area(s) based on the measured and predicted attenuation of the COC away from the source area. Modeling (or an equivalent technique) can be used to predict the attenuation of the COC away from the source area. Relatively simple mathematical models and/or algebraic or semi-analytical expressions can be utilized in this tier; input data can be limited to practicably attainable site-specific data. The following steps should be followed to complete the Tier 2 evaluation:

(1) ESTABLISH THE EXPOSURE POINT(S)

Based on data collected as part of the tier 2 data collection assessment, most exposure point scenarios should fall into one of the following three cases:

Case 1: Where an actual exposure point is identified on the facility property and the off-site ground water is a current source of drinking water, or is reasonably anticipated to be utilized, the established exposure point is on site.

Case 2: Where no actual exposure point is identified on the facility property and the off-site ground water is a current source of drinking water, or is reasonably anticipated to be utilized, the established exposure point should be located hydraulically downgradient of the facility property boundary, or on the off site property if an actual exposure point exists there.

Case 3: Where no actual exposure point is identified on the facility property and the off-site ground water is not reasonably anticipated to be utilized as a source of drinking water, the exposure point should be located hydraulically upgradient of the nearest receptor.

Other exposure points may be established for potential receptors identified in the assessment (e.g., vapors in a basement or utility). The most likely point of exposure closest to the source area should be proposed as the exposure point for each pathway identified. The exposure point concentration of COC where an RBSL has not been established will be developed in consultation (requiring prior approval) with the Region.

(2) ESTABLISH SSTL

a) For the ground-water ingestion pathway, the reduction of the COC in the saturated zone should be estimated using either empirical data or models using site-specific data. Empirical data can be used to estimate the overall concentration reduction factor (CRF) of the COC in the relevant media from the source to the exposure point. For example, if the concentration of benzene in the source area is 100 micrograms per liter (ug/l) and a concentration of 10 ug/l is present in the most downgradient well, benzene has been documented to be reduced by a factor of 10 (i.e., the CRF is 10). The SSTL = exposure point concentration X CRF. Since the Residential RBSL for benzene is 5 ug/l (0.005 mg/l) to be applied at the exposure point, the SSTL for ground water to be met at the source area is 50 ug/l (5 ug/l x 10). NOTE: If the downgradient wells have not been impacted (i.e., CRF = 0), the Region will recommend a "monitoring only" approach for the site. Groundwater will need to be monitored quarterly for one year or at a frequency and duration to be determined on a site by site basis based on site conditions.

Models can also be used to estimate the fate and transport of the COC away from the source area. The DOMENICO MODEL, provided in Appendix D, is a relatively simple analytical model that is appropriate for many LUST sites. Computer fate and transport models may also be appropriate if site-specific conditions require a more complex analysis. For the saturated zone, models such as DOMENICO, SOLUTE, AT123D, and BIOPLUME-II can be used to estimate the transport of COCs. Other models described in peer reviewed literature may also be acceptable. All input parameters and assumptions used in any model must be provided in the report submitted to the Region. NOTE: The decision to proceed with more complex models will be a function of the complexity of the specific site and the data available. For example, a site where a highly variable stratigraphy exists. Such a site would be conducive to a complex model where multiple aquifer input parameters can be varied to produce results. If another model is used, the results need to remain within an order of magnitude to the models listed in this guidance.

b) For the soil leaching to ground water pathway, the SSTL for soil can be calculated using the leachability model provided in Appendix B (for the tier 2 analysis, additional models can be used provided the results remain within an order of magnitude).

c) In Tier 2, SSTL for the dermal contact, soil ingestion, and vapor inhalation pathways is based on a Target Risk Limit of 10^{-6} and a Hazard Quotient of $\leq$ 1 for non-carcinogens to be applied at the exposure point, assuming a residential setting. For a commercial/industrial scenario, a Target Risk Limit of 10^{-5} and a Hazard Quotient of $\leq$ 1 for non-carcinogens should be applied.

(3) ESTABLISH POINT(S) OF COMPLIANCE

The point(s) of compliance should be established hydraulically downgradient of the source area and hydraulically upgradient of an exposure point. At least one point of compliance must be located directly downgradient of the source area (in the area of highest concentration) between the source area and the exposure point. When establishing point(s) of compliance, consider: a) locations of current receptors, b) locations of reasonable potential receptors, c) current and projected local and site land and resource usage, and d) the rate of transport. At least a one year travel time (or other reasonable time frame for response to compliance point exceedance) upgradient of any actual receptor point should be established. Additional point(s) of compliance are necessary where complex hydrogeologic conditions exist that may control COC migration (e.g., preferential pathways due to stratigraphy, fractures).

STEP 7 - TIER 2 ACTION

A decision as to the appropriate action must be made based on the comparison of data in step 6. Four options are available:

1) **Verification Monitoring** - If the concentrations of the COCs are below the SSTL, further COC delineation is not necessary. A CAP proposing a short-term (e.g., two years) monitoring program to verify the modeling results and assumptions used to develop the SSTLs should be submitted. If the concentrations of the COCs are below the SSTL and historical data for at least 2 years (or another timeframe as approved by the Region) is sufficient to verify the model, then a request for site action may be submitted.

2) **Interim Remedial Action** - If the concentrations of the COCs are above the SSTL, partial source removal or other actions may be necessary to reduce the risk. Free-product must be removed to the extent practicable.

3) **Further Tier Evaluation** - If the concentrations of the COC are above the SSTL, further tier evaluation is warranted under the following conditions:

   - If the SSTL developed under further tier evaluation will be significantly different than the Tier 2 SSTL (i.e., concentrations of COC exceed the SSTL but it is predicted that the use of site-specific data will allow different site-specific cleanup goals to be determined consistent with the same risk goals).
   - If the cost of corrective action to SSTL will likely be greater than further tier evaluation (data collection, analysis, review, etc.) and subsequent corrective action.
   - The approach, or assumptions, used to derive the current tier's goals are not appropriate for conditions at the site.

4) **Corrective Action** - If the concentrations of the COCs are above the SSTL and interim remedial action or further tier evaluation are not considered appropriate options, a CAP for active cleanup and/or intrinsic remediation (to collect sufficient data to conclude that concentrations of COCs will not present an unacceptable target risk to human health or the environment using natural biodegradation and/or other natural attenuation mechanisms) should be submitted. See Appendix C for further information on demonstrating intrinsic remediation.

STEP 8 - TIER 3 ASSESSMENT

In Tier 3, SSTL for the source area and the point(s) of compliance are developed on the basis of more sophisticated statistical and/or COC fate and transport analyses using site-specific input parameters for appropriate exposure scenarios. Any additional information required for site-specific modeling efforts must be collected.

STEP 9 - TIER 3 EVALUATION

The Tier 3 evaluation involves the use of more sophisticated mathematical models than used in Tier 2 (e.g., computer analytical models) or numerical ground water modeling codes that predict time-dependent dissolved COC transport under conditions of spatially varying permeability fields to predict exposure point(s) concentrations and to re-calculate SSTL based on more site-specific data. Monte Carlo analysis can be used in a variety of ways in the Tier 3 assessment. First, distributions may be used for the exposure parameters. These will provide the user with a distribution of risk values. The U.S. EPA typically evaluates potential risk at the 90 or 95 percent upper confidence level. Second, if site specific data are available or appropriate data can be identified from the literature, Monte Carlo can be used for the fate and transport parameters used in the modeling. If limited site-specific data are available, then a sensitivity analysis could be conducted to demonstrate which parameters are the most significant for the model.

STEP 10 - TIER 3 ACTION

A decision as to the appropriate action must be made based on the site conditions to the SSTLs calculated in step 9. Two options are available:

1) **Verification Monitoring** - If the concentrations of the COCs are below the SSTL, further COC delineation is not necessary. A CAP proposing a short-term (e.g., two years) monitoring program to verify the modeling results and assumptions used to develop the SSTLs should be submitted. If the concentrations of the COCs are below the SSTL and historical data for at least 2 years (or another timeframe as approved by the Region) is sufficient to verify the model, then a request for site action may be submitted.

2) **Corrective Action** - If the concentrations of the COC are above the SSTL, a CAP for active cleanup and/or intrinsic remediation should be submitted.

STEP 11 - CORRECTIVE ACTION PROGRAM

Based on the target levels (Tiers 1, 2, or 3), choose measures to achieve those levels and/or eliminate exposure pathways. It may also be appropriate to initiate active remediation at a site (perhaps to further address the source area) and to then implement a verification monitoring program to demonstrate intrinsic remediation for the residual COC.

All corrective actions will require a Regionally approved CAP. Detailed design specifications must be developed for installation and operation of the selected corrective action option(s). The Region will review and approve CAPs on a case-by-case basis.

STEPS 12 & 13 - VERIFICATION MONITORING

Following, or during, a corrective action, a compliance monitoring program may be required to insure: 1) that target goals continue to be met, and 2) assumptions and predictions used in Tier 2 and 3 are verified. The monitoring frequency will be established on a site-by-site basis. Once monitoring data verifies the model predictions and supports the conclusion that no threat to human health, safety, or the environment exists currently or in the future, a site action decision will be considered by the Region.

III. SITE ACTION DECISIONS

"Site Action" decisions are based on site-specific land use assumptions and conditions. Land and/or ground water use, and the associated exposure conditions, should not be changed such that risk is increased. For example, if concentrations of COC are present in the ground water that prevent human consumption but no further actions are required (based on demonstration that the release does not pose a risk to human health or the environment), the conditions and assumptions (e.g., the ground water should not be used for consumption) will be documented in the "site action" letter to the responsible party. Also, this agency will keep files on releases responded to as part of this policy.

Example language of a site action letter can include: "Based upon current information, the U.S. EPA Region 5 anticipates no need to take further RCRA enforcement, investigatory or cleanup action at this site unless new information warranting further RCRA consideration or conditions not previously known regarding the site are discovered."

APPENDIX A

RBCA Classification/Priority System

1. Sites are placed in Classification 1 if:

    - an emergency situation exists
    - a fire or explosion hazard exists
    - vapors or free product exists in a structure or utility
    - concentrations of COC have been detected in a potable water supply or surface water supply intake
    - free product exists on surface water
    - COC exist in surface water

2. Sites are placed in Classification 2 if:

    Classification 2a:

    - a significant near term (0 to 1 year) threat to human health, safety, or sensitive environmental receptors exists
    - potable supply wells or surface water supply intakes are located < 1 year ground-water travel distance downgradient of the source area

    Classification 2b:

    - free product exists in a monitoring well measured at > 1 foot thickness
    - potable supply wells or surface water supply intakes are located < 1000 feet downgradient of the source area (where ground-water velocity data is not available).

3. Sites are placed in Classification 3 if:

    Classification 3a:

    - a short term (1 to 2 years) threat to human health, safety, or sensitive environmental receptors exists
    - potable supply wells or surface water supply intakes are located > 1 year and < 2 years ground-water travel distance downgradient of the source area
    - sensitive habitats or surface water exist < 1 year ground-water travel distance downgradient of the source area and the ground water discharges to the sensitive habitat or surface water

    Classification 3b:

    - free product exists in a monitoring well measured at > 0.01 foot thickness
    - concentrations of COC above the RBSL have been detected in a non-potable water supply well
    - hydrocarbon-containing surface soil (< 3 feet below grade) exists in areas that are not paved
    - sensitive habitats or surface water used for contact recreation exist < 500 feet downgradient of the source area (where ground-water velocity and discharge location data are not available).

- the site is located in a sensitive hydrogeologic setting, determined based on the presence of fractured or carbonate bedrock hydraulically connected to the impacted aquifer
- ground water is encountered < 15 feet below grade and the site geology is predominantly sand or gravel

4. Sites are placed in Classification 4 if:

   Classification 4a:

   - a long term (> 2 years) threat to human health, safety, or sensitive environmental receptors exists
   - potable supply wells or surface water supply intakes are located > 2 years and < 5 years ground-water travel distance downgradient of the source area
   - non-potable supply wells are located < 1 year ground water travel distance downgradient of the source area

   Classification 4b:

   - free product exists as a sheen in any monitoring wells
   - non-potable supply wells are located < 1000 feet downgradient of the source area (where ground-water velocity data is not available)
   - the ground water is encountered < 15 feet and the site geology is predominantly silt or clay

5. Sites are placed in Classification 5 if:

   - there is no demonstrable threat, but additional data are needed to show that there are no unacceptable risks posed by the site
   - assessment data for the site indicate concentrations in some samples are above the RBSL or SSTL, as appropriate, and further assessment is needed
   - assessment data for the site indicate concentrations in samples are below the RBSL or SSTL, as appropriate, but the samples are determined to not be representative; therefore, further assessment is needed

Appendix B - LEACHABILITY MODEL FOR PETROLEUM CONTAMINATED SOIL

The following approach is provided to determine whether leachates from petroleum contaminated soils will migrate to ground water and to determine Site Specific Target Levels (SSTLs) for cleanup of impacted soil. If soil concentrations are above the Risk Based Screening Levels (RBSLs) outlined in the Risk-Based Corrective Action Criteria Document, the soil leachability model can be used to determine if soil remediation is necessary. The model utilizes a series of mathematical equations that quantify contaminant partitioning, transport, degradation, and dilution processes.

Data Acquisition

If a Tier 1 limited evaluation has already been completed, no additional assessment will be necessary to utilize the soil leachability model and this section may be skipped.

Soil borings and monitoring wells are necessary to use the model. The size of the source area (map view) should be measured. At least one boring is to be placed within the most probable area of concern and completed to the water table*. Split spoon soil samples shall be collected at five foot intervals, or less if direct push methods are used. Each soil sample shall be screened in the field for organic volatiles and lithologically classified (e.g. silty sand, clay, etc.). For other less volatile contaminants such as diesel or kerosene, alternative screening methods (e.g. field GC, immunoassay, etc.) can be used to determine the worst case sample.

A soil sample from the depth (vadose zone) that exhibited the highest organic reading (field) is to be analyzed. For gasoline releases, analyze for: benzene, toluene, ethylbenzene and xylene (BTEX); for diesel: BTEX and polynuclear aromatic hydrocarbons (EPA method 610 or equivalent). Further, a soil sample from the bottom of the boring shall be analyzed using a grain size/hydrometer test. The sand, silt and clay fractions shall be segregated at .074 mm (#200 screen) and .004 mm, respectively.

The depth to the water table should be measured with appropriate instrumentation and hydraulic gradient determined. A ground-water sample shall be collected and analyzed for the appropriate parameters.

A second soil boring shall be installed outside of the area of known soil contamination (based on existing data). A soil sample should be collected below the "A" horizon (NOTE: "horizon" derived from standard geological textbooks) unless a shallow water table precludes this collection. The soil sample should be lithologically described and analyzed for total organic carbon by EPA Analytical Method 415.1. The presence of calcareous soil should be noted for possible analytical interferences.

Any visual staining of surficial soil should be noted, including the presence of asphalt or concrete over the impacted soil. Any potential exposure points to the impacted soil should be noted (e.g. contaminated soil exposed at surface or enclosed spaces that may accumulate vapors).

* If field readings from three consecutive split spoon samples indicate non-detectable concentrations of COC, then advancement of the boring to the water table may not be necessary. In that situation, an additional soil sample should be collected from the termination depth to verify the vertical depth of the soil impact. This sample shall be analyzed for those constituents as described above. Depth to water measurements and ground-water quality analyses would not be necessary.

SOIL LEACHABILITY MODEL INPUT PARAMETERS

The following input parameters are needed to utilize the equations. An In-Situ Soil Risk Evaluation form is included with this document, which evaluates soil leachability into risk. Page 1 of that form can be used to summarize the pertinent soil leachability data. Page 2 provides a concise format to summarize the results from each equation and conclusions. **The following equations are valid for:**

aqueous concentration of COC < solubility limit of COC
5% < Sand < 70%
5% < Clay < 60%

For sediments that are outside these ranges, the nearest maximum or minimum values should be used.

$\mathbf{B_d}$	**Bulk density** (g/ml) is defined as the weight of oven dry soil divided by the total volume of soils (solids + pores). Based on the grain size distribution, B_d can be estimated from Figure 1.
$\mathbf{C_{rbsl}}$	**Risk-based screening level** (mg/l) for COC in ground water
$\mathbf{C_s}$	**Concentration of COC** (mg/kg) in soil
$\mathbf{C_{sstl}}$	**Site-specific target level** (mg/kg) for COC in soil
$\mathbf{f_{oc}}$	The **fraction of organic carbon in soil** (kg/kg), typically determined by analysis of total organic carbon (TOC) by EPA method 415.1.
H'	The **Henry's Law Constant** (dimensionless units) relates the partial pressure of a gas and its corresponding solubility in water at a given temperature.
I	**Average annual recharge** (precipitation minus evapotranspiration and runoff). Assume 18 centimeters unless additional information is available.
$\mathbf{K_{oc}}$	The **soil/water partitioning coefficient** (K_{oc}) (ml/g) is compound specific and provides an indication of the tendency of COC to partition between particles containing organic carbon and water. Some averaged values for typical petroleum constituents are provided in Table A. Please note that the values in Table A are most applicable for soils containing an $\mathbf{f_{oc}}$ **value ≥ 1%**.

Table A

COC	K_{oc} * (ml/g)	H' $\frac{mg/l}{mg/l}$ *	$t_{1/2}$ ** (days)
Benzene	81	.226	300
Toluene	133	.301	28
Ethylbenzene	176	.280	228
Xylene	639	.278	360
Naphthalene	1543	.002	258
Benzo(a)anthracene	1,380,384	.0002	1360
Benzo(b)fluoranthene	549,541	.0005	1220
Benzo(k)fluoranthene	4,365,158	.043	4280
Chrysene	245,471	3.02×10^{-18}	2000
Dibenz(a,h)anthracene	1,659,587	3.05×10^{-7}	1880

* From Montgomery. J.H. et.al., 1991. Groundwater Chemicals Desk Reference. Lewis

	Publishers.
**	From Howard, P.H. et.al., 1991. Environmental Degradation Rates, Lewis Publishers.
L	The **distance** in centimeters (cm) between the depth of the soil sample exhibiting the highest concentration of COC and the depth of the measured water table. For example, if the soil sample with the highest concentration of COC occurred at 10 feet below land surface (bls) and ground water was encountered at 20 bls, then L = 304.8 centimeters (10 feet).
ϕ	**Porosity** (l/l) is the percentage of the rock or soil that is void of material. Based on the grain size distribution, the porosity can be estimated from Figure 2.
ϕ_w	Water-filled porosity (l/l) is expressed as a ratio of the volume of water in the soil divided by the bulk volume of the soil sample.
$t_{1/2}$	The **biodegradation "half-life"** (days) of COC. This is compound specific. Some conservative values for typical petroleum constituents are provided in Table A.

insert figures 1 and 2 here

Equation 1 - Determine concentration of COC in pore water at the source

Calculate the concentration of the COC in soil pore water directly in contact with contaminated soil. The equilibrium partitioning of the COC between the sorbed, aqueous and vapor phases is described by the following equation:

$$\mathbf{C_w = C_s * B_d /(B_d*K_{oc}*f_{oc} + \phi_w + (\phi - \phi_w)} * H'\mathbf{)} \leq \text{solubility}$$

where,

C_w = concentration (mg/l) of the COC in soil pore water at the source,
C_s = concentration (mg/kg) of the COC in soil at the source (worst case sample),
B_d = bulk density (g/ml) of soil,
K_{oc} = organic/water partitioning coefficient (ml/g) of the COC (see Table A),
f_{oc} = fraction of organic carbon (kg/kg) in the soil,
ϕ = porosity (l/l) of the soil,
ϕ_w = water filled porosity (l/l) of the soil in the vadose zone, and
H' = Henry's Law Constant (unitless) of the COC (Table A).

Because the most conservative situation is assumed (only physical partitioning of the contaminant), the value for C_w is likely to exceed the RBSL for the COC. The remaining equations are utilized to account for infiltration velocities, attenuation and biological degradation effects and will be applied to C_w to determine the risk to ground water.

Equation 2 - Determine unsaturated zone flow velocity

Calculate the velocity of water via one-dimensional unsaturated flow through the vadose zone without dispersion. This is determined by the ground water recharge rate (or infiltration rate) and the water filled porosity of the unsaturated soil in the vadose zone (assumed to be constant with depth), as shown in the equation below, not by the saturated hydraulic conductivity of the soil.

$$\mathbf{V_w = I/\phi_w}$$

where,

V_w = velocity (cm/yr) of water in the vadose zone,
I = rate of recharge or infiltration rate (cm/yr) to ground water, and
ϕ_w = water filled porosity (l/l) of the soil in the vadose zone.

Equation 3 - Determine COC velocity considering an organic retardation effect

Calculate the velocity of the COC in the vadose zone with the organic retardation effect using the following equation:

$$\mathbf{V_c = V_w/(1 + B_d * K_{oc} * f_{oc}/ \phi_w)}$$

where,

V_c = velocity (cm/yr) of the COC in the vadose zone,
V_w = velocity (cm/yr) of water through the vadose zone,
B_d = bulk density (g/ml) of soil,
K_{oc} = organic/water partitioning coefficient (ml/g) of the COC (see Table A),
f_{oc} = fraction of organic carbon (kg/kg) in the soil,
ϕ_w = water filled porosity (l/l) of the soil in the vadose zone.

Equation 4 - Determine COC travel time to ground water

Calculate the time it takes for the COC to travel from its source to the ground water through the vadose zone using the following equation:

$$\mathbf{T_c = L/V_c}$$

where,

T_c = travel time (yr) of the COC in the soil pore water,
L = distance (cm) from the source of the COC in ground water, and
V_c = velocity (cm/yr) of the COC in the soil pore water

NOTE: multiply T_c by 365 days/year to convert from years to days for the next equation.

Equation 5 - Determine COC concentration at ground water considering biodegradation effect

Calculate the concentration of the COC just above the ground water table with the biodegradation effect during transport through the vadose zone.

$$\mathbf{C_p = C_w * \exp(\ln(0.5)/t_{1/2} * T_c)}$$

where,

C_p = concentration (mg/l) of the COC in soil pore water just above the water table,
C_w = concentration (mg/l) of the COC in soil pore water at the source,
$t_{1/2}$ = biodegradation "half-life" (days) of the COC, and
T_c = travel time (days) of the COC through the vadose zone.

Assuming no dilution or dispersion of the COC upon mixing of the leachate with ground water, the concentration of the COC in ground water will be exactly the same as the concentration in soil pore water just above the water table.

Equation 6 - Determine COC concentration in ground water considering dilution/attenuation effect

Calculate the concentration of the COC in ground water at the location of a potential receptor considering the effect of dilution and attenuation. The **Dilution/Attenuation Factor** (DAF) is a unitless number which expresses the magnitude of dilution and attenuation which occurs after the leachate generated from the soil encounters ground water.

Utilizing a Monte Carlo modeling approach, a range of typical site parameters were evaluated by the Region to determine appropriate DAFs. Parameters that were considered include: hydraulic conductivity, hydraulic gradient, ground water recharge rates, dimensions of the impacted soil, and aquifer thickness. Based upon a source length of ten feet, ground water recharge rate of 18 cm/year, and an aquifer thickness of 10 feet, and typical hydraulic gradients of .005 to .02, the following DAFs should be utilized as default values:

TABLE B

Sandy Soil (hydraulic conductivity $\geq 10^{-4}$ cm/sec);	DAF = 8
Clay Soil (hydraulic conductivity $\leq 10^{-4}$ cm/sec);	DAF = 2

The concentration of the COC in ground water at the location of a potential receptor can be calculated using the following equation:

$$\mathbf{C_{gw} = C_p/DAF}$$

where,

C_{gw} = concentration (mg/l) of COC in ground water at the receptor,
C_p = concentration (mg/l) of COC in ground water directly below the source, and
DAF = dilution/attenuation factor (unitless) see Table B.

If $C_{gw} < C_{rbsl}$, there is no need to proceed any further

If $C_{gw} > C_{rbsl}$, proceed to Equation 7.

where C_{rbsl} = risk based screening level (mg/l) of COC in ground water.

Equation 7 - Determine Site Specific Target Level

Calculate the site specific target level of the COC in soil based on the parameters at this particular site. The equilibrium partitioning of the COC between sorbed and aqueous phases is described by the following equation:

$$C_{sstl} = C_{rbsl} * DAF / \exp(\ln(0.5)/t_{1/2} * T_c) * ((B_d * K_{oc} * f_{oc} + \phi_w + (\phi - \phi_w)) * H')/B_d$$

where,

C_{sstl} = Site-specific target level (mg/kg) for the COC in soil,
C_{rbsl} = risk based screening level (mg/l) of COC in ground water,
DAF = dilution/attenuation factor (unitless) (from Table B),
$t_{1/2}$ = biodegradation "half-life" (days) of the COC,
T_c = travel time (days) of the COC through the vadose zone.
B_d = bulk density (g/ml) of soil,
K_{oc} = organic/water partitioning coefficient (ml/g) of the COC (see Table A),
f_{oc} = fraction of organic carbon (kg/kg) in the soil,
ϕ = porosity (l/l) of the soil,
ϕ_w = water filled porosity (l/l) of the soil in the vadose zone, and
H' = Henry's Law constant (unitless) of the COC (Table A).

IN SITU SOIL RISK EVALUATION

SITE DATA

Site ID # ____

Site Name ____

Site Address ____

SOIL RISK EVALUATION DATA

Soil % SAND _______ %

} from soil grain size analysis

Soil % CLAY _______ %

Highest Level Benzene _______ mg/kg C_s
Soil Analysis Toluene _______ mg/kg C_s
Ethylbenzene _______ mg/kg C_s
Xylenes _______ mg/kg C_s

Fraction of Organic Carbon _______ kg/kg f_{oc}

Average Annual Recharge _______ cm/yr H_w

Distance from highest Soil Contamination to water table _______ cm L

Bulk Density of Soil _______ g/cc B_d from Figure 1

Porosity of soil _______ dec % ϕ from Figure 2

List Possible human or sensitive receptor exposure pathways from surface soil.

____

____

____

____

____

____

____

IN SITU SOIL RISK EVALUATION

SITE DATA

Site ID # ____

Site Name ____

INSTRUCTIONS

Provide results, separately, for each constituent in the highest level soil analyses.

DATA

List Constituent: ___________
(BTEX)

Bioremediation Half Life _______ days $t_{1/2}$
(from Table A - Appendix B)

Soil/water partitioning coefficient _______ ml/g K_{oc}
(from Table A - Appendix B)

RESULTS

				Equation
Leachate Concentration	_______	mg/l	C_w	1
Velocity of Water	_______	ft/yr	V_w	2
Velocity of COC	_______	ft/yr	V_c	3
Time to Reach Ground Water	_______	days	T_c	4
Concentration reaching GW	_______	mg/l	C_p	5
Concentration at receptor	_______	mg/l	C_{gw}	6
Site Specific Target Level	_______	mg/l	C_{sstl}	7

CONCLUSIONS

Does concentration of chemical of concern in soil exceed SSTL?

_______ yes _______ no

Is there a risk of exposure to a Human or Sensitive Receptor due to contaminated soil?

_______ yes _______ no

APPENDIX C
INTRINSIC REMEDIATION

Intrinsic remediation includes biological degradation and one or a number of natural attenuation processes (e.g., advection, dispersion). The following information addresses naturally occurring biodegradation processes in the subsurface. **A similar demonstration should be made if other natural attenuation processes are predicted to reduce concentrations of COC.** In general, the demonstration for approval of intrinsic remediation as a corrective action includes hydrologic (rates of ground water flow), geochemical (adsorption properties), microbiologic (rates of biodegradation), and receptor (exposure point) considerations. Specifically, the following should be demonstrated in the CAP:

- the source(s) (e.g. leaking tanks, free phase product) must be removed or controlled;

- hydrologic parameters at the site, including aquifer porosity, permeability, thickness, dispersivity, and potentiometric data must be characterized so that directions and rates of ground water flow can be ascertained;

- sorption characteristics of the COC using site aquifer materials must be determined. This determination may be made by laboratory methods to estimate distribution coefficient (K_d) values, or by calculating K_d values from organic matter content of the aquifer material (Appendix C);

- confirmation that the COC are readily biodegradable, and estimates made of COC biodegradation rates. Biodegradation rates may be determined from one or a combination of methods: 1) field data showing the attenuation of COC in the direction of ground water flow as corrected for the effects of adsorption and hydrodynamic dispersion, **or** 2) laboratory experiments, conducted with aquifer material from the site and under geochemical conditions (e.g., aerobic/anaerobic, temperature, pH, saturated/unsaturated) characteristic of the site, showing the biological degradation of specific COC over time. Geochemical conditions in water-saturated ground water systems are typically more variable than in the unsaturated zone, and using published values for biodegradation rates in ground water systems (as can be estimated in unsaturated soils; Appendix B) is not presently technically feasible;

- initial confirmation, often accomplished through modeling, (using hydrologic, geochemical, and microbiological data from the assessment) that the COC appears to be at, or near, equilibrium (additional migration is minimal or nonexistent). COC fate and transport modeling, that includes consideration of hydrodynamic dispersion, adsorption, and microbial degradation rates are commonly used to predict plume migration;

- the evaluation of intrinsic biological degradation is conducted as part of the RBCA decision making and therefore the potential exposure routes and potential receptors are evaluated prior to making a decision to consider intrinsic bioremediation. For example, if an impact to a water supply well is predicted in a time frame that is inconsistent with the predicted natural degradation of the COC (present or future), then intrinsic remediation is not an immediate option, and;

- the total cost to monitor intrinsic biological degradation. For example, if the monitoring cost over a long period of time exceeds the total cost to operate, maintain, and monitor a more aggressive active remediation over a shorter period of time, intrinsic remediation is not recommended.

Some site-specific characteristics to consider when evaluating the natural biodegradation of COC in the subsurface may include (the specific list of parameters to measure or estimate will depend upon the data needs of the specific modeling to be conducted for the site):

Tier 1

* pH
* dissolved oxygen
* soil moisture (vadose zone)
* porosity/permeability
* temperature
* total organic carbon/ organic matter content
* soil bulk density

Tier 2

* water retention/field capacity (vadose zone)
* redox potential
* soil gas oxygen content
* total organic nitrogen

Tier 3

* soluble salts
* buffer index
* iron, sulfate, soluble potassium
* sodium, calcium, sulfur, boron, copper, and zinc
* cation exchange capacity and exchangeable cations
* inorganic nitrogen, soluble phosphorus, soluble manganese

Natural biodegradation of COC in unsaturated soil may be most applicable for sites with the following characteristics:

o soil moisture content: 25 to 85 percent field capacity;

o oxygen transport: minimum air-filled pore space of 10 percent;

o permeability: saturated hydraulic conductivity greater than 1 x 10^{-5} centimeters per second;

o pH 5.5 to 8.5;

o redox potential: greater than 100 millivolts;

o nutrients: total organic nitrogen greater than 1.5 percent; carbon/nitrogen ratio less than 40; carbon/potassium ratio less than 120.

Appropriate analytical parameters should be routinely monitored to show that intrinsic remediation (biodegradation and attenuation) of the COC is occurring. Both direct (specific COC) and indirect (e.g.,dissolved oxygen, CO_2, nitrogen, methane, temperature, etc.) measurements of degradation may be appropriate.

Appendix D DOMENICO'S MODEL

Contaminant transport in the saturated or the unsaturated zone can be estimated using the **Domenico Model**. This analytical model utilizes three dimensional dispersion, seepage velocity, and biological degradation principles to predict the spatial and temporal decrease in concentration of COC away from the source. The calculations can be completed with a hand calculator or can be incorporated into a computer program.

The Domenico Model is based on the following assumptions:

1) One dimensional flow and three dimensional dispersion,
2) The medium is isotropic and homogeneous,
3) The source concentration is constant,
4) The areal source is perpendicular to the direction of flow, and
5) decay of the contaminant in the dissolved and adsorbed phases occurs at the same rate resulting in a first order decay rate.

The Domenico Model requires the following data:

Description	Symbol	Units
Concentration of COC at source	C_o	mg/l
Width of the source perpendicular to GW flow	Y	m
Vertical thickness of source	Z	m
Distance from source to well (x-coordinate)	x	m
y and z coordinates of well relative to source	y,z	m
Longitudinal dispersivity (x/10)	a_x	(m^2/day)
Transverse dispersivity ($a_x/3$)	a_y	(m^2/day)
Vertical dispersivity ($a_x/20$)	a_z	(m^2/day)
Seepage Velocity (m/s) *	v	m/s
Error Function **	erf	N/A
Complimentary error function**	erfc	N/A
First Order Decay Rate ***	λ	N/A
Time is calculated in days		

* If the COC adsorbs, the seepage velocity (v) is replaced by the retarded velocity (v/R), where R is the retardation factor in the saturated zone. The Retardation factor can be calculated with the following equation:

$$R = 1+ \frac{K_{oc} * f_{oc} * Bd}{\phi}$$

where,

K_{oc} = chemical specific soil/water partitioning coefficient (ml/g) derived from literature.
Bd = Bulk Density (g/cm^3)
ϕ = porosity
f_{oc} = fraction of organic carbon in decimal percent of soil.

** The Error Function and Complimentary Error Function are dimensionless numbers which can be derived from an erf and erfc table. These tables can be found in many hydrogeology reference and textbooks.

*** If the first order decay rates have not been determined on a site specific basis, the decay rate (λ) shall be assumed to be 0.

EQUATION 1

Equation 1 should be used if the receptor is located along the centerline (x - axis) and hydraulically downgradient of the source. In that case, y = z = 0, and λ = 0.

$$C(x,0,0,t)=(C_o/2)erfc[(x-vt)/2(\alpha_x vt)^{1/2}]erf[Y/4(\alpha_y x)^{1/2}]erf[Z/4(\alpha_z x)^{1/2}]$$

EQUATION 2

If the receptor is not located along the x-axis centerline, y and z $\neq 0$, and $\lambda = 0$.

$$C(x,y,z,t)=(C_o/8)erfc[(x-vt)/2(\alpha_x vt)^{1/2}]$$

$$[erf[(y+Y/2)/2(\alpha_y x)^{1/2}]-erf[(y-Y/2)/2(\alpha_y x)^{1/2}]]$$

$$[erf[(z+Z)/2(\alpha_z x)^{1/2}]-erf[(z-Z)/2)(\alpha_z x)^{1/2}]]$$

EQUATION 3

Equation 3 considers for first order decay of the COC. This equation should only be used when sufficient site specific data exists to determine the first order decay rate (i.e., $\lambda \neq 0$)

$$C(x,y,z,t)=(C_o/8)exp[(x/2\alpha_x)[1-(1+4\lambda\alpha_x/v)^{1/2}]]$$

$$\mathrm{erfc}[\frac{[x-vt(1+4\lambda\alpha_x/v)^{1/2}]}{2(\alpha_x vt)^{1/2}}]$$

$$[erf[(y+Y/2)/2(\alpha_y x)^{1/2}]-erf[(y-Y/2)/2(\alpha_y x)^{1/2}]]$$

$$[erf[(z+Z)/2(\alpha_z x)^{1/2}]-erf[(z-Z)/2)(\alpha_z x)^{1/2}]]$$

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TABLE 4 - RBSL'S FOR GROUND WATER

Ground Water - Injestion (mg/l)

Chemical of Concern	Residential Concentration (mg/l)	Commecial/ Industrial Concentration (mg/l)
Benzene	.005	0.10
Toluene	1	20
Ethylbenzene	.7	10
Xylenes	10	204
MTBE*	0.2	0.2
Naphthalene*	0.02	0.02
Benzo(a)anthracene	0.0002	0.004
Benzo(a)pyrene	0.0002	0.004
Benzo(b)fluoranthene	0.0002	0.004
Benzo(k)fluoranthene	0.0012	0.004
Chrysene	0.0002**	0.4
Dibenz(a,h)anthracene	0.0003**	0.0004

* Lifetime health advisory
** from 1993 U.S. EPA Drinking Water Regulations and Health Advisories

RISK-BASED SCREENING LEVEL LOOK-UP TABLES

The RBSLs (for residential scenario) for Chemicals of Concern in ground water are based upon the Maximum Contaminant Levels (MCL) published in the Environmental Protection Agency Drinking Water Regulations and Health Advisories. In some cases, proposed MCLs and Health Advisories are used. There is also a set of values for a Commercial/Industrial scenario, based on a target risk level of 1 in 100,000. RBSLs for soil were calculated using the leachability model included in Appendix B. Assumptions for calculation of soil RBSLs were:

- **fraction of organic carbon: 2000 mg/kg, or 0.002**
- **ground water recharge rate: 18 cm/yr**
- **organic/water partitioning coefficient: published literature**
- **porosity: for sandy soil - .47, for clay soil - .43**
- **bulk density: for sandy soil - 1.55 g/cc, for clay soil - 1.6 g/cc**
- **half-life biodegradation rate: published literature**
- **water-filled porosity in the vadose zone: for sandy soil - 0.3, for clay soil - 0.3**

TABLE 1
POTENTIAL INITIAL RESPONSE ACTIONS: IMMEDIATE THREAT

Scenario	Potential Initial Response
Explosive levels or concentrations of vapors are present in a residence or other building	Evacuate occupants, begin abatement measures such as subsurface ventilation
Explosive levels are present in subsurface utility system	Evacuate immediate vicinity, begin abatement measures
Free-product is present in significant quantities at ground surface, on surface water bodies, in utilities	Prevent further free-product migration, institute free-product recovery
An active water supply well, water supply line, or public surface water intake is impacted or immediately threatened	Notify users, provide alternate water supply, hydraulically control contaminant migration, treat water at point-of-use
A sensitive habitat or sensitive resources are impacted	Minimize extent of impact by containment measures and implement habitat management to minimize exposure

TABLE 2
EXAMPLE FORMAT FOR SUMMARIZING COMPLETE EXPOSURE PATHWAYS AT A SITE (CURRENT LAND USE)

For Tables 2 & 3, selection of exposure pathways is based on the following: Source of COC - release of gasoline from a leaking UST, soil in former UST area and ground water contain levels of COC in excess of RBSL, Current and Expected Use of Land and Ground Water - The site is abandoned but is zoned commercial, surrounding properties are residential, public water and sewer is available, Receptors - No water wells or other potential receptors identified in the area. Inhalation of volatiles assumes either surficial or sub surface soil contamination volatilizing into an indoor area.

Potentially Exposed Population	Exposure Route, Medium, and Exposure Point	Pathway Selected for Evaluation?	Reason for Selection or Non-Selection
Off-site resident	Ingestion of ground water from impacted water well	No	No drinking water wells in area
	Direct contact with surface soil	No	Off-site soil is uncontaminated
	Inhalation while showering	No	Residents do not use ground water for showering
	Dermal contact while showering	No	Residents do not use ground water for showering
	Inhalation of volatiles	Yes	Volatile emissions are possible
On-site resident	Ingestion of ground water	No	No residents on-site
	Direct contact with surface soil	No	
	Inhalation while showering	No	
	Dermal contact while showering	No	
	Inhalation of volatiles	No	
Worker	Ingestion of ground water	No	No water well located on-site
	Direct contact with surface soil	Yes	On-site soil is impacted
	Inhalation while showering	No	N/A
	Dermal contact while showering	No	N/A
	Inhalation of volatiles	Yes	Volatile emissions are possible
Visitor	Ingestion of ground water	No	No water well located on-site
	Direct contact with surface soil	Yes	On-site soil is impacted
	Inhalation while showering	No	N/A
	Dermal contact while showering	No	N/A
	Inhalation of volatiles	Yes	Volatile emissions are possible

TABLE 3
EXAMPLE FORMAT FOR SUMMARIZING COMPLETE EXPOSURE PATHWAYS AT A SITE (FUTURE LAND USE)

Potentially Exposed Population	Exposure Route, Medium, and Exposure Point	Pathway Selected for Evaluation?	Reason for Selection or Non-Selection
Off-site resident	Ingestion of ground water from impacted water well	Yes	No drinking water wells in area, but possible future installation
	Direct contact with surface soil	No	Off-site soil are uncontaminated
	Inhalation while showering	Yes	Residents use ground water for showering
	Dermal contact while showering	Yes	Residents use ground water for showering
	Inhalation of volatiles	Yes	Volatile emissions are possible
On-site resident	Ingestion of ground water	No	No residents on-site, property is zoned commercial and is reasonably anticipated to remain commercial
	Direct contact with surface soil	No	
	Inhalation while showering	No	
	Dermal contact while showering	No	
	Inhalation of volatiles	No	
Worker	Ingestion of ground water	No	No water well located on-site
	Direct contact with surface soil	Yes	On-site soil is impacted
	Inhalation while showering	No	N/A
	Dermal contact while showering	No	N/A
	Inhalation of volatiles	Yes	Volatile emissions are possible
Visitor	Ingestion of ground water	No	No water well located on-site
	Direct contact with surface soil	Yes	On-site soil is impacted
	Inhalation while showering	No	N/A
	Dermal contact while showering	No	N/A
	Inhalation of volatiles	Yes	Volatile emissions are possible