Delaware Risk-Based Corrective Action Program (DERBCAP)

GUIDE

For Underground Storage Tank (UST) Sites

Delaware Department of Natural Resources and Environmental Control (DNREC)

UST Branch January 2000
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Delaware's Risk Based Corrective Action Program (DERBCAP)

Table of Contents

Page

Delaware's Risk Based Corrective Action Program (DERBCAP)

Table of Contents

Page

Tables

Figures

1. STATEMENT OF PURPOSE

The Delaware Department of Natural Resources and Environmental Control (DNREC) Underground Storage Tank Branch (UST Branch) has developed this guidance to enhance current guidelines provided in its *Technical Guidance Manual (TGM)* regarding petroleum releases and their associated corrective actions. DERBCAP provides for quantitative risk based decision-making at leaking underground storage tank (LUST) sites.

This guidance is based on the American Society for Testing and Materials (ASTM) E 1739-95 Standard Guide for Risk Based Corrective Action (RBCA) at Petroleum Release Sites and meets the requirements in Delaware's *Regulations Governing Underground Storage Tank Systems*. The ASTM standard cannot be adopted bodily, however, before a series of state-specific policy decisions are addressed. Delaware's policy decisions are listed in Appendix 8. The Branch acknowledges the assistance of the ASTM, the Partners in RBCA Implementation (PIRI), the Delaware LUST Committee, and the RBCA Advisory Group in the formulation of this guidance.

Many states have adopted the ASTM RBCA standard to varying degrees in establishing their own risk based corrective action programs. Delaware referred to the ASTM standard and risk based programs from several states including Oklahoma, Idaho, Pennsylvania, Utah and Texas in the formulation of the Delaware RBCA program.

1.1 Risk Glossary, Terms and Definitions

ASTM The **American Society for Testing and Materials** is the body that standardized risk based corrective action, or RBCA. ASTM is a not-for-profit organization that writes standard test methods, specifications, practices, terminologies, guides and classifications for materials, products, systems and services that encompass metals, paints, plastics, textiles, petroleum, construction, energy, the environment, consumer products, medical services and devices, computerized systems, electronics and other areas.

Aesthetic Impact An occurrence of COCs at a point of exposure, which is not a potential risk to human health, but is nevertheless unacceptable because of objectionable odors, taste, vapors or appearance.

Coastal Plain A physiographic province consisting of a broad plain of usually unconsolidated sediment with an oceanic margin that slopes gently toward the water.

COC Chemical of Concern. Specific chemical or constituent that is identified for evaluation in the risk assessment process. COCs may include products or constituents of products released to soil and/or ground water.

Core The region or regions within the soil and ground water plume containing the highest and most mobile COCs and the lowest concentrations of dissolved oxygen, which, over time, can serve as a long-term source of ground water contamination.

Department See DNREC

DERBCAP Delaware's RBCA program (pronounced "derby cap")

DNREC Delaware's Department of Natural Resources and Environmental Control; the Department.

Dose A specified amount; a measure of exposure usually expressed as an amount per unit body weight.

Due Diligence As defined in Black's Law Dictionary, Fifth Edition (1979), the measure of prudence, activity, or assiduity as is properly to be expected from, and ordinarily exercised by, a reasonable and prudent [person]… Under DERBCAP, due diligence would apply to the activities involving the purchase of existing or former LUST sites with residual COC levels.

Engineering Control An engineering control is a physical means of reducing the potential impacts of a release at a site. An engineering control can be used to eliminate a pathway to reduce future risk. Engineering controls can be, but are not limited to: caps, liners, slurry walls or vapor barriers.

Environmentally Sensitive Area Environmentally sensitive areas can be but are not limited to: surface waters, wetlands, excellent aquifer recharge areas, areas within 1000 feet of a public or domestic water supply well, and habitats of threatened or endangered species.

Exposure Contact of a human or other ecological organism with COCs.

Fill Man-made deposits of natural soils or rock product and waste materials.

Hazard Index In the case of non-carcinogens, the sum of more than one hazard quotient for multiple substances and/or multiple exposure pathways. The hazard index is calculated separately for chronic, sub-chronic and shorter duration exposures.

Hazard Quotient For a particular chemical and mechanism of intake (e.g., oral, dermal, inhalation), the hazard quotient is the ratio of the estimated receptor dose divided by the published reference dose. The reference dose values are determined using the U. S. EPA Integrated Risk Information System (IRIS), or HEAST tables.

Institutional Control An institutional control is an administrative or formal legal means of limiting exposure to contaminants at an impacted site. An institutional control can be a conditional no further action letter, a deed notice, a deed restriction, a zoning restriction, a land use restriction, or a ground water management zone.

MCL Maximum Contaminant Level. A standard for drinking water established by EPA under the Safe Drinking Water Act. The MCL is the maximum permissible level of COCs in water that is used as a drinking water supply. MCLs are recognized in Delaware by the Division of Public Health and DNREC.

NFA A **No Further Action** letter is issued by the Department based upon a determination that no further risk is posed to human health or the environment from a contaminant

source. A standard NFA letter has no conditions and is issued when COC levels fall below Tier 0 action levels. A conditional NFA letter is issued for all other situations. A conditional NFA letter may require a signed acknowledgement. A no further action letter is not a statutory release from future liability. The following caveat language is included in all NFA letters: *This letter, however, does not absolve the responsible party from responsibility for any future problems related to the USTs formerly at this location, pursuant to 7 Del. C. 74. If a related problem is identified, the Department must be notified and immediate action taken to prevent any harm to human health or the environment.*

Pathway A pathway is one of three risk elements. The pathway provides the route for an exposure. The exposure pathway is the course or route COCs take from a contaminant source to a receptor. An exposure pathway describes a unique mechanism by which an individual or population is exposed to COCs. Each exposure pathway includes a source or release from a source, an exposure route and an exposure point. If the exposure point is at a different location from the source, a transport/exposure media (e.g., ground water) is included. Exposure pathways involve transport of contamination through exposure media (air, ground water, and soil). DERBCAP recognizes three (3) pathways for risk: combined direct contact, ground water ingestion, and soil to ground water leaching

Piedmont A physiographic province typically formed at the base of a mountain range consisting of a bedrock surface overlain by a thin veneer of unconsolidated material and shaped by running water.

POC A **Point of Compliance** can be any point between a contaminant source and a point of exposure where a regulatory standard must be met.

POE A **Point of Exposure** can be a well, body of water, soil pile, basement, recharge area or any environmentally sensitive area as determined by the Department. It is the point at which an individual, population or any environmentally sensitive area may come in contact with a COC originating from a site. For the purposes of this document regarding risk management, the terms "receptor" and "Point of Exposure" may be used interchangeably.

RBCA Risk Based Corrective Action (pronounced "Rebecca")

RBEL A **Risk Based Exposure Level** is the risk-based concentration for a COC permitted at a point of exposure based on a level of risk of 1×10^{-5} or less. In Tier 2 modeling, RBCA Toolkit uses these RBEL default values for SSTL calculations. In demonstrating plume stability in Bioscreen, the RBEL concentration must be zero (i.e., COCs will never reach the POE).

RBSL A **Risk Based Screening Level** is a Tier 1 risk-based concentration for a COC determined using conservative non-site-specific (generic) assumptions and default parameters. The RBSL is the concentration of COCs in soils or ground water in the source area or core that will assure an acceptable risk at the POE, based on the assumptions made. An RBSL can also be a site-specific cleanup goal.

Receptor An organism that receives, may receive, or has received exposure to a COC as a result of a release. Under DERBCAP objects such as utilities, wetlands and surface water bodies are also considered receptors.

Risk For purposes of DERBCAP, acceptable risk is set at 1×10^{-5} or one person in 100,000 or less for carcinogens and a hazard quotient of one (1) for non-carcinogenic compounds. For exposure calculations in DERBCAP, the target carcinogenic risk of 1×10^{-5} is the cumulative site risk. Individual compounds can also be calculated at 1×10^{-5} as long as the cumulative site target risk also does not exceed 1×10^{-5}.

Risk Assessment An analysis of the potential for adverse health effects or effects on ecological receptors caused by a COC. It is used to determine the need for remedial action and to develop target levels and clean up goals where remedial action is required.

Risk Management Measures or actions taken to ensure that the level of risk to human health or the environment as a result of possible exposure to COCs does not exceed 1×10^{-5}.

Route of Exposure The course and manner in which COCs come in contact with an organism through ingestion, inhalation or dermal contact.

Soil Sediments or other unconsolidated accumulations of solid particles produced by the physical and chemical disintegration of rocks, which may or may not contain organic matter.

Source Source of contamination can be a leaking tank, tank field, tank system, a spill, or residual contaminated soil or ground water.

SSTL A **Site Specific Target Level** is a Tier 2 risk-based concentration for a COC at the source that will be protective of receptors at some distance away from the source, based on site-specific data. It can also be a cleanup goal.

TGM The Underground Storage Tank Branch's ***Technical Guidance Manual,*** published in 1990 and revised in 1992 (a new revision is currently—1999—in preparation).

Tier A tier refers to the amount of COC-specific and site-specific information that is required to assess potential risks to human health and the environment at a site. Each successive tier requires a greater amount of site-specific data, but allows for clean up goals that are less conservative. DERBCAP recognizes four (4) tiers, 0 to 3.

Used Oil A petroleum based or synthetic oil used as an engine lubricant, engine oil, motor oil or lubricating oil for use in an internal combustion engine, or a lubricant for motor vehicle transmissions, gears or axles, which through use or handling has become unsuitable for its original purpose due to the presence of impurities or loss of original properties.

1.2 Basic Risk Concepts

1.2.1 Dose

Any substance can be considered a toxic agent. Gasoline is a toxic agent. Gasoline, however, is a complex mixture of over 100 constituents, many of which do not pose a human health risk. Some of these constituents are toxic, however. Individual constituents of complex petroleum mixtures, like gasoline, are considered chemicals of concern (COCs) based on factors such as carcinogenicity and mobility in the environment. A toxic agent at a specific concentration administered over a given duration is a dose.

1.2.2 Pathway

There are three exposure routes: dermal or direct contact, inhalation and ingestion. Within each exposure route are multiple exposure pathways that can contribute a dose to a given receptor. For example, within the inhalation route, there are the following inhalation pathways: volatilization from surface soils, volatilization from ground water, vapor migration into buildings, and shower off-gassing (particularly for benzene). Within the direct contact route, there are the following pathways: soil contact and ground water contact through bathing. Within the ingestion route there are the following pathways: soil ingestion, ground water ingestion and food ingestion.

1.2.3 Receptor

Receptors can be human, ecological or physical. Human receptors are often broken down by age group, usually child, adult, and senior. An ecological receptor can be a sensitive animal or plant population. A physical receptor can be a well, basement, property line or ground water protection area. There are other ecological and physical receptors.

1.2.4 Risk

For risk to occur, all three elements, dose, pathway, and receptor must be present (Figure 1). If any of these elements is missing, a risk does not exist. Calculating risk involves the use of mathematical equations relating a variety of factors such as concentration of contaminants, duration of exposure, body weight, and inges-

tion rate. Once quantified, risk can be used to determine the need for further action at a site.

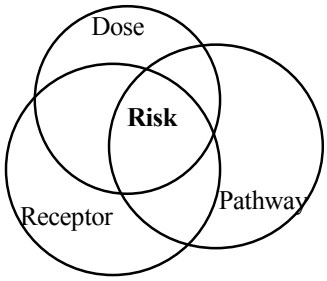


Figure 1. The Risk Concept

If chemical of concern (COC) concentrations fall below prescribed risk based concentrations, no further action may be required. However, in some cases, aesthetic concerns from an odor, taste, or visual standpoint may require further action such as removal of surface soils for treatment or disposal, or capping.

Aesthetics often come into play when dealing with ground water used for drinking or bathing, particularly when dealing with compounds like methyl tertiary butyl ether (MTBE) which have low odor and taste thresholds. Although concentrations present may not pose a health risk, they may make drinking water unpalatable or malodorous, and therefore require further action.

1.3 Risk Based Corrective Action Concepts

The concept of risk based corrective action, or RBCA ("Rebecca") standardized by the American Society for Testing and Materials (ASTM) in *"Standard Guide E 1739-95 for risk-based corrective action applied at petroleum release sites,"* provides the basis for Delaware's risk based corrective action program. The formulation of the ASTM standard was a joint effort between federal, state, local and industry officials.

The ASTM standard is a tiered quantitative approach to risk assessment that utilizes chemicals of concern rather than the total petroleum hydrocarbon analysis method. A three tiered risk assessment method is used to evaluate the risk to human health posed by multiple constituents in petroleum-contaminated soil, ground water and air at sites. As the tier level increases from one to three, the

level of site specificity and data sufficiency increases. The responsible party (RP) may remediate at any tier to cleanup levels specified at each tier, or move to the next tier where more site-specific data must be collected and analyzed and where consequently, remediation may not be required based upon fate and transport modeling-derived risk.

ASTM RBCA determines RBSLs and SSTLs for soil and ground water using a backward mode of calculation. The standard mathematical exposure equations are used to calculate COC concentrations for a specified level of risk. The RBSLs and SSTLs are compared to site-specific data to identify the need for further action. RBCA also utilizes a site-specific risk characterization process that includes identification of complete exposure pathways, estimation of receptor dose, and calculation of associated risk levels. A decision on further action will be either no further action, clean up to the current tier's RBSLs or SSTLs, or move on to the next higher tier.

1.4 Delaware's RBCA Concept

The Department chose to be conservative but realistic in its implementation of the ASTM RBCA standard. Accordingly, Delaware's Risk Based Corrective Action Program, or DERBCAP, was born.

Prior to DERBCAP, Delaware's UST program incorporated risk into decision-making from a qualitative standpoint. Site characterization and prioritization using the three risk categories, A, B, and C, were based on proximity of sensitive receptors and land use. These categories assured that sites that demanded a higher level of concern received the level of attention necessary to protect human health and the environment. This risk-based decision-making process has been enhanced with RBCA concepts to retool the process with a quantitative framework. This quantitative framework will allow for more defensible decision-making, and continue Delaware's established site-specific approach, while maintaining a high level of protection for human health and the environment.

Like the ASTM RBCA standard, DERBCAP is a multi-tiered risk based corrective action process. While the ASTM standard specifies three (3) tiers,

DERBCAP includes an additional tier, Tier 0, to cover the existing removal/abandonment process. In Delaware a site may enter the program at a variety of stages. A tank removal or abandonment must enter at Tier 0. An existing leaking underground storage tank (LUST) site may enter at Tiers 1, 2, or 3 depending on the amount of site specific data gathered.

To remain consistent with other Delaware programs, a risk of 1×10^{-5} is assumed in all calculations. All numerical risks are based on human exposure but environmental and ecological factors are integrated into DERBCAP as points of exposure or POEs. Additionally, a risk is presumed to exist until proven otherwise through investigations conducted at the site. DERBCAP's multi-tier structure, like ASTM RBCA, requires increasingly more accurate site-specific COC and site characteristic data as a site progresses through the tiers. Tier 0 action levels and Tier 1 RBSLs are based on the following statewide generic assumptions:

- grab soil samples are assumed to be collected at the top of the water table,
- ground water is assumed to be used for drinking water,
- current land use is assumed to be residential, and
- soils are assumed to be well sorted, permeable, fine-to medium-grained sand.

Unlike ASTM RBCA, the DERBCAP Tier 1 RBSLs are determined by distance from source to a POE or POC for each COC.

At Tier 2 and 3, the Tier 1 RBSLs, derived by generic statewide assumptions, are replaced with site specific chemical and site characteristics which are used in increasingly complex contaminant fate and transport modeling to evaluate risks to receptors. The DERBCAP tier structure is further explained in Section 1.6.

In addition, the DERBCAP generic exposure assessment is based on three conceptual exposure pathways:

- direct contact with impacted soils, whether by dermal contact, particulate ingestion or inhalation of dust,
- ingestion of impacted ground water, and
- chemicals adsorbed to soil particles in the unsaturated zone above the water table, which can be remobilized either by downward-infiltrating

surface water from precipitation or, in the case of Delaware where the water table may be less than ten feet deep, remobilization from below by the periodic rise and fall of the water table. Ground water impacted by either of these remobilization processes is then ingested.

Vapor pathways are not included in a DERBCAP site assessment. However, the potential for vapor accumulations in enclosed spaces should always be noted. This exposure pathway must be eliminated as a direct impact before a DERBCAP assessment can proceed. The DERBCAP conceptual exposure pathways are further explained in Section 3.1. The policy decisions that are the basis of DERBCAP are listed in Appendix 8.

1.5 DERBCAP Applicability

DERBCAP applies to UST sites that are regulated under Title 7, Delaware Code, Chapter 74, the *Underground Storage Tank Act* and other sites that may be referred to the UST Branch for follow-up remedial action. It remains the responsibility of the RP or owner/operator to achieve compliance with all other applicable environmental programs.

DERBCAP provides quantitative performance standards for the management of potential risks to human health at leaking underground storage tank sites in Delaware. It also provides the means to address potential risks to human safety, environmental and aesthetic impacts.

Before potential risks to human health may be assessed at a leaking underground storage tank site, immediate risks to human safety and environmental impacts must be addressed and resolved. These include:

- eliminate any direct impacts caused by a release (e.g., impact to water supply wells),
- alleviate all direct vapor and odor impacts caused by the release, especially by ventilation of enclosed locations such as utility conduits and basements,
- remove all free phase product to the extent practicable, wherever it occurs.

Aesthetic impacts occur when soils visibly stained by petroleum or soils that are the source of petroleum odors are either encountered at the surface or are

brought to the surface by excavation. Aesthetic impacts are addressed by requiring that such soils be managed as though they exceed Tier 1 RBSLs, *whether or not they actually do.* Such soils are typically stockpiled on-site for bioremediation or are incorporated into on-site landscaping secured under a vegetative cover. If transported off-site for any purpose, they are considered solid waste and must be transported by a Delaware-licensed solid waste hauler. They may not be reused as "clean fill" unless laboratory analyses confirm that all contaminants are "Non-Detectable (ND)."

1.5.1 Alternative drinking water supplies

If water supply wells are rendered unusable because of a release from a leaking underground storage tank, alternative supplies must be provided. Carbon filters may be installed on the existing, impacted supply as a short-term step providing immediate protection. The emphasis is on permanent alternatives, however, which include:

- Replacing shallow wells with deeper wells,
- Connecting impacted users to public water-supply systems, and
- Remediating the ground water until the impacted supply wells are once again usable.

Fate and transport segments of DERBCAP can be used to back-calculate soil and groundwater contaminant concentrations that are acceptable at the source area and which will be protective of receptors at various distances from the source area.

1.5.2 Removal of free-phase product

In accordance with both Federal and State regulations, free-phase product must be removed to the maximum extent practicable. Free-phase petroleum product can be removed by hand-bailing, use of sorbent materials or by pumping recovery wells, by installing passive sumps or constructing interception trenches, by implementing soil vapor extraction (which can cause free-phase product to volatilize for removal) or by other means.

1.5.3 Odor and Vapor Impacts

Odors are aesthetically objectionable and may indicate the accumulation of potentially explosive vapors in any enclosed space in the vicinity. Adequate ventilation is a short-term step to provide immediate relief and may be part of an engineered long-term solution. Whatever specific steps are taken at a site must permanently preclude objectionable vapors and the accumulation of potentially explosive vapors.

1.5.4 Site closure under DERBCAP

When the immediate impacts described above have been successfully addressed, then a leaking underground storage tank site can be assessed under DERBCAP and specific closure criteria under Tier 0,1,2 or 3 can be defined for the RP or the tank owner or operator.

1.6 DERBCAP Process Overview

DERBCAP is a one-way process through each successive Tier (Figure 2). At each Tier a decision must be made to either clean up and close to that Tier's risk based level or move on to the next Tier (Table 1).

Table 1. Tier Structure of DERBCAP

Tier	Chemistry	Site Characteristics
0	Generic chemicals	Generic statewide assumptions
1	Chemical specific Statewide RBSLs	Generic statewide assumptions
2	Chemical and site specific SSTLs	Site specific characteristics
3	More specific	More specific
Statewide assumptions include: grab soil samples are collected at the water table, ground water is used for drinking water, current land use is residential, and soil is well sorted sand.		

DERBCAP Tier 0 is for sites that enter into the process at the time of tank closure (through removal or abandonment), or other UST system activity where a release from an UST system must be assessed. All regulated USTs closed by removal or abandonment must undergo an assessment to determine whether a release from the UST occurred. Tier 0 soil action levels are the most conservative and assume there is a receptor in the immediate area of the UST. If Tier 0 action

levels are exceeded, the owner/operator or RP has the option to clean up to the Tier 0 levels or move on to Tier 1. Tier 0 is discussed in Section 2.

DERBCAP Tier 1 is for both new sites where Tier 0 levels were exceeded and for existing leaking underground storage tank sites. Tier 1 RBSLs are based on conservative generic site assumptions along with a site-specific distance exposure assessment. The owner/operator can either clean up to the Tier 1 RBSLs established for the site or move onto Tier 2. COCs or pathways of concern can also be screened out at Tier 1 prior to more detailed analysis at Tier 2. The Tier 1 evaluation may be used to screen certain pathways and COCs from further consideration. For example, if the Tier 1 soil limits are not exceeded, there is no need for further soil evaluation. Or, if only the ground water benzene limit is exceeded, then Tier 2 need only address benzene. In this manner, the Tier 1 evaluation can help to focus the investigation or remediation plan. Tier 1 is discussed in Section 3.

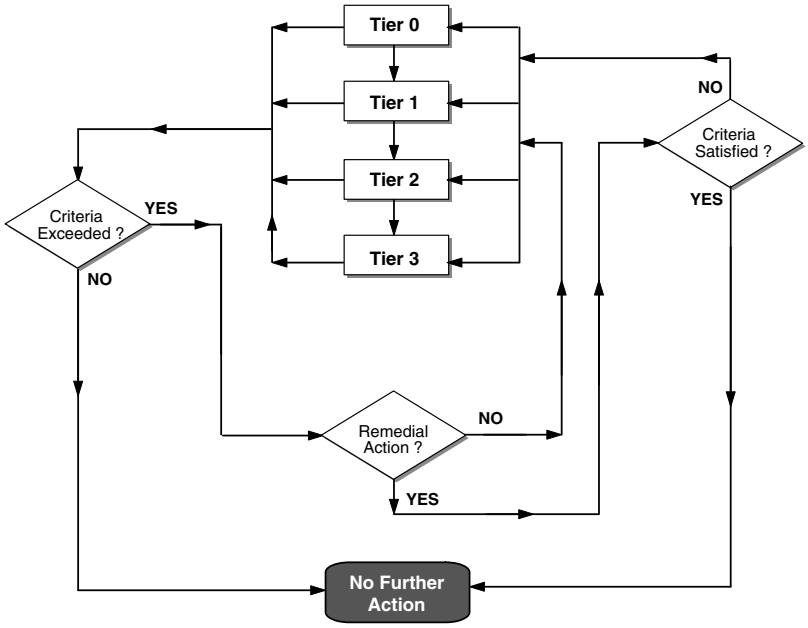


Figure 2. DERBCAP Process Flowchart

DERBCAP Tier 2 and Tier 3 SSTLs are based on ever increasing amounts of site-specific data and complex fate and transport modeling to achieve a more accurate risk evaluation. This assures that the acceptable level of risk is maintained with certainty based on greater site-specific data and not conservative as-

sumptions as in Tiers 0 and 1. As with these lower Tiers, the decision can only be to clean up to the current Tier SSTL or move up to Tier 3. Tier 2 is discussed in Section 4, Tier 3 is discussed in Section 5. Tier 2 can also be used to screen out COCs or pathways of concern prior to more detailed analysis at Tier 3.

2. TIER 0

2.1 Tier 0 Applicability

Tier 0 applies to all regulated UST systems that are to be permanently closed by removal or abandonment. All regulated USTs must undergo an assessment at the time of removal or abandonment to determine whether a release from the UST occurred. This section also applies to other sites where a petroleum release has occurred or that wish to follow the regulated closure process.

Below, in Figures 3 and 4, are the generalized flow charts for the Tier 0 UST abandonment and removal processes.

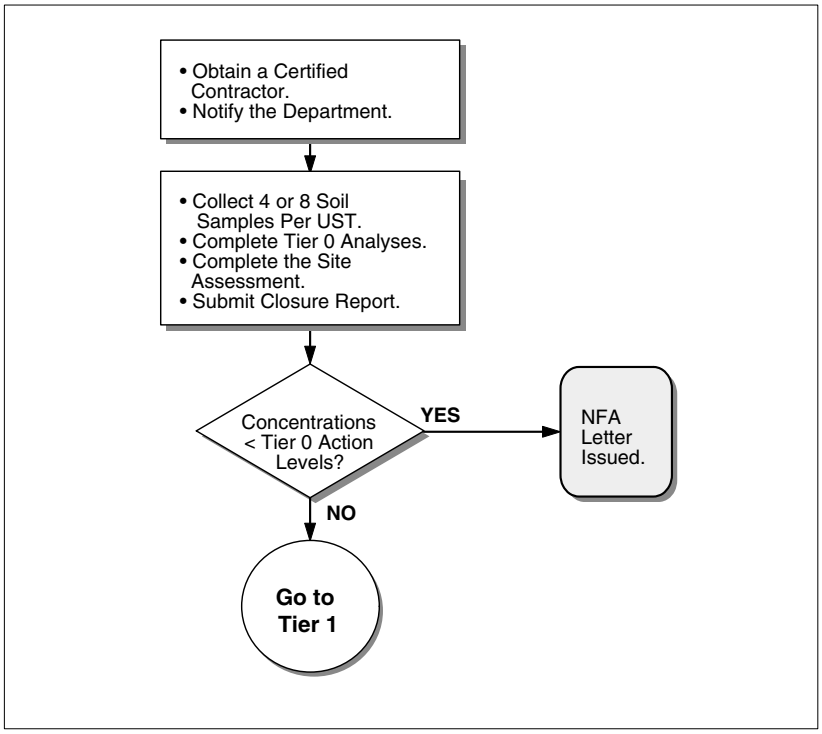


Figure 3. Tier 0 Abandonment Process

2.2 Tier 0 Site Investigation Requirements

A contractor must satisfy all the certification and notification requirements prior to undertaking a removal or abandonment. Additionally, all existing policies, regulations, guidelines and industry-accepted practices as specified in the UST *Regulations* and the *Technical Guidance Manual (TGM)* apply.

At a removal or abandonment 2, 4, or 8 soil samples per tank as well as a dispenser sample must be collected and analyzed as specified in Table 2. A report must be submitted to the Department with the currently required documentation and the analytical results and associated chain of custody. Refer to the TGM for guidance on sample collection and required documentation.

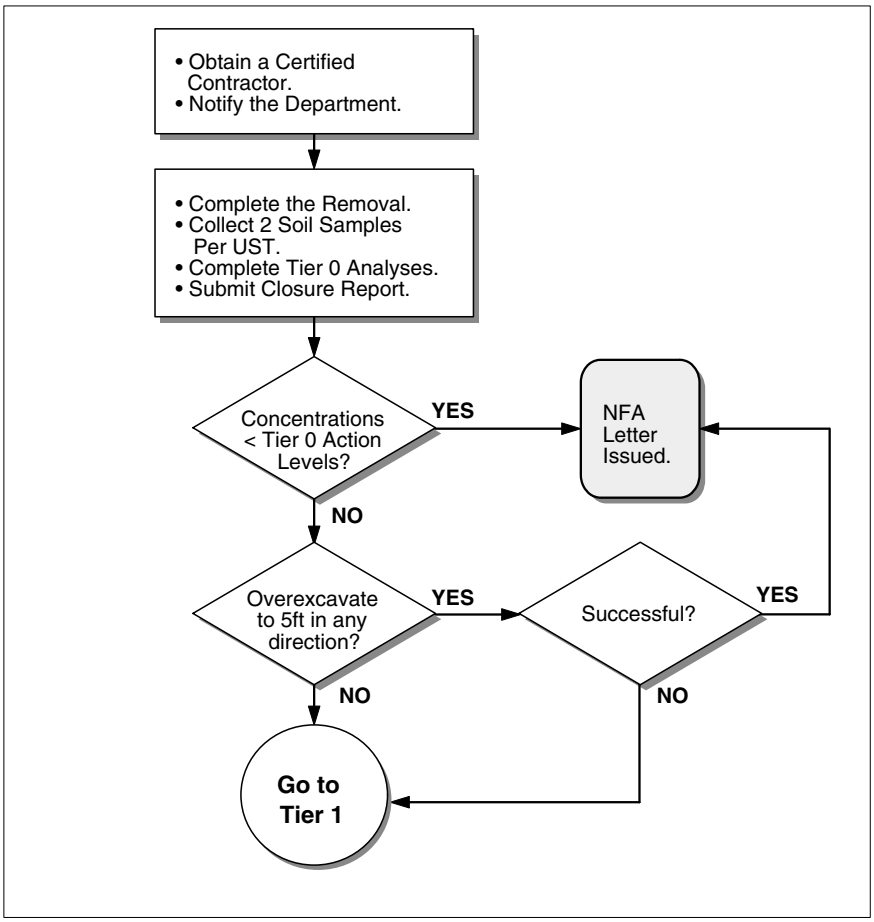


Figure 4. Tier 0 Removal Process

During a removal, an RP has the option to overexcavate up to five (5) feet in all directions to attempt an immediate cleanup to Tier 0 action levels, provided that bedrock, a physical barrier or the water table is not encountered. If any of these

conditions are encountered or if soil contamination extends beyond the allowable five (5) foot maximum, then the RP must move to Tier 1.

2.3 Tier 0 Analytical Requirements and Concentration Limits

Under the Tier 0 process, petroleum hydrocarbons (PHC) analysis for gasoline and diesel range organics (GRO and DRO) by GC FID or GC MS replaces all prior TPH analytical methods. The action levels are 100 and 1000 parts per million (ppm) PHC in soil, respectively. Tier 0 specifies a benzene action level of 230 parts per billion (ppb) with a total BTEX limit of 10 ppm.

Additionally under Tier 0, analysis for methyl tertiary butyl ether (MTBE) is required when sampling for gasoline, kerosene, jet fuel, used oil and aviation gas. Analyses for lead, EDB and EDC are required when sampling for gasoline (see Table 2, footnote 4). Table 2 specifies the new analytical requirements by substance stored and associated action levels.

Table 2. DERBCAP Tier 0 Soil Sample Analytes and Action Levels by Substance Stored

Analyte	Tier 0 Action Level in Soil	Gasoline	Kerosene and Jet Fuels	Diesel and Heating Fuels	Used Oil[1,2]	Aviation Gas	Heavy Oils	Other[6]
BTEX[5]	Benzene 230 ppb, Total BTEX 10 ppm	X	X		X	X		
GRO	100 ppm	X	X		X	X		
DRO	1,000 ppm		X	X	X			
HRO							X	
LEAD[4] **EDB** **EDC**	400 ppm 10 ppb 400 ppb	X						
MTBE[3]	130 ppb	X	X		X	X		
OTHER[6]	Site by site							X

Notes:

[1]Used oil as defined in Part A, Section 2 of the Delaware *Regulations Governing Underground Storage Tank Systems* and the *Delaware Regulations Governing Hazardous Waste.*

[2]Used oil USTs may also be required to analyze for metals, volatiles, semi-volatiles, EDB, EDC, HRO, total lead or any other analyte as required on a site-specific basis depending on the tank contents. Contact the UST Branch for a determination on analytical requirements prior to sampling.

[3]MTBE analysis is required, unless conclusive documentation is presented and pre-approved by the UST Branch confirming that the UST was not in service after January 1, 1978.

[4]For gasoline USTs only, Lead, EDB and EDC analysis is required, unless conclusive documentation is presented and pre-approved by the UST Branch that the UST was installed after January 1, 1988. Lead, EDB and EDC analysis is always required for aviation gas USTs.

[5]In addition to total BTEX, benzene must be reported separately.

[6]If the UST contained anything other than petroleum products, contact the UST Branch for a determination on sampling procedures and analytical requirements prior to site activities.

2.4 Tier 0 Data Evaluation and Response Options

Upon receipt of a Tier 0 closure package, the Department will apply the appropriate Tier 0 action levels shown in Table 2 to determine the need for further action at the site. Each soil sample will be evaluated to determine if the applicable Tier 0 action level has been exceeded. The RP will be issued either a no further action (NFA) letter or given the option to remediate either to Tier 0 levels or move to a Tier 1 site assessment.

Each soil measurement must be less than the applicable Tier 0 limit or additional investigation will be required. Analytical results may not be averaged for comparison to the Tier 0 action levels.

3. TIER 1

3.1 Tier 1 Applicability

Tier 1 is the next level in DERBCAP. An RP may choose to enter the RBCA process at Tier 1 with any currently active LUST site or will move up to Tier 1 from Tier 0 if tank removal/abandonment soil samples exceed Tier 0 action levels. A Tier 1 DERBCAP assessment might prove valuable to an RP where a site has extensive soil contamination, where site constraints prohibit excavation, or where the site has low levels of non-recoverable free phase or dissolved phase hydrocarbons involving extensive monitoring, or where previous remedial efforts have failed.

To assure a constant level of protection for human health and the environment, Tier 1 uses a generic site conceptual model with the following assumptions to calculate RBSLs:

1. Grab soils samples are assumed to be collected at the top of the water table.
2. Ground water is assumed to be used for drinking water.
3. Soils are assumed to be well sorted, permeable, fine to medium grained sand.
4. Petroleum compounds adsorbed onto soils in the unsaturated zone are assumed to be remobilized from below by fluctuating ground-water levels an average of four months per year.
5. Current land use is assumed to be residential.

In Tier 1, specific chemicals of concern (COCs) found in petroleum products are chosen for a variety of factors including, but not limited to, carcinogenicity or other health effects, persistence in the environment, mobility, solubility, vapor pressure, or aesthetic factors. RBSLs are then calculated for each COC for surface soil (direct contact exposure pathway), subsurface soil (soil leaching or partitioning to ground water), and ground water (ground water ingestion exposure pathway.) Since vapor based problems are handled as emergencies, vapor pathways are not part of the RBSL calculations. Figure 5 summarizes the exposure pathways used to calculate DERBCAP RBSLs. See Appendix 5 for formulas used in RBSL calculations.

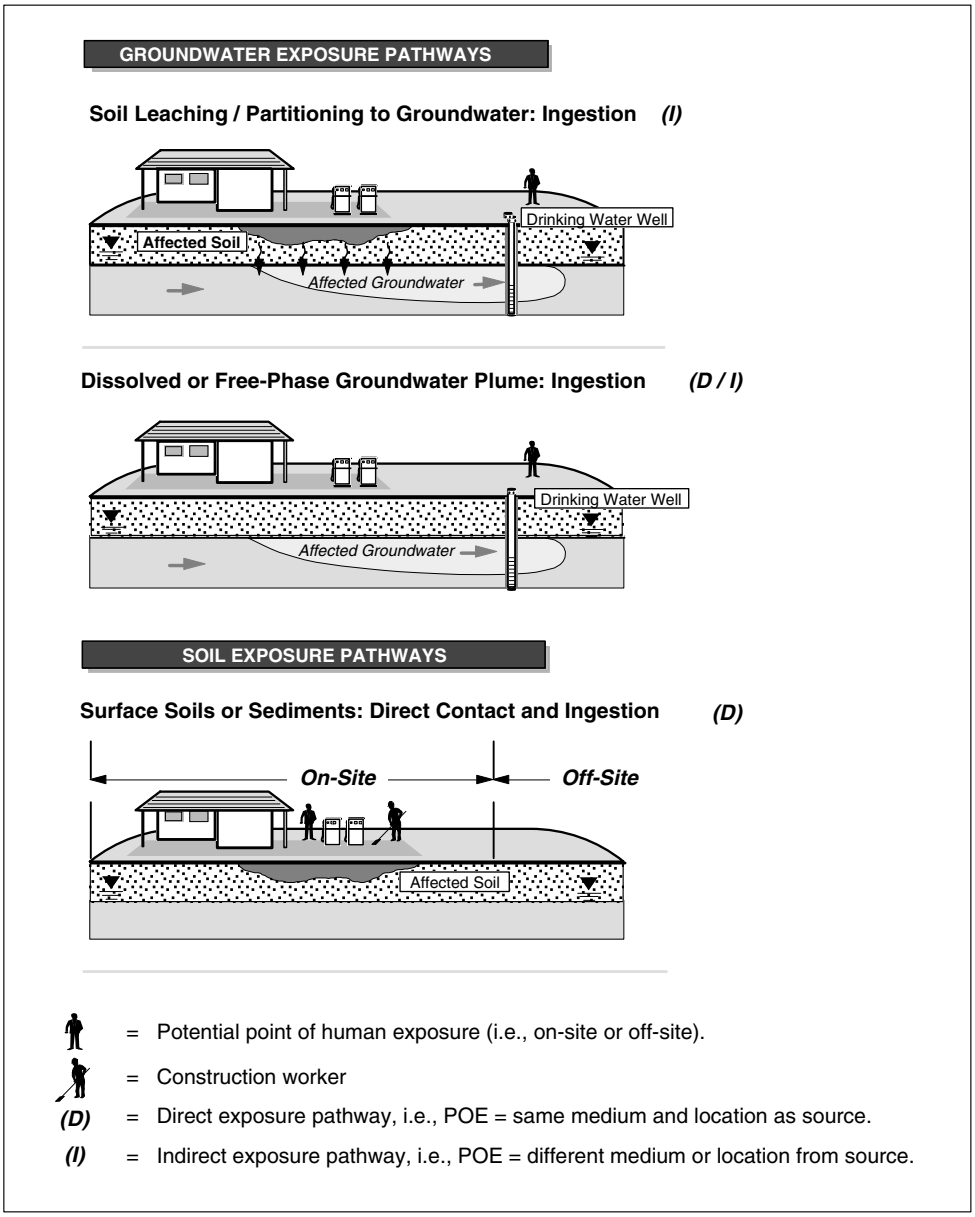


Figure 5. DERCAP Exposure Pathways Chosen from the ASTM Standard

The target risk limit for both individual chemicals and cumulative site risk for carcinogens is 1 x 10^{-5}; for non-carcinogens the hazard quotient (HQ) is less than or equal to 1.

3.2 Tier 1 Site Investigation Requirements

A Tier 1 DERBCAP site assessment requires that all samples be analyzed for all specified COCs based on substance stored and media sampled. If a tank field holds multiple tanks containing more than one type of stored petroleum product,

then all samples must be analyzed for all COCs for all substances stored. Additionally, a DERBCAP Tier 1 site assessment requires the collection of ground water samples.

Ground water sampling may not be required at the Department's discretion when contamination is proven to be limited to the unsaturated zone through field screening and confirmatory sampling, or when bedrock is encountered above the water table. This option will apply primarily to sites located in the Piedmont region.

A DERBCAP Tier 1 hydrogeologic assessment workplan as described in Appendix 9 must be submitted for Department approval prior to implementation and must provide the following:

- Complete delineation of all contaminant phases present both on and off site, whether moving through soils, via ground water, or along manmade conduits (e.g., utility trenches); and
- Determination of ground water flow direction; and
- Location of all area points of exposure (receptors); and
- Interpretation of the data provided; and
- Recommendations for further activity at the site.

Laboratory Method Detection Limits (MDLs) must be less than applicable DERBCAP RBSLs. If this cannot be achieved, then additional samples farther from the source must be collected for analysis. A Tier 1 site assessment may be completed in phases at the responsible party's discretion. The initial investigation phase may use a direct push technology to determine the extent of the release and facilitate the placement of monitoring wells. No further action may be required during any investigation phase at the Department's discretion based on an analysis of the data provided that indicate the contamination is localized in extent and unlikely to migrate and concentrations are less than RBSLs.

3.3 Tier 1 Concentration Limits

Table 3 lists DERBCAP COCs and Table 4 lists the Tier 1 RBSLs. Tier 1 fate and transport default parameters used to calculate the RBSLs are located in Ap-

pendix 2, exposure assumptions are located in Appendix 3. The calculation sheets for each exposure pathway by distance to the POE on which Table 4 RBSLs are based are located in Appendix 4. The equations and methodology used to calculate the Tier 1 RBSLs are located in Appendix 5.

Due to the physical and chemical properties of lead, the RBSL concentration value for less than 50 feet (<50') is applied in all situations at all distances.

3.4 Tier 1 Data Evaluation and Response Options

A detailed site map must be included with the Tier 1 data package submitted to the Department (see Appendix 9 for the complete contents of the data package). All decisions regarding potential risk and cleanup levels center on the distance from the source to all POEs. All measured COC concentrations will be compared to applicable RBSLs based on distance to a POE. See Scenarios in Section 3.5. Upon submittal of a Tier 1 package, the Department will apply the appropriate RBSLs to determine the need for further action at the site. The RP will be issued an NFA letter, a conditional NFA letter, be given the option to cleanup to the appropriate RBSLs, or proceed to Tier 2.

Figure 6 shows the Tier 1 process. Refer to the Tier 1 scenarios in Section 3.5 for determining distance components for RBSLs and corrective action work-plans. Any point within a plume (such as a monitor well) where COC concentrations are greater than Tier 1 RBSLs must be remediated.

The Tier 1 evaluation may be used to screen certain pathways and COCs from further consideration. For example, if the Tier 1 soil limits are not exceeded, there is no need for further soil evaluation. Or, if only the ground water benzene limit is exceeded, then Tier 2 need only address benzene. In this manner, the Tier 1 evaluation can help to focus the investigation or remediation plan.

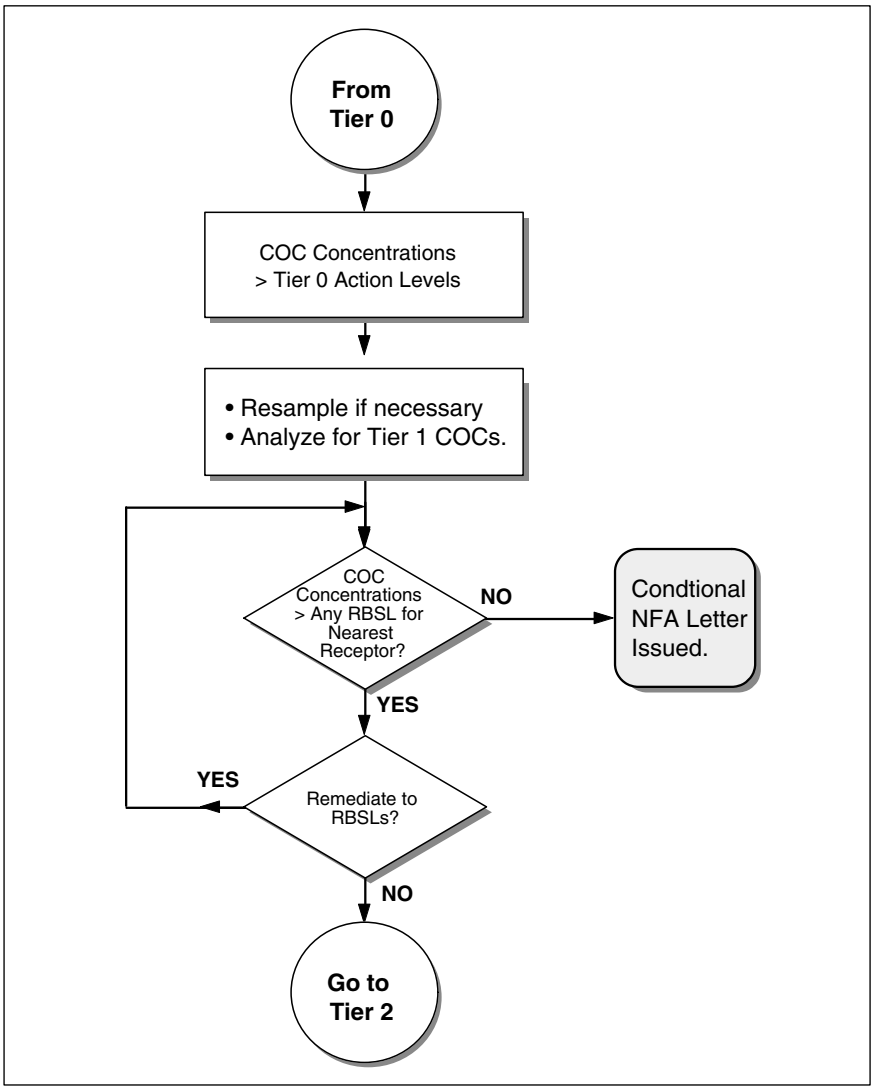


Figure 6. Tier 1 Flowchart

Table 3. DERBCAP Chemicals of Concern

Chemical of Concern (COC)	PRODUCT									
	Gasoline/ Av-Gas		Jet Fuel/Kero		Diesel		Heating Fuel		Used Oil	
	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW	SOIL	GW
VOLATILES										
Benzene	X	X	X	X		X		X	X	X
Toluene	X	X	X	X		X		X	X	X
Ethylbenzene	X	X	X	X		X		X	X	X
Xylene (mixed isomers)	X	X	X	X		X		X	X	X
Isopropylbenzene (Cumene)	X	X		X*					X	
ADDITIVES										
Methyl t-butyl ether (MTBE)[2]	X	X	X	X					X	X
Lead[1,3]	X**(T)	X**(D)							X(T)	X(D)
1,2-Dichloroethane (EDC)[3]	X**	X**	X**	X**						
1,2-Dibromoethane (EDB)[3]	X**	X**								
PAH-CARCINOGENIC										
Benzo(a)Anthracene			X		X		X		X	
Benzo(a)Pyrene			X		X		X		X	
Benzo(b)Fluoranthene					X		X		X	
Benzo(k)Fluoranthene					X		X		X	
Chrysene					X	X	X	X	X	X
Indeno(1,2,3-cd)Pyrene					X		X		X	
PAH-NON-CARCINOGENIC										
Acenaphthene					X	X	X	X	X	X
Anthracene					X		X		X	
Fluoranthene					X		X		X	
Fluorene			X		X		X		X	
Naphthalene	X	X	X	X	X	X	X	X	X	X
Phenanthrene			X	X	X	X	X	X	X	X
Pyrene					X		X		X	
OTHER										
PCBs									X	X
Semi-volatiles									X	X
Volatiles									X	X

Notes:

*JP-4 jet fuel only.

** If leaded gasoline, aviation gasoline, or jet fuel.

(D) Dissolved Lead

(T) Total Lead

[1]Samples collected from point of use must be analyzed for Total Lead; samples collected from the aquifer must be analyzed for dissolved lead.

[2]MTBE analysis is required, unless conclusive documentation is presented and pre-approved by the UST Branch confirming that the UST was not in service after January 1, 1978.

[3]For gasoline USTs only, lead, EDB and EDC analysis is required unless conclusive documentation is presented and pre-approved by the UST Branch that the gasoline UST was installed after January 1, 1988. Lead, EDB, and EDC analysis is always required for aviation gasoline USTs.

Table 4. DERBCAP Risk-Based Screening Levels (RBSLs)

Chemicals of Concern (COC) Units: mg/Kg or mg/L	DISTANCE TO POINT OF EXPOSURE (POE) OR POINT OF COMPLIANCE (POC)										
	<50 ft			51-100 ft		101-300 ft		301-500 ft		>500 ft	
	$SOIL_{GW}$	$SOIL_{DC}$	GW	$SOIL_{GW}$	GW	$SOIL_{GW}$	GW	$SOIL_{GW}$	GW	$SOIL_{GW}$	GW
VOLATILES											
Benzene	0.23	19	0.029	0.40	0.051	1.2	0.16	23	3.0	150	19
Toluene	210	3800	7.3	>750	>520	>750	>520	>750	>520	>750	>520
Ethylbenzene	350	2300	3.7	>630	24	>630	>170	>630	>170	>630	>170
Xylene (mixed isomers)	>500	43900	73	>500	>200	>500	>200	>500	>200	>500	>200
Isopropylbenzene (Cumene)	>8.2	1900	3.7	>8.2	>50	>8.2	>50	>8.2	>50	>8.2	>50
ADDITIVES											
Methyl t-butyl ether (MTBE)[4]	0.13	200	0.18	0.16	0.24	0.39	0.56	2.9	4.2	7.9	12
Lead[3,5]	400	400	0.015	400	0.015	400	0.015	400	0.015	400	0.015
1,2-Dichloroethane (EDC)[5]	0.4	6.1	0.0094	0.4	0.021	0.4	0.081	7.2	3.1	76	33
1,2-Dibromoethane (EDB)[5]	0.01	0.01	0.00005	0.01	0.00007	0.01	0.00064	2.0	0.25	100	13
PAH-CARCINOGENIC											
Benzo(a)Anthracene	>79	5.5	0.0012	>79	>0.0057	>79	>0.0057	>79	>0.0057	>79	>0.0057
Benzo(a)Pyrene	>17	0.55	0.00012	>17	>0.0016	>17	>0.0016	>17	>0.0016	>17	>0.0016
Benzo(b)Fluoranthene	>81	5.5	0.0012	>81	>0.015	>81	>0.015	>81	>0.015	>81	>0.015
Benzo(k)Fluoranthene	>24	55	>0.0043	>24	>0.0043	>24	>0.0043	>24	>0.0043	>24	>0.0043
Chrysene[5]	>3.6	3.5	0.009	>3.6	>0.0018	>3.6	>0.0018	>3.6	>0.0018	>3.6	>0.0018
Indeno(1,2,3-cd)Pyrene	520	5.5	0.0012	>21000	>0.062	>21000	>0.062	>21000	>0.062	>21000	>0.062
PAH-NON-CARCINOGENIC											
Acenaphthene	>280	10300	2.2	>280	>3.9	>280	>3.9	>280	>3.9	>280	>3.9
Anthracene	>6.4	51400	>0.045	>6.4	>0.045	>6.4	>0.045	>6.4	>0.045	>6.4	>0.045
Fluoranthene	>78	6900	>0.21	>78	>0.21	>78	>0.21	>78	>0.21	>78	>0.21
Fluorene	>120	6900	1.5	>120	>1.7	>120	>1.7	>120	>1.7	>120	>1.7
Naphthalene	>620	58900	15	>620	>31	>620	>31	>620	>31	>620	>31
Phenanthrene	>230	5100	1.1	>230	>1.6	>230	>1.6	>230	>1.6	>230	>1.6
Pyrene	>61	5100	>0.16	>61	>0.16	>61	>0.16	>61	>0.16	>61	>0.16
OTHER											
PCBs	3.1	2.0	0.00043	4.0	0.00056	9.5	0.0013	71	0.0098	190	0.027

NOTES:

1) $SOIL_{GW}$=RBSL for soil partitioning/leaching to groundwater ingestion pathway.
   $SOIL_{DC}$=RBSL for soil direct contact (ingestion, inhalation, and dermal contact) pathway; applies for on-site exposure only.
   GW=RBSL for groundwater ingestion pathway.
2) ">" indicates that the groundwater cleanup standard is greater than the constituent's aqueous solubility or the soil cleanup standard is greater than the soil residual saturation.
3) 0-50 ft RBSLs apply for all distances to POE for lead.
4) Values established based on Delaware-specific case histories (Ellis, 1999).
5) Values established by DNREC's Site Investigation and Restoration Branch and adopted here for inter-program consistency.

3.5 DERBCAP Tier 1 RBSL and Tier 2 SSTL Scenarios

The following scenarios illustrate the application of DERBCAP procedures to various conditions that may be encountered on-site. In all cases, the goals are to:

- minimize potential risks to human health and the environment, and
- prevent further environmental degradation.

Under this section, source is further defined as any point within a plume, such as at a monitoring well, where COC concentrations are greater than either Tier 1 RBSLs or Tier 2 SSTLs. In the scenarios described in this section substitute SSTLs for RBSLs at Tier 2. The use of these scenarios as an integral part of DERBCAP is to determine whether or not ground-water plumes are stable or shrinking and no further degradation of ground water is occurring. This is done as a risk management goal to assure that the potential for future risk due to exposure to residual soil and ground water petroleum contamination is minimized.

Table 5 below describes the applicable scenario for a site with a ground water plume that has not spread beyond the property boundary for site-specific COC concentrations and distance to the closest POE. Table 6 below describes the applicable scenario for a site with a ground-water plume that has spread beyond the property boundary for site-specific COC concentrations and distance to the closest POE.

Table 5. Scenario Lookup Table For On-Site Plumes

POE < 500 ft.		No POE < 500 ft.	
COC concentrations exceed RBSLs	COC concentrations do not exceed RBSLs	COC concentrations exceed > 500 ft. RBSLs	COC concentrations do not exceed > 500 ft. RBSLs
Go to Scenario 1	Go to Scenario 3A	Go to Scenario 2	Go to Scenario 3B
Note: This table does not apply for lead. See Section 3.3.			

Table 6. Scenario Lookup Table For Off-Site Plumes

POE < 500 ft.		No POE <500 ft.	
COC concentrations in the source and/or the off-site portion exceed RBSLs	COC concentrations in the source and the off-site portion do not exceed RBSLs	COC concentrations in the source exceed the source to POC distance derived RBSLs	COC concentrations in the source do not exceed the source to POC distance derived RBSLs
Go to Scenario 4	Go to Scenario 6A	Go to Scenario 5	Go to Scenario 6B
Note: This table does not apply for lead. See Section 3.3.			

3.5.1 Scenario 1: On-Site Plume, POE less than 500 ft from Downgradient Property Line.

If the groundwater plume is located *in its entirety* within the boundaries of the property, at least three (3) monitoring wells, including at least one (1) Point of Compliance (POC) monitoring well, must be installed. The POC well(s) must be located on the most down-gradient property line. If a point of exposure (POE) located within 500 feet downgradient of the site is identified, groundwater cleanup goals in each monitor well will be a function of the distance from the source to the POE. For example, if a monitor well is installed 75 feet from a POE in a ground water plume contaminated with gasoline COCs, cleanup goals for the COCs in the monitor well will be the 51-100 foot Risk Based Screening Levels (RBSLs). If the concentrations of the COCs in any or all of the monitor wells exceed the RBSLs, remediation must be performed. Cleanup goals for each monitor well will be the RBSLs assigned to each monitor well within the plume.

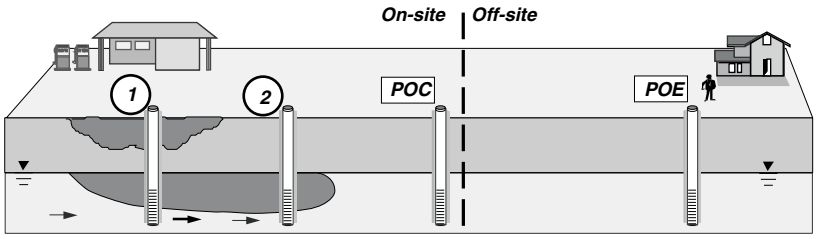
However, if at any time COC contaminants are identified in the POC well(s), the Department will assign new cleanup goals. The new goals will be a function of the distance from each monitor well to the closest POC well. Upon termination of all remedial activities at least one (1) year of quarterly groundwater monitoring must be performed, during which the concentrations of the COCs in all monitoring wells must remain at or below the cleanup goals established for the site.

REMEDIATION SCENARIO 1:	On-Site Plume, POE < 500 ft

Plume Off-Site ?	*No*
POE Dist. < 500 ft ?	*Yes*
COC Conc. > RBSLs ?	*Yes*

Example Data: Benzene in GW

Well	*Conc.*	*Dist to POE:*	*RBSL:*	*RBSL Exceeded:*
1	*300 ppb*	*75 ft*	*51-100 ft*	*Yes*
2	*50 ppb*	*49 ft*	*0 - 50 ft*	*Yes*
POC	*0*	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 based on distance to POE. If POC impacted, new cleanup goals to be assigned for Wells 1 and 2 based on distance to POC, and SW must be installed between POC and POE.***

NOTES:

C = COC Concentration	*POC = Point of Compliance*	*RBSL = Risk-Based Screening Limit*
COC = Constituent of Concern	*POE = Point of Exposure*	*SW = Sentinel Well*

3.5.2 Scenario 2: On-Site Plume, POE greater than 500 ft from Downgradient Property Line.

If the groundwater plume is located *in its entirety* within the boundaries of the site and no POEs located within 500 feet downgradient of the site are identified, cleanup goals will be the >500' RBSLs for soil and groundwater. At least three (3) monitoring wells, including one POC well must be installed. The POC well(s) must be located on the most downgradient property line. If the concentrations of the COCs in any or all of the monitor wells exceed the >500 feet RBSLs, remediation must be performed. Cleanup goals will be the >500 feet RBSLs.

However, if at any time COC contaminants are identified in the POC well(s), the Department will assign new cleanup goals. The new goals for each monitor well will be a function of the distance from each monitor well to the closest POC well. Upon termination of all remedial activities at least one (1) year of quarterly groundwater monitoring must be performed, during which the concentrations of the COCs in all monitor-

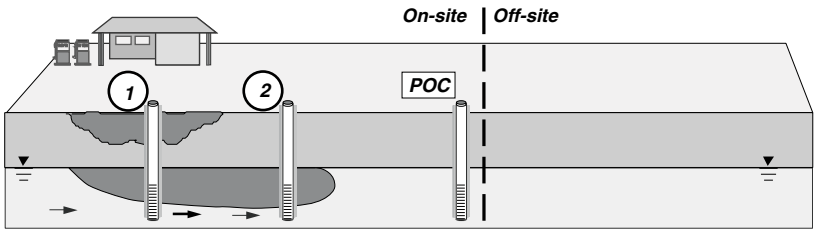
ing wells must remain at or below the cleanup goals established for the site.

REMEDIATION SCENARIO 2: **On-Site Plume, POE > 500 ft**

Plume Off-Site ?	No
POE Dist. < 500 ft ?	No
COC Conc. > RBSLs ?	Yes

Example Data: Benzene in GW

Well	Conc.	Dist to POE:	RBSL:	RBSL Exceeded:
1	25 ppm	1000 ft	> 500 ft	Yes
2	30 ppm	974 ft	> 500 ft	Yes
POC	0	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 based on > 500 ft distance to POE. If POC impacted, new cleanup goals to be assigned for Wells 1 and 2 based on distance to POC.***

NOTES:
C = COC Concentration
COC = Constituent of Concern
POC = Point of Compliance
POE = Point of Exposure
RBSL = Risk-Based Screening Limit

3.5.3 Scenarios 3A and 3B: On-Site Plume, COC Concentrations less than RBSLs.

If the groundwater plume is located *in its entirety* within the boundaries of the site and the concentrations of the COCs in the soil and groundwater are already less than the RBSLs assigned to your site (as described in Scenarios 1 or 2) you must either:

1. Monitor the site quarterly for no more than one (1) year to show that the groundwater concentrations are stable or decreasing, or
2. Perform DERBCAP Tier 2 modeling with site specific data to show that the plume is stable or decreasing.

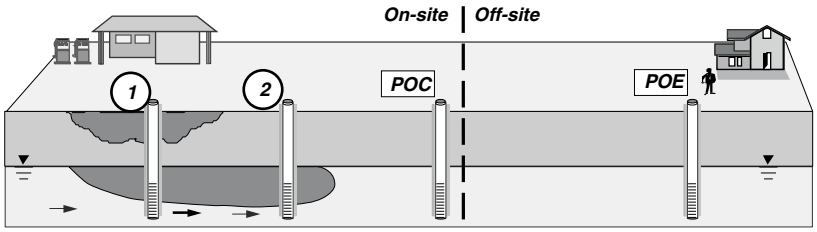
At least three (3) monitoring wells, including one POC well must be installed. The POC well(s) must be located on the most down-gradient property line.

MONITORING SCENARIO 3A: **On-Site Plume, COC Conc. < RBSLs**

Plume Off-Site ?	*No*
POE Dist. < 500 ft ?	*Yes*
COC Conc. > RBSLs ?	*No*

Example Data: Benzene in GW

Well	Conc.	Dist to POE:	RBSL:	RBSL Exceeded:
1	35 ppm	75 ft	51-100 ft	No
2	10 ppm	49 ft	0-50 ft	No
POC	0	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 based on distance to POE. If POC impacted, new cleanup goals to be assigned for Wells 1 and 2 based on distance to POC, and SW must be installed between POC and POE.***

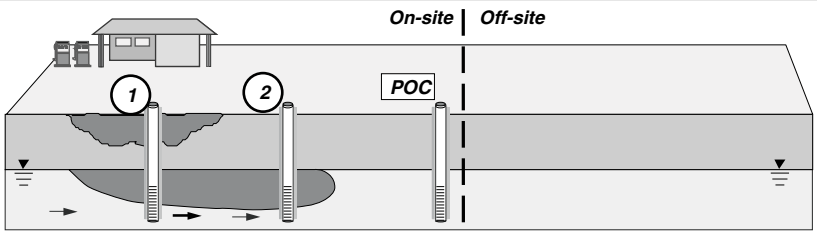
NOTES:
C = COC Concentration
COC = Constituent of Concern
POC = Point of Compliance
POE = Point of Exposure
RBSL = Risk-Based Screening Limit
SW = Sentinel Well

MONITORING SCENARIO 3B: **On-Site Plume, COC Conc. < RBSLs**

Plume Off-Site ?	*No*
POE Dist. < 500 ft ?	*No*
COC Conc. > RBSLs ?	*No*

Example Data: Benzene in GW

Well	Conc.	Dist to POE:	RBSL:	RBSL Exceeded:
1	1 ppm	1000 ft	> 500 ft	No
2	500 ppm	800 ft	> 500 ft	No
POC	0	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 based on > 500 ft distance to POE. If POC impacted, new cleanup goals to be assigned for Wells 1 and 2 based on distance to POC.***

NOTES:
C = COC Concentration
COC = Constituent of Concern
POC = Point of Compliance
POE = Point of Exposure
RBSL = Risk-Based Screening Limit

However, if at any time COC contaminants are identified in the POC well(s), the Department will assign new cleanup goals. The new goals will be a function of the distance of the source of your plume to the clos-

est POC well. In addition, if at any time during the course of one year of groundwater monitoring the concentrations of the groundwater or soil COCs exceed the RBSLs assigned to your site, remediation or Tier 2 modeling will be required. *Indefinite groundwater monitoring will not be permitted.*

3.5.4 Scenario 4: Off-Site Plume, POE less than 500 ft from Downgradient Property Line.

If the groundwater plume *has spread off-site*, at least three (3) monitoring wells, including at least one (1) Point of Compliance (POC) well, must be installed. The POC well(s) must be located on the most downgradient property line. If a POE located within 500 feet downgradient of the site is identified, a sentinel monitoring well must also be installed. The sentinel well must be placed between the leading edge of the plume and the POE. Cleanup goals for the monitor wells within the plume will be a function of the distance from each monitor well to the closest POC well. If the concentrations of any of the COCs in the monitor wells exceed the RBSLs assigned to each monitor well, remediation must be performed. The RBSLs assigned to each monitor well will be the cleanup goals for each monitor well.

However, if at any time contaminants are discovered in the sentinel well, cleanup goals for the off-site portion of the plume will become a function of either the distance from the POC well to the sentinel well or from the sentinel well to the POE. The Department will use the *shortest* distance when establishing off-site cleanup goals. If the concentrations of the COCs in the off-site portion of the plume exceed the assigned RBSLs, remediation must be performed. Cleanup goals for the COCs in the off-site portion of the plume (i.e., from the POC well to the sentinel well) will be the RBSLs assigned to the off-site portion of the plume. In addition, the Department will require the installation of a new sentinel well between the old sentinel well and the POE. Upon termination of all remedial activities at least one (1) year of quarterly groundwater monitoring must be performed, during which the concentrations of the COCs

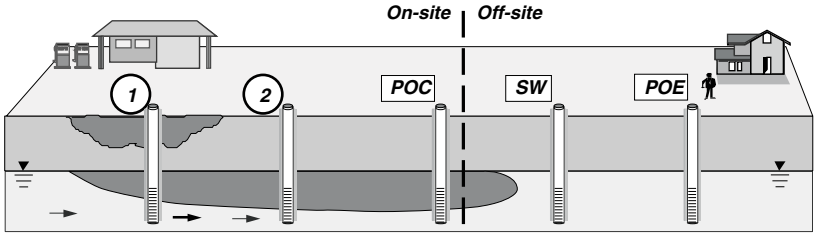
in all monitoring wells must remain at or below the cleanup goals established for the site.

MONITORING SCENARIO 4: **Off-Site Plume, COC Conc. < RBSLs**

Plume Off-Site ?	*Yes*
POE Dist. < 500 ft ?	*Yes*
COC Conc. > RBSLs ?	*Yes*

Example Data: Benzene in GW

Well	Conc.	Dist to POE:	RBSL:	RBSL Exceeded:
1	300 ppb	75 ft	51-100 ft	Yes
2	80 ppb	60 ft	51-100 ft	Yes
POC	35 ppb	49 ft	0-50 ft	Yes
SW	0	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 and POC based on distance to POE. If SW impacted, new cleanup goals to be assigned for off-site portion of plume based on distance between POC and SW or between SW and POE, whichever is less, and new SW must be installed between old SW and POE.***

NOTES:
C = COC Concentration *POC = Point of Compliance* *RBSL = Risk-Based Screening Limit*
COC = Constituent of Concern *POE = Point of Exposure* *SW = Sentinel Well*

3.5.5 Scenario 5: Off-Site Plume, POE greater than 500 ft from Downgradient Property Line.

If the groundwater plume *has spread off-site* and no POEs located within 500 feet downgradient of the site are identified, cleanup goals for the monitor wells in the plume will be a function of the distance from each monitor well to the closest POC well. At least three (3) monitoring wells, including at least one (1) Point of Compliance (POC) monitoring well must be installed. The POC well(s) must be located on the most down-gradient property line. If the concentrations of the COCs in any monitor well exceed the RBSLs assigned to that monitor well, remediation must be performed. The RBSLs assigned to the core will be cleanup goals for the source. Upon termination of all remedial activities at least one (1) year of quarterly groundwater monitoring must be performed,

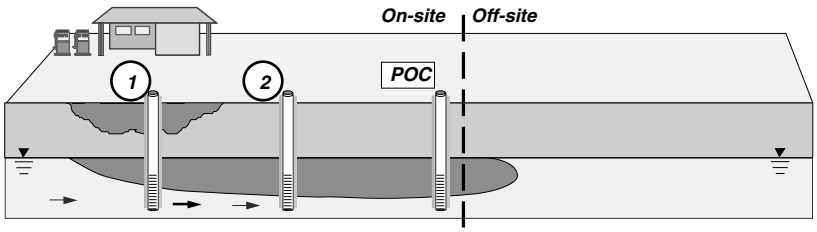
during which the concentrations of the COCs in all monitoring wells must remain at or below the cleanup goals established for the site.

REMEDIATION SCENARIO 5: Off-Site Plume, POE > 500 ft

Plume Off-Site ?	*Yes*
POE Dist. < 500 ft ?	*No*
COC Conc. > RBSLs ?	*Yes*

Example Data: Benzene in GW

Well	Conc.	Dist. to POE:	Dist. to POC:	RBSL:	RBSL Exceeded:
1	25 ppm	1000 ft	75 ft	51-100 ft	Yes
2	30 ppm	800 ft	49 ft	0 - 50 ft	Yes
POC	5 ppm	600 ft	0 ft	0 - 50 ft	Yes



Groundwater Cleanup Goals: ***RBSLs for Wells 1, 2 and POC based on distance to POC.***

NOTES:
C = COC Concentration *POC = Point of Compliance* *RBSL = Risk-Based Screening Limitl*
COC = Constituent of Concern *POE = Point of Exposure*

3.5.6 Scenarios 6A and 6B: Off-Site Plume, COC Concentrations less than RBSLs.

If the groundwater plume *has spread off-site* and the concentrations of the COCs in the soil and groundwater are less than the RBSLs assigned to your site (as described in either Scenario #4 or Scenario #5) you must either:

1. Monitor the site quarterly for no more than one (1) year to show that the COC concentrations in the ground water are stable or decreasing, or
2. Perform DERBCAP Tier 2 modeling with site specific data to show that the plume is stable or decreasing.

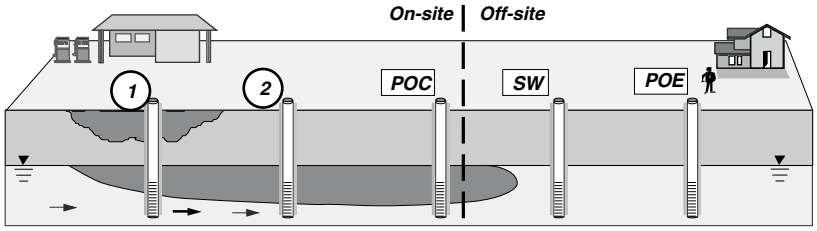
However, if at any time during the course of one year of ground-water monitoring the concentrations of the soil or groundwater COCs exceed the RBSLs assigned to your site, remediation or Tier 2 modeling will be required. *Indefinite groundwater monitoring will not be permitted*.

MONITORING SCENARIO 6A: **Off-Site Plume, COC Conc. < RBSLs**

Plume Off-Site ?	*Yes*
POE Dist. < 500 ft ?	*Yes*
COC Conc. > RBSLs ?	*No*

Example Data: Benzene in GW

Well	*Conc.*	*Dist to POE:*	*RBSL:*	*RBSL Exceeded:*
1	*45 ppb*	*75 ft*	*51-100 ft*	*No*
2	*35 ppb*	*60 ft*	*51-100 ft*	*No*
POC	*25 ppb*	*49 ft*	*0-50 ft*	*No*
SW	*0*	—	—	—



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 and POC based on distance to POE. If SW impacted, new cleanup goals to be assigned for off-site portion of plume based on distance between POC and SW or between SW and POE, whichever is less, and new SW must be installed between old SW and POE.***

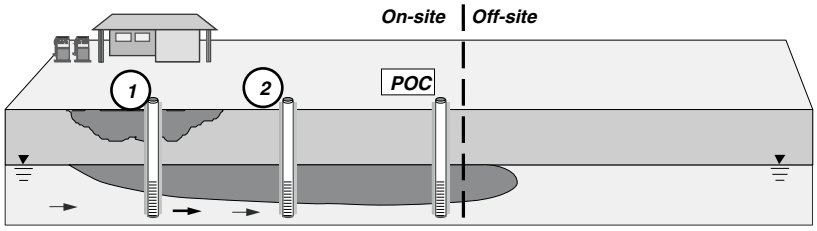
NOTES:
C = COC Concentration *POC = Point of Compliance* *RBSL = Risk-Based Screening Limit*
COC = Constituent of Concern *POE = Point of Exposure* *SW = Sentinel Well*

MONITORING SCENARIO 6B: **Off-Site Plume, COC Conc. < RBSLs**

Plume Off-Site ?	*Yes*
POE Dist. < 500 ft ?	*No*
COC Conc. > RBSLs ?	*No*

Example Data: Benzene in GW

Well	*Conc.*	*Dist. to POE:*	*Dist. to POC:*	*RBSL:*	*RBSL Exceeded:*
1	*45 ppm*	*1000 ft*	*75 ft*	*51-100 ft*	*No*
2	*25 ppm*	*974 ft*	*49 ft*	*0 - 50 ft*	*No*
POC	*10 ppm*	*925 ft*	*0 ft*	*0 - 50 ft*	*No*



Groundwater Cleanup Goals: ***RBSLs for Wells 1 and 2 and POC based on distance to POC.***

NOTES:
C = COC Concentration *POC = Point of Compliance* *RBSL = Risk-Based Screening Limit*
COC = Constituent of Concern *POE = Point of Exposure*

4. TIER 2

4.1 Tier 2 Applicability

Under Tier 2, the RP may derive SSTLs based on site-specific receptor locations and other site-specific soil and ground water input parameters. The Tier 2 evaluation only applies to those exposure pathways (i.e., soil direct contact, soil leaching to ground water, and ground water ingestion) and those constituents that fail Tier 1 (Figure 7).

If concentrations of COCs exceed Tier 1 RBSLs, then a Tier 2 site assessment can be conducted as an alternative to remediating contamination to the level of Tier 1 RBSLs. At Tier 2, site-specific hydrogeologic parameters are substituted for corresponding Tier 1 assumptions and are used to calculate site-specific target levels or SSTLs for the chemicals of concern. SSTLs become the new cleanup goals for the site. Note, for calculating a SSTL for MTBE, the Delaware specific methodology described in Appendix 11 (Ellis, 1999) must be followed.

A Tier 2 site assessment may not be conducted without prior written approval from the Underground Storage Tank Branch.

4.2 Tier 2 Site Investigation Requirements

A Tier 2 site assessment includes:

- Site-specific geologic characterization.
- Measurement or calculation of site-specific physical characteristics.
- Calculation of SSTLs, using Department-approved models.

Appendix 2 lists the site-specific Tier 2 parameters that must be substituted for the Tier 1 generic assumptions in calculating SSTLs. Appendix 9 lists the requirements for a Tier 2 hydrogeologic investigation.

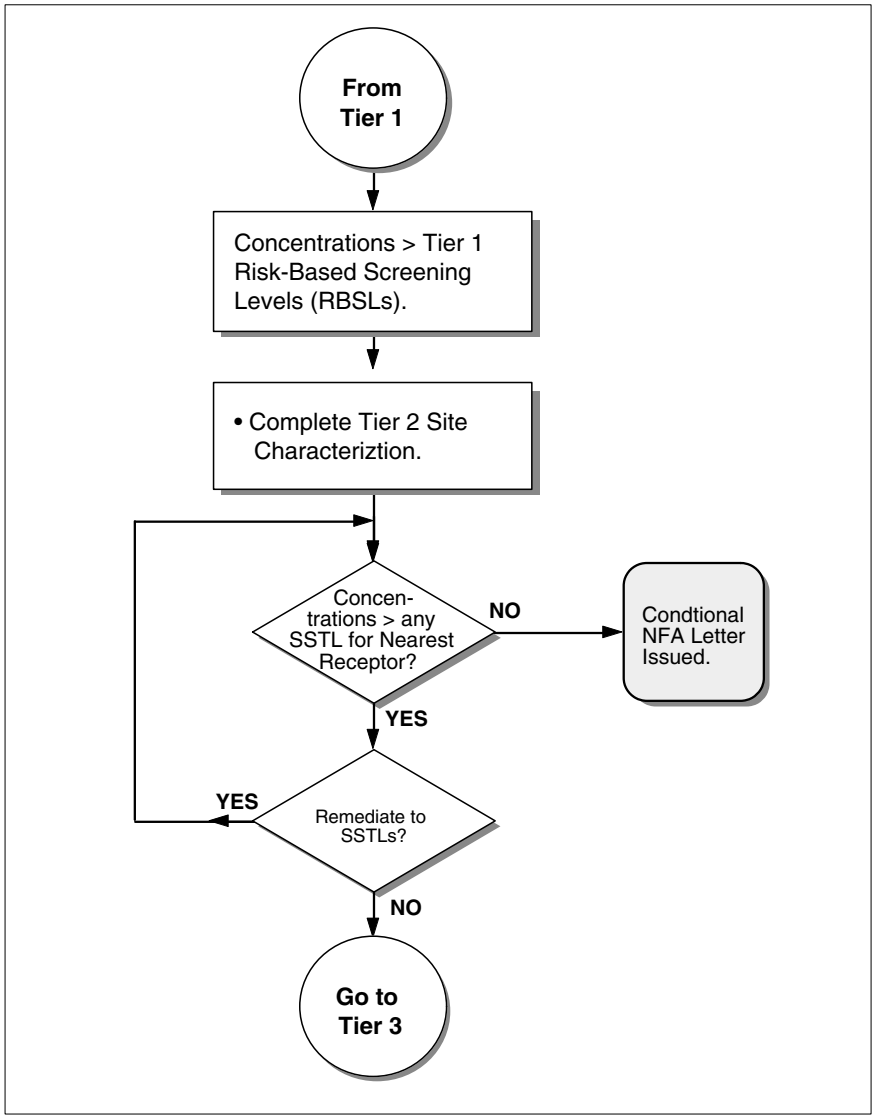


Figure 7. Tier 2 Flowchart

4.2.1 Tier 2 Site-specific Parameter Variations

The following parameters significantly influence the calculation of Tier 2 SSTLs:

1. Fraction organic carbon, f_{oc}.
2. Depth to ground water.
3. Source area width.
4. Ground-water velocity.

1. *The fraction of organic carbon in the soils* is the total mass of organic carbon divided by a unit mass of soils. *Soil samples that are analyzed for fraction organic carbon must be collected outside the area of contamination.* This is because it is the carbon that occurs naturally in soils that influences how much hydrocarbon contamination leaches from the soils into the ground water. Collecting soils samples that are hydrocarbon-contaminated for the calculation of f_{oc} will result in underestimating the amount of contamination leaching into the ground water, which, in turn, will result in SSTLs that are much higher than they should be and the corresponding potential health risks will be miscalculated. Requirements for collection and analysis of soils samples to determine f_{oc} are similar to those for benzene, toluene, ethylbenzene and xylenes (BTEX) and other VOCs. The number of samples required to be collected to determine f_{oc} will be determined on a site-specific basis. The default value for saturated soils may be used instead of direct field measurement (Table 7).

Table 7. Laboratory Methods and Defaults for Determining Fraction Organic Carbon

Laboratory Method	Type of Analysis	Default f_{oc} Value
SW 846-9060	Carbonaceous analyzer	Unsaturated soil—0.01 Saturated soil—0.001
EPA 415.1	Catalytic combustion or wet chemical oxidation	
EPA 415.2	UV promoted persulfate oxidation	

2, 3. *Determination of depth to ground water and source area width* versus ground-water flow direction is done routinely as part of a hydrogeologic investigation at leaking underground storage tank sites in Delaware. Depth to ground water can be measured in wells with an oil/water interface probe. If measurable free-phase petroleum product is present, a correction must be calculated to determine the true depth to ground water. Then, after the wells are surveyed to a common datum, the measured depths are converted to water table

elevations, which are used to determine the direction of ground-water movement and calculate the hydraulic gradient.

4. *Ground-water flow velocity* is usually calculated as *seepage velocity*

$$v_s = Q/n_eA = Kdh/n_edl$$

where

v = seepage velocity
Q = discharge
n_e = effective porosity
A = cross-sectional area of flow
K = hydraulic conductivity
dh/dl = hydraulic gradient

Laboratory methods can be used to determine effective porosity or the ASTM RBCA default value of 0.38 may be used. Hydraulic conductivity can be determined by slug tests, pumping tests or certain laboratory tests.

Slug tests. Slug tests are easier to perform than pumping tests and require the use of only one well. Slug tests have the advantage of not generating large quantities of ground water that may be contaminated and must be disposed.

Slug tests reflect hydraulic conductivity only in the immediate vicinity of the tested well. Therefore, if slug tests are used to determine hydraulic conductivity, they should be conducted on more than one well to accurately reflect variations in conductivity across the site. Replicate tests on the same well may be performed for quality control purposes.

Pumping tests. Pumping tests involve removing ground water from a well at a known rate and measuring the drawdown of ground-water elevations in piezometers that are at known distances from the pumping well. Pumping continues until steady-state conditions are attained. Plots of time versus drawdown and distance versus drawdown are used to determine the hydraulic conductivity of the aquifer.

Pumping tests have the advantage of determining *in-situ* the average hydraulic conductivity for a large area of the aquifer. But typical monitoring wells at leaking underground storage tank sites are usually unsuitable for service as the pumped well in a pumping test because their screens are not completely in the saturated zone. A separate pumping well is usually required to serve as the pumped well.

Laboratory tests. Two laboratory tests that can be used to determine hydraulic conductivity are the:

- Constant Head Test (ASTM D2434).
- Standard Consolidation Test (ASTM D2435): Often preferred for silts or clays where hydraulic conductivity is less than 0.01 feet per day.

If a laboratory test is selected, one must make sure that all samples remain undisturbed from the time of sample collection in the field until the test is completed.

4.2.2 Tier 2 Soil Parameter Estimation Option

Hydraulic conductivity can be estimated using Table 8 for homogeneous, non-fractured clay, with no human disturbances. For all other soil types K must be measured or the Tier 1 default must be used. Soil classification must be done in accordance with the Unified Soil Classification System in order to accurately use Table 8.

Table 8. Estimation of Soil Parameters From USCS Soil Types

USCS SOIL TYPE		DEFAULT SOIL PARAMETERS			DEFAULT HYDRAULIC CONDUCTIVITY
SYMBOL	**DESCRIPTION**	θ_T	θ_{ws}	θ_{as}	**K (cm/s)[4]**
CL	CLAY, sandy, low plasticity	0.38	0.31	0.07	10^{-6}
CL	CLAY, silty, low plasticity	0.36	0.34	0.02	10^{-7}
CH	CLAY, high-plasticity	0.38	0.38	0	10^{-8}

Note:
1) Default values for total porosity (qT) volumetric water (qws) and volumetric air (qas) contents from Connor et al., (1997).
2) Typical saturated hydraulic conductivity values matched to median values reported by Freeze and Cherry (1979) and Rawls and Brakensiek (1985).
3) Unified Soil Classification System (USCS) described in Lambe et al (1969) and ASTM Standard D-2487.
4) K can be estimated using this table for homogeneous, non-fractured undisturbed clay, all other soil types must be measured or use the Tier 1 default parameter.

4.3 Risk and Concentration Limits

All concentration limits shown by SSTLs are calculated based on a cumulative risk of 1 x 10^{-5} for carcinogenic effects and a cumulative hazard quotient of 1.0 for non-carcinogenic effects. This is the same as for Tier 0 and Tier 1. It is for this reason that the exposure parameters (average volume of drinking water ingested per day, average length of exposure, etc.) used in DERBCAP, adopted from values determined by the U.S. EPA, may not be altered. Site-specific geologic inputs and specific distance to a POE are also factors used to develop SSTLs.

4.4 Data Evaluation and Response Options

SSTLs differ from RBSLs in that:

- site-specific soil and ground water parameters may be used in place of Tier 1 defaults and
- the POE type and location may be matched to actual site conditions.

In calculating SSTLs, site-specific data is substituted for the conservative generic assumptions of Tier 0 and Tier 1. This allows the margin of safety to decrease, while maintaining a constant level of protection against potential risks to public health. The Delaware module of the RBCA Toolkit (available from Groundwater Services, Inc., Houston, Texas) may be used to calculate SSTLs under DERBCAP. The Tier 1 assessment may screen out some COCs or pathways of concern prior to conducting the more detailed Tier 2 analysis.

Having performed a Tier 2 site assessment and scenario examination, a Responsible Party may:

- Not have to perform any further remediation if the concentrations of the COCs are less than the applicable SSTLs.
- Have to perform further remediation if the concentrations of the COCs are greater than the applicable SSTLs.

- Request permission from the Underground Storage Tank Branch to proceed with a Tier 3 site assessment.

Any point within a plume (such as a monitor well) where COC concentrations are greater than either Tier 1 RBSLs or Tier 2 SSTLs must be remediated.

For non-residential sites exposure factors in Appendix 3 may be used instead of the Tier 1 residential default values.

4.4.1 Tier 2 Modeling Options

In the risk assessment process, a model is used to predict the transport of specific chemicals of concern through a ground-water system using detailed, site-specific, hydrogeological information. Tier 2 modeling in DERBCAP may be appropriate for those chemicals of concern that have concentrations that exceed Tier 1 RBSLs. By demonstrating, through modeling, that a contaminant plume is stable or shrinking and will never reach a POE, a conditional no further action letter may be issued. If, however, the modeling provides insufficient evidence of plume stability and concentrations are above the SSTLs calculated in Tier 2, the site may be remediated to Tier 2 SSTLs or it may enter Tier 3, which involves detailed, three-dimensional, numerical modeling.

The purpose of modeling in Tier 2 of the RBCA process is to derive a conservative estimate of the natural reduction in COC concentrations occurring between the source and POE. This estimated "natural attenuation factor" can then be used to derive an SSTL value (RBCA Tool Kit) at the source location, which will prevent exceeding the applicable RBEL (Risk Based Exposure Level) limits at the POE. The natural attenuation factor for each applicable exposure pathway and COC may be estimated using appropriate fate-and-transport models.

Alternatively, empirical measurements may be used to show that the contaminants will never reach the POE. For example, time-series groundwater monitoring data may demonstrate that the affected ground-

water plume is in a stable or shrinking condition, in which case, POEs outside the current plume area will not be impacted. When available, such time-series data regarding plume stability is considered more reliable than fate-and-transport modeling. The quality of the field data is essential to the validity of the modeling effort. Unrepresentative data will result in unreliable modeling results.

There are several models available, some more involved than others, that all solve specific equations that form the basis of the model. Fate and transport models are the most prevalent and practical of the groundwater models. In hydrogeology, they are used to predict the distribution of chemicals, such as the Tier 1 COCs, through the sub-surface. Fate and transport models can be analytical or numerical. Analytical fate and transport models use mathematical solutions to governing equations that are continuous in space and time and are based on assumptions of uniform properties and regular geometry (ASTM, 1999). They require specific inputs and provide unique answers. Analytical models are generally fast and easy to solve, require less field data and therefore are usually good for quick field screening. Numerical models, on the other hand, can provide non-unique answers using various input data sets that require geological interpretation. They require more site-specific information and can take hours to solve more representative field conditions. Numerical models allow field conditions to vary in space and time, thus resulting in a better representation of the complex geology. Generally, in the RBCA process, more complex models require much more field data.

At Tier 2, the RP is afforded two modeling options. RBCA Toolkit, which is used to derive Site Specific Target Levels (SSTLs), and BIOSCREEN, which can be used to show that the contaminated plume is shrinking and will not reach a POE. The models may be used individually or together to accomplish the goals set out prior to modeling. The Tier 2 evaluation only applies to those exposure pathways (i.e., soil direct contact, soil leaching to ground water, and ground water ingestion) and those constituents that failed Tier 1.

The DERBCAP module of the RBCA Toolkit software (Ground Water Services, Inc.) is an analytical fate and transport model that allows the user to calculate site specific target levels or SSTLs. SSTLs are Tier 2 cleanup levels for the proper COCs and are based upon site-specific measurements, not the site conceptual model assumptions used in Tier 1.

BIOSCREEN is a two-dimensional, analytical, fate and transport model that models in the forward direction, that is, contaminant concentrations are predicted based on concentrations of a source. BIOSCREEN is most frequently used to simulate Remediation through Natural Attenuation (RNA). It predicts the migration of a contaminated plume if no engineering controls are implemented and answers how long the plume will last. Like the DERBCAP module, BIOSCREEN also requires the collection of site specific data and contains three modeling types: 1) solute transport without decay; 2) solute transport with biodegradation modeled as a first-order decay process; 3) solute transport with biodegradation modeled as an instantaneous reaction. BIOSCREEN is not useful for sites with a complicated flow system or for sites that require three-dimensional analysis. BIOSCREEN can be used to prove that a COC that fails the SSTLs will not spread and will never reach a POE over time. In certain circumstances, BIOSCREEN may also be used to derive SSTLs as long as it is specified when the RBEL goals need to be met at the POE. In other words, a certain concentration of chemical "X" can exist at the source as long as it is demonstrated, through effective modeling, that it will not reach the POE after "N" years. BIOSCREEN can be downloaded at no charge from the following EPA website:

http://www.epa.gov/ahaazvuc/bioscreen.html

After the additional Tier 2 site-specific data is gathered, a consultant will model the data and submit a report that includes the following:

- Purpose of the model
- Data input used in modeling
- Parameters changed during calibration runs

- Sensitivity analyses that were preformed
- Any maps that may be useful
- Conclusion and recommendations to the Department

The Department will consider additional modeling options that are publicly available on a site-specific basis. *Prior* to Tier 2 modeling, Departmental approval must be obtained to use such models.

5. TIER 3

One of the goals of any risk-based site assessment procedure is to prioritize sites so that available resources can be allocated to those sites requiring more attention. A successful procedure will provide for the distribution of the population of sites across all tiers.

Thus, Tier 0 will address a certain proportion of new tank removals or abandonments that are "clean." It is expected that more new tank removals or abandonments or existing LUST sites will be addressed under Tier 1 or Tier 2.

Tier 3 is provided for new tank removals or abandonments or existing LUST sites that cannot be adequately handled under the previous tiers because of extreme complexity of the site. The complexity may derive from extreme variability of the site's geology, an extensive or unusual suite of contaminants with complex interactions, which may require a cooperative approach with other environmental programs within the Department, or unusual temporal considerations.

A DERBCAP Tier 3 site assessment may not be performed without prior approval from the Underground Storage Tank Branch. The responsible party is responsible for developing the entire site investigation, assessment, data analysis and remediation workplan, including definition of all decision point criteria. Exposure factors may only be selected from those already defined by the U. S. EPA.

It is expected that a DERBCAP Tier 3 site assessment will include numerical computer modeling based on extensive site investigation, sampling, testing and analysis conducted under strict QA/QC and data validation procedures. Proprietary computer models may not be used.

Tier 3 is where alternative modeling or data evaluation methods that may serve to improve the risk-based site assessment are used. To refine the SSTL calculation, such alternative methods will require collection of

additional site data as needed to support use of more complex modeling methods and site-specific risk assessment. Under DERBCAP, alternative methods may only include models that DNREC is both trained in and owns. Any alternative method used in Tier 3 must receive approval from DNREC before it can be considered for use.

Visual-Modflow (Waterloo Hydrogeologic, Inc.) along with the MT3D fate and transport extension is capable of three-dimensional, numerical modeling. Visual-Modflow assumes the saturated zone can be heterogeneous and anisotropic and it can also manage cell by cell anisotropy for hydraulic conductivity. Visual-Modflow requires more site-specific field data and more time for calibration.

6. LABORATORY METHODS

Analyses of soils and ground-water samples collected for a DERBCAP site assessment must be performed in accordance with the methods listed below unless the acceptability of alternate methodologies can be established to the satisfaction of DNREC.

Table 9. Laboratory Analytical Methods

Analytes	EPA SW-846 Methods	EPA Drinking Water Methods	Primary Equipment	Sample Preparation [1]
TPHs	4030[2]		Immunoassay	Included in kit
PAHs	4035[2]		Immunoassay	Included in kit
Aliphatic and Aromatic Hydrocarbons; GRO DRO HRO	8015[3]		GC/FID	Extraction (SVOCs)[4]; Purge-and-Trap and Headspace (VOCs)[4];
Select VOCs	8021[3,5]/601/602	502.1/502.2	GC/ELCD/PID	Purge-and-Trap
VOCs EDC EDB	8260[6]/624	524.2	GC/MS	Purge-and-Trap; Azeotropic Distillation[4]
EDB	8011[7]	504	GC/ECD/ELCD	Micro-extraction
SVOCs/PAHs	8270/625	525, 550, 550.1	GC/MS	Extraction[4]
PAHs	8270/8310[8]	550, 550.1	GC/MS, High Performance Liquid Chromatography (HPLC)	Extraction[4]
Lead	6010, 6020 7000 Series	200 Series	ICP, ICP/MS FLAA, GFAA	Digestion[1]

Footnotes:

[1]These are the standard methods of preparation for the corresponding method. They may vary depending upon specific analytical needs.

[2] Can be used for a screening method for soils only. For carcinogenic PAH analysis, use the carcinogenic PAH kit.

[3]MTBE can be analyzed for with U.S. EPA SW-846 Method 8021, but this method is subject to interference in highly contaminated samples, and tends to be more economical than Method 8260 by providing BTEX data in the same analysis. Concerns about co-elution with some alkanes requires at least one confirmatory analysis with SW-846 Method 8260 per site.

[4]See Chapter 4 of SW-846 for specific appropriate methods.

[5]8021replaces 8010 and 8020.

[6]8260 replaces 8240.
[7]8011 has a lower MDL is for water/wastewater samples only.
[8]PAHs can be analyzed for with U.S. EPA SW-846 Method 8310, but this method is subject to interference in highly contaminated samples, and tends to be more economical than Method 8270. Concerns about interference requires at least one confirmatory analysis with SW-846 Method 8270 per site.

NOTE: This table adapted from Table B-1 in Appendix B of "Expedited Site Assessment Tools for Underground Storage Tank Sites: A Guide for Regulators" (EPA 510-B-97-001).

7. MANAGING FUTURE ENVIRONMENTAL AND HEALTH IMPACTS

For sites with COC concentrations below the Tier 1 RBSLs or the Tier 2 SSTLs and below 100 parts per million TPH-GRO and 1000 parts per million TPH-DRO, the residual petroleum contamination is considered a solid waste.

At sites with contaminated soils and ground water that meet the definition of solid waste, (1) excavated soils, (2) ground water, and (3) future land use changes will need to be managed to prevent impact to human health, safety and the environment and to comply with Delaware's *Regulations Governing Solid Waste*. Soils and ground water with petroleum odor, and petroleum-saturated soils are also a potential source of environmental and aesthetic impacts both on site and off site.

Soils and ground water that meet the definition of a solid waste must be managed as a solid waste *when disturbed by digging or excavating in the case of soil, or pumping of ground water.* Future changes to land use may change the risk based assumptions and corresponding clean up level under which the site was originally closed. Reassessment of clean up levels and management of residual contamination may be required when land use changes.

At these sites some type of institutional control may be needed to address future soil excavation and disposal and ground water use concerns (Table 10). Proper notification of future site users regarding soil excavation and disposal restrictions or restrictions on ground water use are needed to maintain the established DERBCAP risk management performance standards.

7.1 Administrative Institutional Controls

Administrative institutional controls include such Department actions as:

- Issuing a conditional NFA letter with a signed acknowledgement by the RP that limits or controls future activity in the area of residual petroleum contamination at a site, or
- Managing future ground water use in an area in or near residual ground water contamination by issuing water well permits with conditions on location, well construction and water use, or
- Facilitating private party due diligence through access to site files, and
- Maintaining a Geographic Information System (GIS) database with UST site positions accessible to public view through Department Internet links.

7.2 Formal Institutional Controls

There are two kinds of formal institutional controls. They are applied simultaneously:

- Ground water Management Zone
- Deed Restriction/Deed Notice

7.2.1 Ground-water Management Zone

Ground-water Management Zones (GMZs) are based on a Memorandum of Understanding concluded between the Division of Air and Waste Management (DAWM), Underground Storage Tank Branch, and the Division of Water Resources (DWR), Water Supply Branch. GMZs "run with the property" and can only be terminated by joint agreement of the UST Branch and DWR.

A GMZ is defined by the UST Branch and may be subdivided into sub-zones. For example, wells of all kinds may be prohibited in the most highly contaminated portion of an impacted site; depth-restricted, double-cased wells may be allowed in the next less contaminated sub-zone; and monitoring alone may be required in an outermost sub-zone.

The Point of Compliance (POC) is *any* boundary of the GMZ. If contaminant compliance concentrations are exceeded at any POC, then remedial action is required.

7.2.2 Deed Restriction/Deed Notice

A Deed Restriction (DR) or Deed Notice (DN) addresses residual contamination on a property. They "run with the property." It requires that anyone planning to disturb the residual contamination at any time in the future first seeks and receives approval from DNREC of a contaminated materials management plan.

DRs and DNs are filed with the Registrar of Deeds in each county. A tax parcel number for the property is needed to file a DR.

The UST Branch pre-approves the DR or DN for each property and the RP pays to have it registered and attached to the property's deed. The alternative to a DR or DN is that the RP will be required to clean up the property to Tier 0 concentrations of COCs.

Table 10. Options for Managing Future Environmental and Health Impacts

Tiers 1 and 2	• Administrative controls such as: 1. A conditional NFA letter with an acknowledgement, or 2. Management of future ground water use through water well permits with conditions
Tiers 2 and 3	• Formal Institutional Controls such as: 1. Deed restrictions/deed notices 2. Ground water management zones

APPENDIX 1. REFERENCES

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APPENDIX 2. FATE AND TRANSPORT PARAMETERS

PARAMETER	UNITS	TIER 1 DEFAULT VAULE		TIER 2 VALUE(1)
		ASTM	DERBCAP	
Site Parameters				
Lower depth of surficial soil zone	cm	100	60 (2 ft) (3)	D
Width of soil source area parallel to wind	cm	1500 (50 ft)	ASTM	SS
Width of soil source area parallel to groundwater flow	cm	1500 (50 ft)	ASTM	SS
Distance from plume "core" to POE	ft	0	0 - 50 ft 50 – 100 ft 100 – 300 ft 300 – 500 ft > 500 ft	SS
Ambient air mixing zone height	cm	200	ASTM	D
Wind speed above ground surface in ambient air mixing zone	cm/s	225	ASTM	D
Averaging time for vapor flux: -Resident and commercial worker -Construction worker	 s s	 9.46×10^{8} (30 yr) 3.15×10^{7} (1 yr)	 ASTM ASTM	 D D
Particulate emission factor (PEF): -Resident and commercial worker -Construction worker	 $g/cm^2/s$ $g/cm^2/s$	 6.0×10^{-14} 6.1×10^{-9}	 ASTM ASTM	 D D
Hydrogeologic Parameters				
Total soil porosity	cm^3/cm^3	0.38 (4)	ASTM	E
Volumetric air content in vadose zone soil	cm^3/cm^3	0.26	ASTM	E
Volumetric water content in vadose zone soil	cm^3/cm^3	0.12	ASTM	E
Soil bulk density	gm/cm^3	1.7	1.78 (5)	D
Fraction organic carbon in vadose zone soil	g/g	0.01	ASTM	D/SS
Infiltration rate of water in vadose zone	cm/yr	30	35 (6)	D
Groundwater mixing zone height	cm	200 (6.5ft)	ASTM	D
Groundwater Darcy velocity -Hydraulic conductivity -Hydraulic gradient	cm/yr cm/s cm/cm	2500 (82ft/yr) (8×10^{-3}) (0.01)	915 (30ft/yr) (7) (2.9×10^{-3}) (ASTM)	- E SS
Effective soil porosity	cm^3/cm^3	0.38	ASTM	E
Fraction organic carbon in groundwater zone	g/g	NA	0.001	D
Longitudinal dispersivity	cm	NA	0.1 x dist. to POE	D
Transverse dispersivity	cm	NA	0.33 x long. disp.	D
Vertical dispersivity	cm	NA	0.05 x long. disp.	D
Chemical-Specific Parameters				
Organic carbon partition coefficient	g/g	CS	CS	CS
First-order degradation rate	day^{-1}	CS	CS	CS

Notes:

1) Recommended sources for Tier 2 values:

   D = Use of DERBCAP Tier 1 default value is recommended for parameters which i) exhibit only a moderate degree of site-specific variability and ii) cannot be easily obtained on a site-specific basis;

   E = Use of default estimate based on soil type is recommended for parameters which i) exhibit only a moderate degree of variability within a particular soil type and ii) methods available to measure site-specific values are unlikely to be significantly more accurate than soil type estimates (Table 8 can be used to estimate these parameter values);

   SS = Use of site-specific measured values is recommended for parameters which i) exhibit a wide range of site-specific variability that may significantly impact model predictions and ii) are amenable to characterization based on limited site-specific measurements;

   CS = Parameter value is chemical-specific and should be taken from appropriate literature sources.

2) POE = Point of Exposure;
   NA = Not applicable.

3) DERBCAP Tier 1 default for lower depth of surfical soil zone based on SIRB remediation standard guidance.

4) ASTM Tier 1 default for total soil porosity based on 150 ft/day permeability of clean sand.

5) DERBCAP Tier 1 default for soil bulk density based on 1.5 $tons/yd^3$.

6) DERBCAP Tier 1 default for infiltration rate of water through vadose zone based on DGS state average of 14 inches infiltration and 44 inches total precipitation.

7) DERBCAP Tier 1 default for groundwater Darcy velocity based on groundwater seepage velocity of 79 ft/yr.

APPENDIX 3: STANDARD EXPOSURE ASSUMPTIONS

EXPOSURE FACTORS	UNITS	ASTM/DERBCAP TIER 1 DEFAULT VALUE
Averaging time – carcinogens (AT_c)	yr	70
Averaging time – non-carcinogens (AT_n)	yr	
-On-site commercial worker		25
-On/off-site resident (adult)		30
-On/off-site resident (child)		6
-Construction worker		1
Body weight (BW)	kg	
-Adult receptors		70
-Child receptors		15
Exposure duration (ED)	yr	
-On-site commercial worker		25
-On/off-site resident (adult)		30
-On/off-site resident (child)		6
-Construction worker	yr	1
Exposure frequency (EF)	days/yr	
-On/off-site commercial worker		250
-On/off-site residents		350
-Construction worker		183
Soil Ingestion rate (IR_{soil})	mg/day	
-On-site commercial worker		50
-On/off-site resident (adult)		100
-On/off-site resident (child)		200
-Construction worker		100
Daily water ingestion rate (IR_w)	L/day	
-On/off-site resident (adult)		2
-On/off-site resident (child)		1
-Construction worker		1
Soil-skin adherence factor (M)	mg/cm^2	0.5
Oral relative absorption factor (RAF_o)	---	1
Dermal relative absorption factor (RAF_d)	---	
-Volatiles		0.5
-PAHs		0.05

APPENDIX 4. EXPOSURE PATHWAY CALCULATION SHEETS

RBCA Tool Kit for Chemical Releases, Version 1.0

RBCA SITE ASSESSMENT — Input Parameter Summary

Site Name: DERBCAP Tier 1 RBSL Calculations
Site Location: Dist. to POE = 0, 50, 100 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

Exposure Parameters		Residential			Commercial/Industrial	
		Adult	(1-6yrs)	(1-16 yrs)	Chronic	Construc.
AT_c	Averaging time for carcinogens (yr)	70				
AT_n	Averaging time for non-carcinogens (yr)	30			25	1
BW	Body weight (kg)	70	15	35	70	
ED	Exposure duration (yr)	30	6	16	25	1
τ	Averaging time for vapor flux (yr)	30			25	1
EF	Exposure frequency (days/yr)	350			250	180
EF_D	Exposure frequency for dermal exposure	350			250	
IR_w	Ingestion rate of water (L/day)	2			1	
IR_s	Ingestion rate of soil (mg/day)	100	200		50	100
SA	Skin surface area (dermal) (cm^2)	5800		2023	5800	5800
M	Soil to skin adherence factor	1				
ET_{swim}	Swimming exposure time (hr/event)	3				
EV_{swim}	Swimming event frequency (events/yr)	12	12	12		
IR_{swim}	Water ingestion while swimming (L/hr)	0.05	0.5			
SA_{swim}	Skin surface area for swimming (cm^2)	23000		8100		
IR_{fish}	Ingestion rate of fish (kg/yr)	0.025				
FI_{fish}	Contaminated fish fraction (unitless)	1				

Complete Exposure Pathways and Receptors	On-site	Off-site 1	Off-site 2
Groundwater:			
Groundwater Ingestion	Residential	Residential	Residential
Soil Leaching to Groundwater Ingestion	Residential	Residential	Residential
Applicable Surface Water Exposure Routes:			
Swimming			NA
Fish Consumption			NA
Aquatic Life Protection			NA
Soil:			
Direct Ingestion and Dermal Contact	Residential		
Outdoor Air:			
Particulates from Surface Soils	Residential	None	None
Volatilization from Soils	Residential	None	None
Volatilization from Groundwater	None	None	None
Indoor Air:			
Volatilization from Subsurface Soils	None	NA	NA
Volatilization from Groundwater	None	NA	NA

Receptor Distance from Source Media	On-site	Off-site 1	Off-site 2	(Units)
Groundwater receptor	0	50	100	(ft)
Soil leaching to groundwater receptor	0	50	100	(ft)
Outdoor air inhalation receptor	0	NA	NA	(ft)

Target Health Risk Values		Individual	Cumulative
TR_{ab}	Target Risk (class A&B carcinogens)	1.0E-5	1.0E-5
TR_c	Target Risk (class C carcinogens)	1.0E-5	
THQ	Target Hazard Quotient (non-carcinogenic risk)	1.0E+0	1.0E+0

Modeling Options	
RBCA tier	Tier 2
Outdoor air volatilization model	Surface & subsurface models
Indoor air volatilization model	NA
Soil leaching model	Delaware submergence model
Use soil attenuation model (SAM) for leachate?	No
Air dilution factor	NA
Groundwater dilution-attenuation factor	Domenico model w/ biodeg.

Delaware Soil Submergence Model Parameters		Value	(Units)
θ_N	Residual NAPL content in submerged soils	3.0E-2	(-)
f	Water table fluctuation cycles per year	1.0E+0	(1/yr)
t_{HU}	Duration of high water table condition	1.2E+2	(d)

NOTE: NA = Not applicable

Surface Parameters		General	Construction	(Units)
A	Source zone area	2.4E+3	NA	(ft^2)
W	Length of source-zone area parallel to wind	4.9E+1	NA	(ft)
W_{gw}	Length of source-zone area parallel to GW flow	4.9E+1		(ft)
U_{air}	Ambient air velocity in mixing zone	6.4E+5		(ft/d)
δ_{air}	Air mixing zone height	6.6E+0		(ft)
P_a	Areal particulate emission rate	6.9E-14		(g/cm^2/s)
L_{ss}	Thickness of affected surface soils	2.0E+0		(ft)

Surface Soil Column Parameters		Value			(Units)
h_{cap}	Capillary zone thickness	NA			(ft)
h_v	Vadose zone thickness	NA			(ft)
ρ_s	Soil bulk density	1.8E+0			(g/cm^3)
f_{oc}	Fraction organic carbon	1.0E-2			(-)
θ_T	Soil total porosity	3.8E-1			(-)
K_{vs}	Vertical hydraulic conductivity	1.0E+4			(ft/yr)
k_v	Vapor permeability	1.1E-11			(ft^2)
L_{gw}	Depth to groundwater	9.8E+0			(ft)
L_s	Depth to top of affected soils	0.0E+0			(ft)
L_{base}	Depth to base of affected soils	9.8E+0			(ft)
L_{subs}	Thickness of affected soils	9.8E+0			(ft)
pH	Soil/groundwater pH	6.8E+0			(-)
		capillary	vadose	foundation	
θ_w	Volumetric water content	0.342	0.12	0.12	(-)
θ_a	Volumetric air content	0.038	0.26	0.26	(-)

Building Parameters		Residential	Commercial	(Units)
L_b	Building volume/area ratio	NA	NA	(ft)
A_b	Foundation area	NA	NA	(cm^2)
X_{crk}	Foundation perimeter	NA	NA	(ft)
ER	Building air exchange rate	NA	NA	(1/d)
L_{crk}	Foundation thickness	NA	NA	(ft)
Z_{crk}	Depth to bottom of foundation slab	NA	NA	(ft)
η	Foundation crack fraction	NA	NA	(-)
dP	Indoor/outdoor differential pressure	NA	NA	(g/cm/s^2)
Q_s	Convective air flow through slab	NA	NA	(ft^3/d)

Groundwater Parameters		Value	(Units)
δ_{gw}	Groundwater mixing zone depth	6.6E+0	(ft)
I_f	Net groundwater infiltration rate	1.4E+1	(in/yr)
U_{gw}	Groundwater Darcy velocity	3.0E+1	(ft/yr)
V_{gw}	Groundwater seepage velocity	7.9E+1	(ft/yr)
K_s	Saturated hydraulic conductivity	NA	(ft/yr)
i	Groundwater gradient	NA	(-)
S_w	Width of groundwater source zone	4.9E+1	(ft)
S_d	Depth of groundwater source zone	6.6E+0	(ft)
θ_{eff}	Effective porosity in water-bearing unit	NA	(-)
$f_{oc\text{-}sat}$	Fraction organic carbon in water-bearing unit	1.0E-3	(-)
pH_{sat}	Groundwater pH	6.2E+0	(-)
	Biodegradation considered?	1st Order	

Transport Parameters		Off-site 1	Off-site 2	Off-site 1	Off-site 2	(Units)
Lateral Groundwater Transport		Groundwater Ingestion		Soil Leaching to GW		
α_x	Longitudinal dispersivity	5.0E+0	1.0E+1	5.0E+0	1.0E+1	(ft)
α_y	Transverse dispersivity	1.7E+0	3.3E+0	1.7E+0	3.3E+0	(ft)
α_z	Vertical dispersivity	2.5E-1	5.0E-1	2.5E-1	5.0E-1	(ft)
Lateral Outdoor Air Transport		Soil to Outdoor Air Inhal.		GW to Outdoor Air Inhal.		
σ_y	Transverse dispersion coefficient	NA	NA	NA	NA	(ft)
σ_z	Vertical dispersion coefficient	NA	NA	NA	NA	(ft)
ADF	Air dispersion factor	NA	NA	NA	NA	(-)

Surface Water Parameters		Off-site 2	(Units)
Q_{sw}	Surface water flowrate	NA	(ft^3/d)
W_{pl}	Width of GW plume at SW discharge	NA	(ft)
δ_{pl}	Thickness of GW plume at SW discharge	NA	(ft)
DF_{sw}	Groundwater-to-surface water dilution factor	NA	(-)

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations | Completed By: Groundwater Services, Inc. | Job ID: G-2227

Site Location: Dist. to POE = 0, 50, 100 ft. | Date Completed: 8-Oct-99 | 1 OF 1

SOIL (0 - 9.8 ft) SSTL VALUES

Target Risk (Class A & B) 1.0E-6
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - First Order (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Soil Leaching to Groundwater Ingestion			Soil Vol. to Indoor Air	X Soil Volatilization and Surface Soil Particulates to Outdoor Air				X Surface Soil Inhalation, Ingestion,Dermal Contact		Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (50 ft)	Off-site 2 (100 ft)	On-site (0 ft)	On-site (0 ft)		Off-site 1 (0 ft)	Off-site 2 (0 ft)	On-site (0 ft)				Only if □yes □ left
CAS No.	Name	(mg/kg)	Residential	Residential	Residential	None	Residential	Construction Worker	None	None	Residential	Construction Worker	(mg/kg)	"■" if yes	
71-43-2	Benzene		2.3E-1	4.0E-1	1.2E+0	NA	1.6E+2	NA	NA	NA	1.9E+1	NA	2.3E-1	□	NA
108-88-3	Toluene		2.1E+2	>7.5E+2	>7.5E+2	NA	>7.5E+2	NA	NA	NA	3.8E+3	NA	2.1E+2	□	NA
100-41-4	Ethylbenzene		3.5E+2	>6.3E+2	>6.3E+2	NA	>6.3E+2	NA	NA	NA	2.3E+3	NA	3.5E+2	□	NA
1330-20-7	Xylene (mixed isomers)		>5.0E+2	>5.0E+2	>5.0E+2	NA	>5.0E+2	NA	NA	NA	4.4E+4	NA	4.4E+4	□	NA
98-82-8	Cumene		>8.2E+0	>8.2E+0	>8.2E+0	NA	>8.2E+0	NA	NA	NA	1.9E+3	NA	1.9E+3	□	NA
1634-04-4	Methyl t-Butyl ether		2.5E-1	3.3E-1	7.8E-1	NA	>9.2E+3	NA	NA	NA	2.0E+2	NA	2.5E-1	□	NA
107-06-2	Dichloroethane, 1,2-		2.1E-2	4.8E-2	1.9E-1	NA	5.0E+1	NA	NA	NA	6.1E+0	NA	2.1E-2	□	NA
106-93-4	Dibromoethane, 1,2-		7.9E-5	5.6E-4	5.1E-3	NA	5.9E+0	NA	NA	NA	5.2E-3	NA	7.9E-5	□	NA
56-55-3	Benzo(a)Anthracene		>7.9E+1	>7.9E+1	>7.9E+1	NA	>7.9E+1	NA	NA	NA	5.5E+0	NA	5.5E+0	□	NA
50-32-8	Benzo(a)Pyrene		>1.7E+1	>1.7E+1	>1.7E+1	NA	2.6E+0	NA	NA	NA	5.5E-1	NA	5.5E-1	□	NA
205-99-2	Benzo(b)Fluoranthene		>8.1E+1	>8.1E+1	>8.1E+1	NA	1.5E+1	NA	NA	NA	5.5E+0	NA	5.5E+0	□	NA
207-08-9	Benzo(k)Fluoranthene		>2.4E+1	>2.4E+1	>2.4E+1	NA	>2.4E+1	NA	NA	NA	5.5E+1	NA	5.5E+1	□	NA
218-01-9	Chrysene		>3.6E+0	>3.6E+0	>3.6E+0	NA	>3.6E+0	NA	NA	NA	3.5E+0	NA	3.5E+0	□	NA
193-39-5	Indeno(1,2,3,c,d)Pyrene		5.2E+2	>2.1E+4	>2.1E+4	NA	>2.1E+4	NA	NA	NA	5.5E+0	NA	5.5E+0	□	NA
83-32-9	Acenaphthene		>2.8E+2	>2.8E+2	>2.8E+2	NA	NC	NA	NA	NA	NC	NA	>2.8E+2	□	NA
120-12-7	Anthracene		>6.4E+0	>6.4E+0	>6.4E+0	NA	NC	NA	NA	NA	NC	NA	>6.4E+0	□	NA
206-44-0	Fluoranthene		>7.8E+1	>7.8E+1	>7.8E+1	NA	NC	NA	NA	NA	NC	NA	>7.8E+1	□	NA
86-73-7	Fluorene		>1.2E+2	>1.2E+2	>1.2E+2	NA	NC	NA	NA	NA	NC	NA	>1.2E+2	□	NA
91-20-3	Naphthalene		>6.2E+2	>6.2E+2	>6.2E+2	NA	>6.2E+2	NA	NA	NA	5.9E+4	NA	5.9E+4	□	NA
85-01-8	Phenanthrene		>2.3E+2	>2.3E+2	>2.3E+2	NA	NC	NA	NA	NA	NC	NA	>2.3E+2	□	NA
129-00-0	Pyrene		>6.1E+1	>6.1E+1	>6.1E+1	NA	NC	NA	NA	NA	NC	NA	>6.1E+1	□	NA

">" indicates risk-based target concentration greater than constituent residual saturation value. NA = Not applicable. NC = Not calculated.

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations | Completed By: Groundwater Services, Inc. | Job ID: G-2227

Site Location: Dist. to POE = 0, 50, 100 ft. | Date Completed: 8-Oct-99 | 1 OF 1

GROUNDWATER SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - First Order (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Groundwater Ingestion			GW Vol. to Indoor Air	Groundwater Volatilization to Outdoor Air			Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (50 ft)	Off-site 2 (100 ft)	On-site (0 ft)	On-site (0 ft)	Off-site 1 (0 ft)	Off-site 2 (0 ft)			Only if □yes□
CAS No.	Name	(mg/L)	Residential	Residential	Residential	None	None	None	None	(mg/L)	"■" if yes	left
71-43-2	Benzene		2.9E-2	5.1E-2	1.6E-1	NA	NA	NA	NA	2.9E-2	□	NA
108-88-3	Toluene		7.3E+0	>5.2E+2	>5.2E+2	NA	NA	NA	NA	7.3E+0	□	NA
100-41-4	Ethylbenzene		3.7E+0	2.4E+1	>1.7E+2	NA	NA	NA	NA	3.7E+0	□	NA
1330-20-7	Xylene (mixed isomers)		7.3E+1	>2.0E+2	>2.0E+2	NA	NA	NA	NA	7.3E+1	□	NA
98-82-8	Cumene		3.7E+0	>5.0E+1	>5.0E+1	NA	NA	NA	NA	3.7E+0	□	NA
1634-04-4	Methyl t-Butyl ether		3.7E-1	4.8E-1	1.1E+0	NA	NA	NA	NA	3.7E-1	□	NA
107-06-2	Dichloroethane, 1,2-		9.4E-3	2.1E-2	8.1E-2	NA	NA	NA	NA	9.4E-3	□	NA
106-93-4	Dibromoethane, 1,2-		1.0E-5	7.1E-5	6.4E-4	NA	NA	NA	NA	1.0E-5	□	NA
56-55-3	Benzo(a)Anthracene		1.2E-3	>5.7E-3	>5.7E-3	NA	NA	NA	NA	1.2E-3	□	NA
50-32-8	Benzo(a)Pyrene		1.2E-4	>1.6E-3	>1.6E-3	NA	NA	NA	NA	1.2E-4	□	NA
205-99-2	Benzo(b)Fluoranthene		1.2E-3	>1.5E-2	>1.5E-2	NA	NA	NA	NA	1.2E-3	□	NA
207-08-9	Benzo(k)Fluoranthene		>4.3E-3	>4.3E-3	>4.3E-3	NA	NA	NA	NA	>4.3E-3	□	NA
218-01-9	Chrysene		7.4E-4	>1.8E-3	>1.8E-3	NA	NA	NA	NA	7.4E-4	□	NA
193-39-5	Indeno(1,2,3,c,d)Pyrene		1.2E-3	>6.2E-2	>6.2E-2	NA	NA	NA	NA	1.2E-3	□	NA
83-32-9	Acenaphthene		2.2E+0	>3.9E+0	>3.9E+0	NA	NA	NA	NA	2.2E+0	□	NA
120-12-7	Anthracene		>4.5E-2	>4.5E-2	>4.5E-2	NA	NA	NA	NA	>4.5E-2	□	NA
206-44-0	Fluoranthene		>2.1E-1	>2.1E-1	>2.1E-1	NA	NA	NA	NA	>2.1E-1	□	NA
86-73-7	Fluorene		1.5E+0	>1.7E+0	>1.7E+0	NA	NA	NA	NA	1.5E+0	□	NA
91-20-3	Naphthalene		1.5E+1	>3.1E+1	>3.1E+1	NA	NA	NA	NA	1.5E+1	□	NA
85-01-8	Phenanthrene		1.1E+0	>1.6E+0	>1.6E+0	NA	NA	NA	NA	1.1E+0	□	NA
129-00-0	Pyrene		>1.6E-1	>1.6E-1	>1.6E-1	NA	NA	NA	NA	>1.6E-1	□	NA

">" indicates risk-based target concentration greater than constituent solubility value. NA = Not applicable. NC = Not calculated.

APPENDIX 4. EXPOSURE PATHWAY CALCULATION SHEETS *(cont'd)*

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT — Input Parameter Summary

Site Name: DERBCAP Tier 1 RBSL Calculations
Site Location: Dist. to POE = 300, 500 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

1 OF 1

Exposure Parameters		Residential			Commercial/Industrial	
		Adult	(1-6yrs)	(1-16 yrs)	Chronic	Construc.
AT_c	Averaging time for carcinogens (yr)	70				
AT_n	Averaging time for non-carcinogens (yr)	30			25	1
BW	Body weight (kg)	70	15	35	70	
ED	Exposure duration (yr)	30	6	16	25	1
τ	Averaging time for vapor flux (yr)	30			25	1
EF	Exposure frequency (days/yr)	350			250	180
EF_D	Exposure frequency for dermal exposure	350			250	
IR_w	Ingestion rate of water (L/day)	2			1	
IR_s	Ingestion rate of soil (mg/day)	100	200		50	100
SA	Skin surface area (dermal) (cm^2)	5800		2023	5800	5800
M	Soil to skin adherence factor	1				
ET_{swim}	Swimming exposure time (hr/event)	3				
EV_{swim}	Swimming event frequency (events/yr)	12	12	12		
IR_{swim}	Water ingestion while swimming (L/hr)	0.05	0.5			
SA_{swim}	Skin surface area for swimming (cm^2)	23000		8100		
IR_{fish}	Ingestion rate of fish (kg/yr)	0.025				
FI_{fish}	Contaminated fish fraction (unitless)	1				

Complete Exposure Pathways and Receptors	On-site	Off-site 1	Off-site 2
Groundwater:			
Groundwater Ingestion	None	Residential	Residential
Soil Leaching to Groundwater Ingestion	None	Residential	Residential
Applicable Surface Water Exposure Routes:			
Swimming			NA
Fish Consumption			NA
Aquatic Life Protection			NA
Soil:			
Direct Ingestion and Dermal Contact	None		
Outdoor Air:			
Particulates from Surface Soils	None	None	None
Volatilization from Soils	None	None	None
Volatilization from Groundwater	None	None	None
Indoor Air:			
Volatilization from Subsurface Soils	None	NA	NA
Volatilization from Groundwater	None	NA	NA

Receptor Distance from Source Media	On-site	Off-site 1	Off-site 2	(Units)
Groundwater receptor	NA	300	500	(ft)
Soil leaching to groundwater receptor	NA	300	500	(ft)
Outdoor air inhalation receptor	NA	NA	NA	(ft)

Target Health Risk Values		Individual	Cumulative
TR_{ab}	Target Risk (class A&B carcinogens)	1.0E-5	1.0E-5
TR_c	Target Risk (class C carcinogens)	1.0E-5	
THQ	Target Hazard Quotient (non-carcinogenic risk)	1.0E+0	1.0E+0

Modeling Options	
RBCA tier	Tier 2
Outdoor air volatilization model	NA
Indoor air volatilization model	NA
Soil leaching model	Delaware submergence model
Use soil attenuation model (SAM) for leachate?	No
Air dilution factor	NA
Groundwater dilution-attenuation factor	Domenico model w/ biodeg.

Delaware Soil Submergence Model Parameters		Value	(Units)
θ_N	Residual NAPL content in submerged soils	3.0E-2	(-)
f	Water table fluctuation cycles per year	1.0E+0	(1/yr)
t_{hU}	Duration of high water table condition	1.2E+2	(d)

NOTE: NA = Not applicable

Surface Parameters		General	Construction	(Units)
A	Source zone area	NA	NA	(ft^2)
W	Length of source-zone area parallel to wind	NA	NA	(ft)
W_{gw}	Length of source-zone area parallel to GW flow	4.9E+1		(ft)
U_{air}	Ambient air velocity in mixing zone	NA		(ft/d)
δ_{air}	Air mixing zone height	NA		(ft)
P_a	Areal particulate emission rate	NA		(g/cm^2/s)
L_{ss}	Thickness of affected surface soils	NA		(ft)

Surface Soil Column Parameters		Value			(Units)
h_{cap}	Capillary zone thickness	NA			(ft)
h_v	Vadose zone thickness	NA			(ft)
ρ_s	Soil bulk density	1.8E+0			(g/cm^3)
f_{oc}	Fraction organic carbon	1.0E-2			(-)
θ_T	Soil total porosity	3.8E-1			(-)
K_{vs}	Vertical hydraulic conductivity	1.0E+4			(ft/yr)
k_v	Vapor permeability	1.1E-11			(ft^2)
L_{gw}	Depth to groundwater	9.8E+0			(ft)
L_s	Depth to top of affected soils	NA			(ft)
L_{base}	Depth to base of affected soils	NA			(ft)
L_{subs}	Thickness of affected soils	NA			(ft)
pH	Soil/groundwater pH	6.8E+0			(-)
		capillary	vadose	foundation	
θ_w	Volumetric water content	0.342	0.12	0.12	(-)
θ_a	Volumetric air content	0.038	0.26	0.26	(-)

Building Parameters		Residential	Commercial	(Units)
L_b	Building volume/area ratio	NA	NA	(ft)
A_b	Foundation area	NA	NA	(cm^2)
X_{crk}	Foundation perimeter	NA	NA	(ft)
ER	Building air exchange rate	NA	NA	(1/d)
L_{crk}	Foundation thickness	NA	NA	(ft)
Z_{crk}	Depth to bottom of foundation slab	NA	NA	(ft)
η	Foundation crack fraction	NA	NA	(-)
dP	Indoor/outdoor differential pressure	NA	NA	(g/cm/s^2)
Q_s	Convective air flow through slab	NA	NA	(ft^3/d)

Groundwater Parameters		Value	(Units)
δ_{gw}	Groundwater mixing zone depth	6.6E+0	(ft)
I_f	Net groundwater infiltration rate	1.4E+1	(in/yr)
U_{gw}	Groundwater Darcy velocity	3.0E+1	(ft/yr)
V_{gw}	Groundwater seepage velocity	7.9E+1	(ft/yr)
K_s	Saturated hydraulic conductivity	NA	(ft/yr)
i	Groundwater gradient	NA	(-)
S_w	Width of groundwater source zone	4.9E+1	(ft)
S_d	Depth of groundwater source zone	6.6E+0	(ft)
θ_{eff}	Effective porosity in water-bearing unit	NA	(-)
$f_{oc\text{-}sat}$	Fraction organic carbon in water-bearing unit	1.0E-3	(-)
pH_{sat}	Groundwater pH	6.2E+0	(-)
	Biodegradation considered?	1st Order	

Transport Parameters		Off-site 1	Off-site 2	Off-site 1	Off-site 2	(Units)
Lateral Groundwater Transport		Groundwater Ingestion		Soil Leaching to GW		
α_x	Longitudinal dispersivity	3.0E+1	5.0E+1	3.0E+1	5.0E+1	(ft)
α_y	Transverse dispersivity	9.9E+0	1.7E+1	9.9E+0	1.7E+1	(ft)
α_z	Vertical dispersivity	1.5E+0	2.5E+0	1.5E+0	2.5E+0	(ft)
Lateral Outdoor Air Transport		Soil to Outdoor Air Inhal.		GW to Outdoor Air Inhal.		
σ_y	Transverse dispersion coefficient	NA	NA	NA	NA	(ft)
σ_z	Vertical dispersion coefficient	NA	NA	NA	NA	(ft)
ADF	Air dispersion factor	NA	NA	NA	NA	(-)

Surface Water Parameters		Off-site 2	(Units)
Q_{sw}	Surface water flowrate	NA	(ft^3/d)
W_{pl}	Width of GW plume at SW discharge	NA	(ft)
δ_{pl}	Thickness of GW plume at SW discharge	NA	(ft)
DF_{sw}	Groundwater-to-surface water dilution factor	NA	(-)

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations | Completed By: Groundwater Services, Inc. | Job ID: G-2227

Site Location: Dist. to POE = 300, 500 ft. | Date Completed: 8-Oct-99 | 1 OF 1

SOIL (0 - 9.8 ft) SSTL VALUES

Target Risk (Class A & B) 1.0E-6
Target Risk (Class C) 1.0E-6
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - First Order (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Soil Leaching to Groundwater Ingestion			Soil Vol. to Indoor Air	Soil Volatilization and Surface Soil Particulates to Outdoor Air				Surface Soil Ingestion and Dermal Contact		Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (300 ft)	Off-site 2 (500 ft)	On-site (0 ft)	On-site (0 ft)		Off-site 1 (0 ft)	Off-site 2 (0 ft)	On-site (0 ft)				Only if □yes □ left
CAS No.	Name	(mg/kg)	None	Residential	Residential	None	None	Construction Worker	None	None	None	Construction Worker	(mg/kg)	"■" if yes	
71-43-2	Benzene		NA	2.3E+1	1.5E+2	NA	NA	NA	NA	NA	NA	NA	2.3E+1	□	NA
108-88-3	Toluene		NA	>7.5E+2	>7.5E+2	NA	NA	NA	NA	NA	NA	NA	>7.5E+2	□	NA
100-41-4	Ethylbenzene		NA	>6.3E+2	>6.3E+2	NA	NA	NA	NA	NA	NA	NA	>6.3E+2	□	NA
1330-20-7	Xylene (mixed isomers)		NA	>5.0E+2	>5.0E+2	NA	NA	NA	NA	NA	NA	NA	>5.0E+2	□	NA
98-82-8	Cumene		NA	>8.2E+0	>8.2E+0	NA	NA	NA	NA	NA	NA	NA	>8.2E+0	□	NA
1634-04-4	Methyl t-Butyl ether		NA	5.8E+0	1.6E+1	NA	NA	NA	NA	NA	NA	NA	5.8E+0	□	NA
107-06-2	Dichloroethane, 1,2-		NA	7.2E+0	7.6E+1	NA	NA	NA	NA	NA	NA	NA	7.2E+0	□	NA
106-93-4	Dibromoethane, 1,2-		NA	2.0E+0	1.0E+2	NA	NA	NA	NA	NA	NA	NA	2.0E+0	□	NA
56-55-3	Benzo(a)Anthracene		NA	>7.9E+1	>7.9E+1	NA	NA	NA	NA	NA	NA	NA	>7.9E+1	□	NA
50-32-8	Benzo(a)Pyrene		NA	>1.7E+1	>1.7E+1	NA	NA	NA	NA	NA	NA	NA	>1.7E+1	□	NA
205-99-2	Benzo(b)Fluoranthene		NA	>8.1E+1	>8.1E+1	NA	NA	NA	NA	NA	NA	NA	>8.1E+1	□	NA
207-08-9	Benzo(k)Fluoranthene		NA	>2.4E+1	>2.4E+1	NA	NA	NA	NA	NA	NA	NA	>2.4E+1	□	NA
218-01-9	Chrysene		NA	>3.6E+0	>3.6E+0	NA	NA	NA	NA	NA	NA	NA	>3.6E+0	□	NA
193-39-5	Indeno(1,2,3,c,d)Pyrene		NA	>2.1E+4	>2.1E+4	NA	NA	NA	NA	NA	NA	NA	>2.1E+4	□	NA
83-32-9	Acenaphthene		NA	>2.8E+2	>2.8E+2	NA	NA	NA	NA	NA	NA	NA	>2.8E+2	□	NA
120-12-7	Anthracene		NA	>6.4E+0	>6.4E+0	NA	NA	NA	NA	NA	NA	NA	>6.4E+0	□	NA
206-44-0	Fluoranthene		NA	>7.8E+1	>7.8E+1	NA	NA	NA	NA	NA	NA	NA	>7.8E+1	□	NA
86-73-7	Fluorene		NA	>1.2E+2	>1.2E+2	NA	NA	NA	NA	NA	NA	NA	>1.2E+2	□	NA
91-20-3	Naphthalene		NA	>6.2E+2	>6.2E+2	NA	NA	NA	NA	NA	NA	NA	>6.2E+2	□	NA
85-01-8	Phenanthrene		NA	>2.3E+2	>2.3E+2	NA	NA	NA	NA	NA	NA	NA	>2.3E+2	□	NA
129-00-0	Pyrene		NA	>6.1E+1	>6.1E+1	NA	NA	NA	NA	NA	NA	NA	>6.1E+1	□	NA

">" indicates risk-based target concentration greater than constituent residual saturation value. NA = Not applicable. NC = Not calculated.

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations | Completed By: Groundwater Services, Inc. | Job ID: G-2227

Site Location: Dist. to POE = 300, 500 ft. | Date Completed: 8-Oct-99 | 1 OF 1

GROUNDWATER SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - First Order (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Groundwater Ingestion			GW Vol. to Indoor Air	Groundwater Volatilization to Outdoor Air			Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (300 ft)	Off-site 2 (500 ft)	On-site (0 ft)	On-site (0 ft)	Off-site 1 (0 ft)	Off-site 2 (0 ft)			Only if □yes□
CAS No.	Name	(mg/L)	None	Residential	Residential	None	None	None	None	(mg/L)	"■" if yes	left
71-43-2	Benzene		NA	3.0E+0	1.9E+1	NA	NA	NA	NA	3.0E+0	□	NA
108-88-3	Toluene		NA	>5.2E+2	>5.2E+2	NA	NA	NA	NA	>5.2E+2	□	NA
100-41-4	Ethylbenzene		NA	>1.7E+2	>1.7E+2	NA	NA	NA	NA	>1.7E+2	□	NA
1330-20-7	Xylene (mixed isomers)		NA	>2.0E+2	>2.0E+2	NA	NA	NA	NA	>2.0E+2	□	NA
98-82-8	Cumene		NA	>5.0E+1	>5.0E+1	NA	NA	NA	NA	>5.0E+1	□	NA
1634-04-4	Methyl t-Butyl ether		NA	8.4E+0	2.3E+1	NA	NA	NA	NA	8.4E+0	□	NA
107-06-2	Dichloroethane, 1,2-		NA	3.1E+0	3.3E+1	NA	NA	NA	NA	3.1E+0	□	NA
106-93-4	Dibromoethane, 1,2-		NA	2.5E-1	1.3E+1	NA	NA	NA	NA	2.5E-1	□	NA
56-55-3	Benzo(a)Anthracene		NA	>5.7E-3	>5.7E-3	NA	NA	NA	NA	>5.7E-3	□	NA
50-32-8	Benzo(a)Pyrene		NA	>1.6E-3	>1.6E-3	NA	NA	NA	NA	>1.6E-3	□	NA
205-99-2	Benzo(b)Fluoranthene		NA	>1.5E-2	>1.5E-2	NA	NA	NA	NA	>1.5E-2	□	NA
207-08-9	Benzo(k)Fluoranthene		NA	>4.3E-3	>4.3E-3	NA	NA	NA	NA	>4.3E-3	□	NA
218-01-9	Chrysene		NA	>1.8E-3	>1.8E-3	NA	NA	NA	NA	>1.8E-3	□	NA
193-39-5	Indeno(1,2,3,c,d)Pyrene		NA	>6.2E-2	>6.2E-2	NA	NA	NA	NA	>6.2E-2	□	NA
83-32-9	Acenaphthene		NA	>3.9E+0	>3.9E+0	NA	NA	NA	NA	>3.9E+0	□	NA
120-12-7	Anthracene		NA	>4.5E-2	>4.5E-2	NA	NA	NA	NA	>4.5E-2	□	NA
206-44-0	Fluoranthene		NA	>2.1E-1	>2.1E-1	NA	NA	NA	NA	>2.1E-1	□	NA
86-73-7	Fluorene		NA	>1.7E+0	>1.7E+0	NA	NA	NA	NA	>1.7E+0	□	NA
91-20-3	Naphthalene		NA	>3.1E+1	>3.1E+1	NA	NA	NA	NA	>3.1E+1	□	NA
85-01-8	Phenanthrene		NA	>1.6E+0	>1.6E+0	NA	NA	NA	NA	>1.6E+0	□	NA
129-00-0	Pyrene		NA	>1.6E-1	>1.6E-1	NA	NA	NA	NA	>1.6E-1	□	NA

">" indicates risk-based target concentration greater than constituent solubility value. NA = Not applicable. NC = Not calculated.

APPENDIX 4. EXPOSURE PATHWAY CALCULATION SHEETS *(cont'd)*

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT — Input Parameter Summary

Site Name:
Site Location:
Completed By:
Date Completed: 0-Jan-00
Job ID:
1 OF 1

Exposure Parameters		Residential			Commercial/Industrial	
		Adult	(1-6yrs)	(1-16 yrs)	Chronic	Construc.
AT_c	Averaging time for carcinogens (yr)	70				
AT_n	Averaging time for non-carcinogens (yr)	30			25	1
BW	Body weight (kg)	70	15	35	70	
ED	Exposure duration (yr)	30	6	16	25	1
τ	Averaging time for vapor flux (yr)	30			25	1
EF	Exposure frequency (days/yr)	350			250	180
EF_D	Exposure frequency for dermal exposure	350			250	
IR_w	Ingestion rate of water (L/day)	2			1	
IR_s	Ingestion rate of soil (mg/day)	100	200		50	100
SA	Skin surface area (dermal) (cm^2)	5800		2023	5800	5800
M	Soil to skin adherence factor	1				
ET_{swim}	Swimming exposure time (hr/event)	3				
EV_{swim}	Swimming event frequency (events/yr)	12	12	12		
IR_{swim}	Water ingestion while swimming (L/hr)	0.05	0.5			
SA_{swim}	Skin surface area for swimming (cm^2)	23000		8100		
IR_{fish}	Ingestion rate of fish (kg/yr)	0.025				
FI_{fish}	Contaminated fish fraction (unitless)	1				

Complete Exposure Pathways and Receptors	On-site	Off-site 1	Off-site 2
Groundwater:			
Groundwater Ingestion	Residential	Residential	Residential
Soil Leaching to Groundwater Ingestion	Residential	Residential	Residential
Applicable Surface Water Exposure Routes:			
Swimming			NA
Fish Consumption			NA
Aquatic Life Protection			NA
Soil:			
Direct Ingestion and Dermal Contact	Residential		
Outdoor Air:			
Particulates from Surface Soils	Residential	None	None
Volatilization from Soils	Residential	None	None
Volatilization from Groundwater	None	None	None
Indoor Air:			
Volatilization from Subsurface Soils	None	NA	NA
Volatilization from Groundwater	None	NA	NA

Receptor Distance from Source Media	On-site	Off-site 1	Off-site 2	(Units)
Groundwater receptor	0	50	100	(ft)
Soil leaching to groundwater receptor	0	50	100	(ft)
Outdoor air inhalation receptor	0	NA	NA	(ft)

Target Health Risk Values		Individual	Cumulative
TR_{ab}	Target Risk (class A&B carcinogens)	1.0E-5	1.0E-5
TR_c	Target Risk (class C carcinogens)	1.0E-5	
THQ	Target Hazard Quotient (non-carcinogenic risk)	1.0E+0	1.0E+0

Modeling Options	
RBCA tier	Tier 2
Outdoor air volatilization model	Surface & subsurface models
Indoor air volatilization model	NA
Soil leaching model	ASTM leaching model
Use soil attenuation model (SAM) for leachate?	No
Air dilution factor	NA
Groundwater dilution-attenuation factor	Domenico model

Delaware Soil Submergence Model Parameters		Value	(Units)
θ_N	Residual NAPL content in submerged soils	NA	(-)
f	Water table fluctuation cycles per year	NA	(1/yr)
t_{hU}	Duration of high water table condition	NA	(d)

NOTE: NA = Not applicable

Surface Parameters		General	Construction	(Units)
A	Source zone area	2.4E+3	NA	(ft^2)
W	Length of source-zone area parallel to wind	4.9E+1	NA	(ft)
W_{gw}	Length of source-zone area parallel to GW flow	4.9E+1		(ft)
U_{air}	Ambient air velocity in mixing zone	6.4E+5		(ft/d)
δ_{air}	Air mixing zone height	6.6E+0		(ft)
P_a	Areal particulate emission rate	6.9E-14		(g/cm^2/s)
L_{ss}	Thickness of affected surface soils	2.0E+0		(ft)

Surface Soil Column Parameters		Value			(Units)
h_{cap}	Capillary zone thickness	NA			(ft)
h_v	Vadose zone thickness	NA			(ft)
ρ_s	Soil bulk density	1.8E+0			(g/cm^3)
f_{oc}	Fraction organic carbon	1.0E-2			(-)
θ_T	Soil total porosity	3.8E-1			(-)
K_{vs}	Vertical hydraulic conductivity	1.0E+4			(ft/yr)
k_v	Vapor permeability	1.1E-11			(ft^2)
L_{gw}	Depth to groundwater	9.8E+0			(ft)
L_s	Depth to top of affected soils	0.0E+0			(ft)
L_{base}	Depth to base of affected soils	9.8E+0			(ft)
L_{subs}	Thickness of affected soils	9.8E+0			(ft)
pH	Soil/groundwater pH	6.8E+0			(-)
		capillary	vadose	foundation	
θ_w	Volumetric water content	0.342	0.12	0.12	(-)
θ_a	Volumetric air content	0.038	0.26	0.26	(-)

Building Parameters		Residential	Commercial	(Units)
L_b	Building volume/area ratio	NA	NA	(ft)
A_b	Foundation area	NA	NA	(cm^2)
X_{crk}	Foundation perimeter	NA	NA	(ft)
ER	Building air exchange rate	NA	NA	(1/d)
L_{crk}	Foundation thickness	NA	NA	(ft)
Z_{crk}	Depth to bottom of foundation slab	NA	NA	(ft)
η	Foundation crack fraction	NA	NA	(-)
dP	Indoor/outdoor differential pressure	NA	NA	(g/cm/s^2)
Q_s	Convective air flow through slab	NA	NA	(ft^3/d)

Groundwater Parameters		Value	(Units)
δ_{gw}	Groundwater mixing zone depth	6.6E+0	(ft)
I_f	Net groundwater infiltration rate	1.4E+1	(in/yr)
U_{gw}	Groundwater Darcy velocity	3.0E+1	(ft/yr)
V_{gw}	Groundwater seepage velocity	7.9E+1	(ft/yr)
K_s	Saturated hydraulic conductivity	NA	(ft/yr)
i	Groundwater gradient	NA	(-)
S_w	Width of groundwater source zone	4.9E+1	(ft)
S_d	Depth of groundwater source zone	6.6E+0	(ft)
θ_{eff}	Effective porosity in water-bearing unit	NA	(-)
$f_{oc\text{-}sat}$	Fraction organic carbon in water-bearing unit	1.0E-3	(-)
pH_{sat}	Groundwater pH	6.2E+0	(-)
	Biodegradation considered?	No	

Transport Parameters		Off-site 1	Off-site 2	Off-site 1	Off-site 2	(Units)
Lateral Groundwater Transport		Groundwater Ingestion		Soil Leaching to GW		
α_x	Longitudinal dispersivity	5.0E+0	1.0E+1	5.0E+0	1.0E+1	(ft)
α_y	Transverse dispersivity	1.7E+0	3.3E+0	1.7E+0	3.3E+0	(ft)
α_z	Vertical dispersivity	2.5E-1	5.0E-1	2.5E-1	5.0E-1	(ft)
Lateral Outdoor Air Transport		Soil to Outdoor Air Inhal.		GW to Outdoor Air Inhal.		
σ_y	Transverse dispersion coefficient	NA	NA	NA	NA	(ft)
σ_z	Vertical dispersion coefficient	NA	NA	NA	NA	(ft)
ADF	Air dispersion factor	NA	NA	NA	NA	(-)

Surface Water Parameters		Off-site 2	(Units)
Q_{sw}	Surface water flowrate	NA	(ft^3/d)
W_{pi}	Width of GW plume at SW discharge	NA	(ft)
δ_{pi}	Thickness of GW plume at SW discharge	NA	(ft)
DF_{sw}	Groundwater-to-surface water dilution factor	NA	(-)

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations--PCBs
Site Location: Dist to POE = 0, 50, 100 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

1 OF 1

SOIL (0 - 9.8 ft) SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - No Decay (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Soil Leaching to Groundwater Ingestion			Soil Vol. to Indoor Air	X Soil Volatilization and Surface Soil Particulates to Outdoor Air				X Surface Soil Inhalation, Ingestion,Dermal Contact		Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (50 ft)	Off-site 2 (100 ft)	On-site (0 ft)	On-site (0 ft)		Off-site 1 (0 ft)	Off-site 2 (0 ft)	On-site (0 ft)				Only if □ yes□ left
CAS No.	Name	(mg/kg)	Residential	Residential	Residential	None	Residential	Construction Worker	None	None	Residential	Construction Worker	(mg/kg)	"■" if yes	
1336-36-3	PCBs		3.1E+0	4.0E+0	9.5E+0	NA	2.2E+0	NA	NA	NA	2.0E+0	NA	2.0E+0	□	NA

">" indicates risk-based target concentration greater than constituent residual saturation value. NA = Not applicable. NC = Not calculated.

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations--PCBs
Site Location: Dist to POE = 0, 50, 100 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

1 OF 1

GROUNDWATER SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - No Decay (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Groundwater Ingestion			GW Vol. to Indoor Air	Groundwater Volatilization to Outdoor Air			Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (50 ft)	Off-site 2 (100 ft)	On-site (0 ft)	On-site (0 ft)	Off-site 1 (0 ft)	Off-site 2 (0 ft)			Only if □ yes□ left
CAS No.	Name	(mg/L)	Residential	Residential	Residential	None	None	None	None	(mg/L)	"■" if yes	
1336-36-3	PCBs		4.3E-4	5.6E-4	1.3E-3	NA	NA	NA	NA	4.3E-4	□	NA

">" indicates risk-based target concentration greater than constituent solubility value. NA = Not applicable. NC = Not calculated.

APPENDIX 4. EXPOSURE PATHWAY CALCULATION SHEETS *(cont'd)*

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT — Input Parameter Summary

Site Name:
Site Location:
Completed By:
Date Completed: 0-Jan-00
Job ID:
1 OF 1

Exposure Parameters		Residential			Commercial/Industrial	
		Adult	(1-6yrs)	(1-16 yrs)	Chronic	Construc.
AT_c	Averaging time for carcinogens (yr)	70				
AT_n	Averaging time for non-carcinogens (yr)	30			25	1
BW	Body weight (kg)	70	15	35	70	
ED	Exposure duration (yr)	30	6	16	25	1
τ	Averaging time for vapor flux (yr)	30			25	1
EF	Exposure frequency (days/yr)	350			250	180
EF_D	Exposure frequency for dermal exposure	350			250	
IR_w	Ingestion rate of water (L/day)	2			1	
IR_s	Ingestion rate of soil (mg/day)	100	200		50	100
SA	Skin surface area (dermal) (cm^2)	5800		2023	5800	5800
M	Soil to skin adherence factor	1				
ET_{swim}	Swimming exposure time (hr/event)	3				
EV_{swim}	Swimming event frequency (events/yr)	12	12	12		
IR_{swim}	Water ingestion while swimming (L/hr)	0.05	0.5			
SA_{swim}	Skin surface area for swimming (cm^2)	23000		8100		
IR_{fish}	Ingestion rate of fish (kg/yr)	0.025				
FI_{fish}	Contaminated fish fraction (unitless)	1				

Complete Exposure Pathways and Receptors	On-site	Off-site 1	Off-site 2
Groundwater:			
Groundwater Ingestion	None	Residential	Residential
Soil Leaching to Groundwater Ingestion	None	Residential	Residential
Applicable Surface Water Exposure Routes:			
Swimming			NA
Fish Consumption			NA
Aquatic Life Protection			NA
Soil:			
Direct Ingestion and Dermal Contact	None		
Outdoor Air:			
Particulates from Surface Soils	None	None	None
Volatilization from Soils	None	None	None
Volatilization from Groundwater	None	None	None
Indoor Air:			
Volatilization from Subsurface Soils	None	NA	NA
Volatilization from Groundwater	None	NA	NA

Receptor Distance from Source Media	On-site	Off-site 1	Off-site 2	(Units)
Groundwater receptor	NA	300	500	(ft)
Soil leaching to groundwater receptor	NA	300	500	(ft)
Outdoor air inhalation receptor	NA	NA	NA	(ft)

Target Health Risk Values		Individual	Cumulative
TR_{ab}	Target Risk (class A&B carcinogens)	1.0E-5	1.0E-5
TR_c	Target Risk (class C carcinogens)	1.0E-5	
THQ	Target Hazard Quotient (non-carcinogenic risk)	1.0E+0	1.0E+0

Modeling Options	
RBCA tier	Tier 2
Outdoor air volatilization model	NA
Indoor air volatilization model	NA
Soil leaching model	ASTM leaching model
Use soil attenuation model (SAM) for leachate?	No
Air dilution factor	NA
Groundwater dilution-attenuation factor	Domenico model

Delaware Soil Submergence Model Parameters		Value	(Units)
θ_N	Residual NAPL content in submerged soils	NA	(-)
f	Water table fluctuation cycles per year	NA	(1/yr)
t_{hU}	Duration of high water table condition	NA	(d)

NOTE: NA = Not applicable

Surface Parameters		General	Construction	(Units)
A	Source zone area	NA	NA	(ft^2)
W	Length of source-zone area parallel to wind	NA	NA	(ft)
W_{gw}	Length of source-zone area parallel to GW flow	4.9E+1		(ft)
U_{air}	Ambient air velocity in mixing zone	NA		(ft/d)
δ_{air}	Air mixing zone height	NA		(ft)
P_a	Areal particulate emission rate	NA		(g/cm^2/s)
L_{ss}	Thickness of affected surface soils	NA		(ft)

Surface Soil Column Parameters		Value			(Units)
h_{cap}	Capillary zone thickness	NA			(ft)
h_v	Vadose zone thickness	NA			(ft)
ρ_s	Soil bulk density	1.8E+0			(g/cm^3)
f_{oc}	Fraction organic carbon	1.0E-2			(-)
θ_T	Soil total porosity	3.8E-1			(-)
K_{vs}	Vertical hydraulic conductivity	1.0E+4			(ft/yr)
k_v	Vapor permeability	1.1E-11			(ft^2)
L_{gw}	Depth to groundwater	9.8E+0			(ft)
L_s	Depth to top of affected soils	NA			(ft)
L_{base}	Depth to base of affected soils	NA			(ft)
L_{subs}	Thickness of affected soils	NA			(ft)
pH	Soil/groundwater pH	6.8E+0			(-)
		capillary	vadose	foundation	
θ_w	Volumetric water content	0.342	0.12	0.12	(-)
θ_a	Volumetric air content	0.038	0.26	0.26	(-)

Building Parameters		Residential	Commercial	(Units)
L_b	Building volume/area ratio	NA	NA	(ft)
A_b	Foundation area	NA	NA	(cm^2)
X_{crk}	Foundation perimeter	NA	NA	(ft)
ER	Building air exchange rate	NA	NA	(1/d)
L_{crk}	Foundation thickness	NA	NA	(ft)
Z_{crk}	Depth to bottom of foundation slab	NA	NA	(ft)
η	Foundation crack fraction	NA	NA	(-)
dP	Indoor/outdoor differential pressure	NA	NA	(g/cm/s^2)
Q_s	Convective air flow through slab	NA	NA	(ft^3/d)

Groundwater Parameters		Value	(Units)
δ_{gw}	Groundwater mixing zone depth	6.6E+0	(ft)
I_f	Net groundwater infiltration rate	1.4E+1	(in/yr)
U_{gw}	Groundwater Darcy velocity	3.0E+1	(ft/yr)
V_{gw}	Groundwater seepage velocity	7.9E+1	(ft/yr)
K_s	Saturated hydraulic conductivity	NA	(ft/yr)
i	Groundwater gradient	NA	(-)
S_w	Width of groundwater source zone	4.9E+1	(ft)
S_d	Depth of groundwater source zone	6.6E+0	(ft)
θ_{eff}	Effective porosity in water-bearing unit	NA	(-)
$f_{oc\text{-}sat}$	Fraction organic carbon in water-bearing unit	1.0E-3	(-)
pH_{sat}	Groundwater pH	6.2E+0	(-)
	Biodegradation considered?	No	

Transport Parameters		Off-site 1	Off-site 2	Off-site 1	Off-site 2	(Units)
Lateral Groundwater Transport		Groundwater Ingestion		Soil Leaching to GW		
α_x	Longitudinal dispersivity	3.0E+1	5.0E+1	3.0E+1	5.0E+1	(ft)
α_y	Transverse dispersivity	9.9E+0	1.7E+1	9.9E+0	1.7E+1	(ft)
α_z	Vertical dispersivity	1.5E+0	2.5E+0	1.5E+0	2.5E+0	(ft)
Lateral Outdoor Air Transport		Soil to Outdoor Air Inhal.		GW to Outdoor Air Inhal.		
σ_y	Transverse dispersion coefficient	NA	NA	NA	NA	(ft)
σ_z	Vertical dispersion coefficient	NA	NA	NA	NA	(ft)
ADF	Air dispersion factor	NA	NA	NA	NA	(-)

Surface Water Parameters		Off-site 2	(Units)
Q_{sw}	Surface water flowrate	NA	(ft^3/d)
W_{pi}	Width of GW plume at SW discharge	NA	(ft)
δ_{pi}	Thickness of GW plume at SW discharge	NA	(ft)
DF_{sw}	Groundwater-to-surface water dilution factor	NA	(-)

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations--PCBs
Site Location: Dist to POE = 300, 500 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

1 OF 1

SOIL (0 - 9.8 ft) SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - No Decay (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Soil Leaching to Groundwater Ingestion			Soil Vol. to Indoor Air	Soil Volatilization and Surface Soil Particulates to Outdoor Air				Surface Soil Ingestion and Dermal Contact		Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (300 ft)	Off-site 2 (500 ft)	On-site (0 ft)	On-site (0 ft)		Off-site 1 (0 ft)	Off-site 2 (0 ft)	On-site (0 ft)				Only if □ yes□ left
CAS No.	Name	(mg/kg)	None	Residential	Residential	None	None	Construction Worker	None	None	None	Construction Worker	(mg/kg)	"■" if yes	
1336-36-3	PCBs		NA	7.1E+1	1.9E+2	NA	NA	NA	NA	NA	NA	NA	7.1E+1	□	NA

">" indicates risk-based target concentration greater than constituent residual saturation value. NA = Not applicable. NC = Not calculated.

RBCA Tool Kit for Chemical Releases (DE-specific), Version DE1.0 beta2

RBCA SITE ASSESSMENT

Site Name: DERBCAP Tier 1 RBSL Calculations--PCBs
Site Location: Dist to POE = 300, 500 ft.

Completed By: Groundwater Services, Inc.
Date Completed: 8-Oct-99

Job ID: G-2227

1 OF 1

GROUNDWATER SSTL VALUES

Target Risk (Class A & B) 1.0E-5
Target Risk (Class C) 1.0E-5
Target Hazard Quotient 1.0E+0

Groundwater DAF Option: Domenico - No Decay (One-directional vert. dispersion)

SSTL Results For Complete Exposure Pathways ("X" if Complete)

CONSTITUENTS OF CONCERN		Representative Concentration	X Groundwater Ingestion			GW Vol. to Indoor Air	Groundwater Volatilization to Outdoor Air			Applicable SSTL	SSTL Exceeded ?	Required CRF
			On-site (0 ft)	Off-site 1 (300 ft)	Off-site 2 (500 ft)	On-site (0 ft)	On-site (0 ft)	Off-site 1 (0 ft)	Off-site 2 (0 ft)			Only if □ yes□ left
CAS No.	Name	(mg/L)	None	Residential	Residential	None	None	None	None	(mg/L)	"■" if yes	
1336-36-3	PCBs		NA	9.8E-3	2.7E-2	NA	NA	NA	NA	9.8E-3	□	NA

">" indicates risk-based target concentration greater than constituent solubility value. NA = Not applicable. NC = Not calculated.

APPENDIX 5. RBSL AND SSTL EQUATIONS

GROUNDWATER EXPOSURE PATHWAY

Groundwater Ingestion

Carcinogens: $$RBSL_{GW} = \frac{TR \cdot BW \cdot AT_C}{SFo \cdot EF \cdot ED \cdot IR_w}$$

Non-Carcinogens: $$RBSL_{GW} = \frac{THQ \cdot RfDo \cdot BW \cdot AT_n}{EF \cdot ED \cdot IR_w}$$

$$SSTL_{GW} = RBSL_{GW} \cdot DAF$$

Soil Leaching or Partitioning to Groundwater → Groundwater Ingestion

Carcinogens: $$RBSL_S = \frac{TR \cdot BW \cdot AT_C}{SFo \cdot EF \cdot ED \cdot IR_w \cdot LF}$$

Non-Carcinogens.: $$RBSL_S = \frac{THQ \cdot RfDo \cdot BW \cdot AT_n}{EF \cdot ED \cdot IR_w \cdot LF}$$

$$SSTL_S = RBSL_S \cdot DAF$$

SOIL EXPOSURE PATHWAY

Surface Soil Ingestion, Inhalation, and Dermal Contact

Carcinogens: $$RBSL_{SS} = \frac{TR \cdot BW \cdot AT_C}{EF \cdot ED \cdot \left[(SFo \cdot IR_s) + \left(URF \cdot 1000 \cdot BW \cdot (VF_{ss} + VF_p)\right) + (SFd \cdot SA \cdot M \cdot RAF_d)\right]}$$

Non-Carc.: $$RBSL_{SS} = \frac{THQ \cdot BW \cdot AT_n}{EF \cdot ED \cdot \left[\left(\frac{IR_s}{RfDo}\right) + \left(\frac{BW \cdot (VF_{ss} + VF_p)}{RfC}\right) + \left(\frac{SA \cdot M \cdot RAF_d}{RfDd}\right)\right]}$$

$$SSTL_{SS} = RBSL_{SS}$$

(No lateral transport; receptor only at source.)

PARAMETER DEFINITIONS

AT_c	Averaging time - carcinogens (yr)	RfC	Reference concentration (mg/m^3)
AT_n	Averaging time - non-carcinogens (yr)	RfDd	Chronic dermal reference dose (mg/kg/d)
BW	Body weight (kg)	RfDo	Chronic oral reference dose (mg/kg/d)
DAF	Lateral groundwater dilution-attenuation factor (unitless)	SA	Skin surface area for soil dermal contact (cm^2)
ED	Exposure duration (yr)	SFd	Dermal slope factor $(mg/kg/d)^{-1}$
EF	Exposure frequency (d/yr)	SFo	Oral slope factor $(mg/kg/d)^{-1}$
IR_S	Soil ingestion rate (kg/d)	$SSTL_{GW}$	Site-specific target level for groundwater (mg/L)
IR_{SW}	Water ingestion rate while swimming (L/hr)	$SSTL_S$	Site-specific target level for soil (mg/kg)
IR_W	Water ingestion rate (L/d)	$SSTL_{SS}$	Site-specific target level for surface soil (mg/kg)
LF	Soil-to-GW leaching factor (mg/L-wat)/(mg/kg-soil)	THQ	Target hazard quotient
M	Soil-to-skin adherence factor ($mg/cm^2/d$)	TR	Target risk
RAF_d	Relative absorption factor for soil dermal contact (unitless)	URF	Unit risk factor $(\mu g/m^3)^{-1}$
$RBSL_{GW}$	Risk-based screening level for groundwater (mg/L)	VF_p	Particulate emission factor (mg/m^3-air)/(mg/kg-soil)
$RBSL_S$	Risk-based screening level for soil (mg/kg)	VF_{ss}	Surface soil to ambient air volatilization factor (mg/m^3-air)/(mg/kg-soil)
$RBSL_{SS}$	Risk-based screening level for surface soil (mg/kg)		

APPENDIX 6
CROSS-MEDIA TRANSFER AND LATERAL TRANSPORT EQUATIONS

Surface Soil Volatilization and Particulate Emission

Surface Soil Volatilization Factor

$$VF_{ss}\left[\frac{(mg/m^3-air)}{(mg/kg-soil)}\right]=\frac{2W\rho_s}{U_{air}\delta_{air}}\sqrt{\frac{D_s^{eff}H}{\pi\tau(\theta_{ws}+k_s\rho_s+H\theta_{as})}}\times 10^3$$

where $D_s^{eff}\left[\frac{cm^2}{s}\right]=D^{air}\frac{\theta_{as}^{3.33}}{\theta_T^2}+\left[\frac{D^{wat}}{H}\right]\left[\frac{\theta_{ws}^{3.33}}{\theta_T^2}\right]$

or

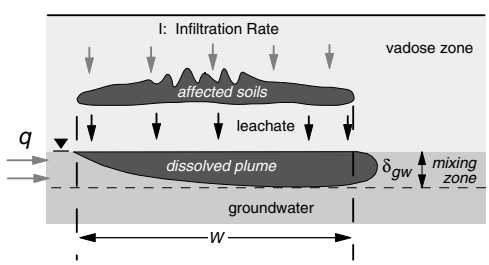
$$VF_{ss}\left[\frac{(mg/m^3-air)}{(mg/kg-soil)}\right]=\frac{W\rho_s d}{U_{air}\delta_{air}\tau}\times 10^3,$$

whichever is less.

Particulate Emission Factor:

$$VF_p\ \frac{(mg/m^3\ \ air)}{(mg/kg\ \ soil)}=\frac{P_eW}{U_{air}\delta_{air}}\times 10^3$$

Soil-to-Groundwater Leaching



3-Phase Equilibrium Partitioning:

$$K_{sw}\ \frac{(mg/L\ \ H_2O)}{(mg/kg\ \ soil)}=\frac{\rho_s}{\theta_{ws}+k_s\rho_s+H\theta_{as}}$$

where $ks = f_{oc,vad} \bullet K_{oc}$

Leachate Dilution Factor:

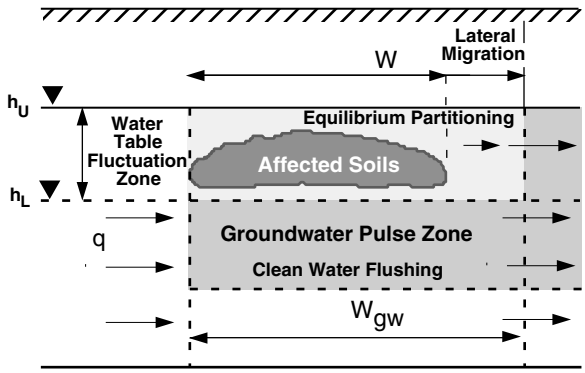
$$LDF[dimensionless]=1+\frac{\delta_{gw}q}{I\ \ W}$$

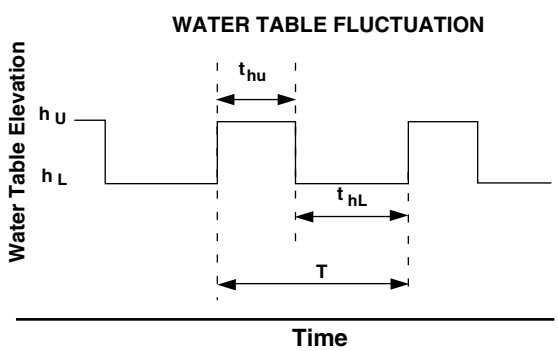
Soil-to-Groundwater Leaching Factor:

$$LF=\frac{K_{sw}}{LDF}$$

APPENDIX 6
CROSS-MEDIA TRANSFER AND LATERAL TRANSPORT EQUATIONS

Soil-to-Groundwater Partitioning Due to Water Table Fluctuation (Delaware Submergence Model)





Water Table Fluctuation:

T = (365 days/yr)/f

4-Phase Equilibrium Partitioning:

$$K_{sw} = \frac{\rho_s}{\theta_{wss} + \theta_N K_N + \rho_s f_{oc,gw} K_{oc}}$$

where $K_N = \frac{MF}{S} \frac{\rho_N}{X}$

Lateral Migration (no dispersion):

$$W_{gw} = W + v' t_{hU}$$

where $v' = \frac{q}{\theta_{eff} + f_{oc,gw} K_{oc} \rho_s}$

Clean Water Flushing (1-D advection-dispersion):

$$AF_{gw} = \frac{1}{T} \int_0^T \left[1 - \left(\frac{1}{2}\right) \mathrm{erfc}\left(\frac{W_{gw} - v'\tau}{\sqrt{4\alpha_x v' \tau}} \right) \right] d\tau$$

(integrated numerically)

where $\alpha_x = 0.1 \cdot W_{gw}$

Fluctuation Dilution Factor:

$$FDF = \frac{2t_{hU} + t_{hL}}{T}$$

Soil-to-Groundwater Transfer Factor:

$$LF' = \frac{K_{sw} \cdot AF_{gw}}{FDF}$$

Lateral Groundwater Dilution Attenuation Factor

Solute Transport with First-Order Decay:

$$\frac{C(x)_i}{Csi} = \exp\left(\frac{x}{2\alpha_x} \left[1 - \sqrt{1 + \frac{4\lambda_i \alpha_x R_i}{v}} \right] \right) erf\left(\frac{S_w}{4\sqrt{\alpha_y x}} \right) erf\left(\frac{S_d}{2\sqrt{\alpha_z x}} \right)$$

where $v' = \frac{q}{\theta_{eff} + f_{oc} K_{oc} \rho_b}$

APPENDIX 6 (cont'd)
CROSS-MEDIA TRANSFER AND LATERAL TRANSPORT EQUATIONS

Model Parameters

		Tier 1 Default
AF_{gw}	Normalized average COC concentration leaving groundwater pulse zone (mg/L)	(See above)
C(x)	COC concentration at distance x downstream of source (mg/L)	--
C_{si}	COC concentration in groundwater source zone (mg/L) or (mg/m^3)	--
d	Lower depth of surficial soil zone (cm)	60
D^{air}	Diffusion coefficient in air (cm^2/s)	CS
D^{wat}	Diffusion coefficient in water (cm^2/s)	CS
f	Frequency of water table fluctuations (1/yr)	1
$f_{oc,vad}$	Fraction of organic carbon in vadose zone soil (g-C/g-soil)	0.01
$f_{oc,gw}$	Fraction of organic carbon in groundwater zone soils (g-C/g-soil)	0.001
H	Henry's law constant (cm^3-H_2O)/(cm^3-air)	CS
h_u	High water table elevation	--
h_L	Normal water table elevation	--
I	Infiltration rate of water through soil (cm/year)	35
K_{oc}	Organic carbon partition coefficient for COC (cm^3-H_2O/g-C)	CS
K_N	Bulk partition factor for COC (mg/L-H_2O/mg/kg-soil)	(See above)
MF	Mass fraction of COC in source material (kg COC/kg-NAPL)	CS
P_e	Particulate emission rate (g/cm^2-s)	6×10^{-14}
q	Groundwater Darcy velocity (cm/yr)	915
S	Aqueous solubility of COC (mg/L)	CS
T	Period of water table fluctuation cycle (days)	(See above)
t_{hU}	Duration of high water level stage (days)	122
t_{hL}	Duration of normal water level stage (days)	243
U_{air}	Wind speed above ground surface in ambient mixing zone (cm/s)	225

		Tier 1 Default
W	Width of source area parallel to wind, or groundwater flow direction (cm)	1500
W_{gw}	Width of groundwater pulse from submerged soils (cm)	(See above)
x	Distance downgradient of source (ft)	---
X	Mole fraction of COC in source material (mol-COC/mol -NAPL	CS
α_x	Longitudinal groundwater dispersivity (cm)	$0.1 \times x$
α_y	Transverse groundwater dispersivity (cm)	$0.33 \times \alpha_x$
α_z	Vertical groundwater dispersivity (cm)	$0.05 \times \alpha_x$
δ_{air}	Ambient air mixing zone height (cm)	200
δ_{gw}	Groundwater mixing zone thickness (cm)	200
θ_{as}	Volumetric air content in vadose zone soils (cm^3-air/cm^3-soil)	0.26
θ_{eff}	Effective porosity of groundwater zone soils (cm^3-pore-space/cm^3-soil)	0.38
θ_N	Volumetric NAPL content of submerged affected soils (cm^3-NAPL/cm^3-soil)	0.03
θ_T	Total soil porosity (cm^3-pore-space/ cm^3-soil)	0.38
θ_{ws}	Volumetric water content in vadose zone soils (cm^3-H_2O/cm^3-soil)	0.12
θ_{wss}	Volumetric water content of submerged affected soils (cm^3-H_2O/cm^3-soil)	0.35
ρ_N	NAPL density (g-NAPL/ cm^3-soil)	0.72
ρ_s	Soil bulk density (g-soil/cm^3-soil)	1.78
τ	Averaging time for vapor flux (s)	9.47×10^8
λ_i	First-order degradation rate (day^{-1})	CS
v'	Retarded groundwater seepage velocity (cm/day)	(See above)

APPENDIX 7
CHEMICAL-SPECIFIC DATA FOR DELAWARE UST-RBCA CHEMICALS OF CONCERN (COCs)

Physical Parameters

Constituent	CAS Number	Molecular Weight (g/mole)	ref	Air Diffusion Coefficient (cm^2/s)	ref	Water Diffusion Coefficient (cm^2/s)	ref	log(Koc) (@ 20-25 C) log(L/kg)	ref	Henry's Law Constant (@ 20-25 C) (unitless)	ref	Vapor Pressure (@ 20-25 C) (mm Hg)	ref	Solubility (@ 20-25 C) (mg/L)	ref
VOLATILES															
Benzene	71-43-2	78.1	1	8.8E-2	1	9.8E-6	1	1.77	1	2.3E-1	1	9.5E+1	1	1.8E+3	1
Toluene	108-88-3	92.4	4	8.5E-2	2	9.4E-6	2	2.13	2	2.6E-1	2	3.0E+1	3	5.2E+2	9
Ethylbenzene	100-41-4	106.2	1	7.5E-2	1	7.8E-6	1	2.56	1	3.2E-1	1	1.0E+1	1	1.7E+2	1
Xylene (mixed isomers)	1330-20-7	106.2	4	7.2E-2	2	8.5E-6	2	2.38	2	2.9E-1	2	7.0E+0	3	2.0E+2	4
Isopropylbenzene (Cumene)	98-82-8	120.2	3	6.5E-2	3	7.1E-6	3	0.00	3	6.0E-1	3	4.6E+0	3	5.0E+1	3
ADDITIVES															
Methyl t-butyl ether (MTBE)	1634-04-4	88.1	4	7.9E-2	5	9.4E-5	6	1.08	2	2.4E-2	-	2.5E+2	-	4.8E+4	2
1,2-Dichloroethane (EDC)	107-06-2	99.0	3	1.0E-1	3	9.9E-6	3	1.76	3	4.9E-2	3	8.0E+1	3	8.7E+3	4
1,2-Dibromoethane (EDB)	106-93-4	187.9	11	2.2E-2	11	1.9E-5	11	2.01	11	2.9E-2	11	1.1E+1	11	4.2E+3	11
PAH-CARCINOGENIC															
Benzo(a)Anthracene	56-55-3	228.3	3	5.1E-2	3	9.0E-6	3	6.14	3	5.7E-7	3	1.5E-7	3	5.7E-3	4
Benzo(a)Pyrene	50-32-8	252.3	1	4.3E-2	1	9.0E-6	1	6.01	1	4.7E-5	1	5.7E-4	1	1.6E-3	1
Benzo(b)Fluoranthene	205-99-2	252.0	4	2.3E-2	5	5.6E-6	6	5.74	8	8.3E-4	8	6.7E-7	8	1.5E-2	8
Benzo(k)Fluoranthene	207-08-9	252.3	3	2.3E-2	3	5.6E-6	3	5.74	3	4.4E-7	3	9.6E-10	3	4.3E-3	3
Chrysene	218-01-9	228.2	3	2.5E-2	3	6.2E-6	3	5.30	3	4.9E-7	3	5.8E-9	3	1.8E-3	4
Indeno(1,2,3-cd)Pyrene	193-39-5	276.3	3	2.3E-2	3	4.4E-6	3	7.53	3	2.1E-10	3	1.0E-9	3	6.2E-2	9
PAH-NON-CARCINOGENIC															
Acenaphthene	83-32-9	154.2	3	4.2E-2	3	7.7E-6	3	3.85	3	3.2E-1	3	5.0E-3	3	3.9E+0	9
Anthracene	120-12-7	178.2	3	3.2E-2	3	7.7E-6	3	4.15	3	2.8E+0	3	1.3E-6	3	4.5E-2	4
Fluoranthene	206-44-0	202.0	3	3.0E-2	3	6.4E-6	3	4.58	3	2.8E+0	3	1.8E-2	3	2.1E-1	4
Fluorene	86-73-7	166.0	3	3.6E-2	3	7.9E-6	3	3.86	3	4.8E-3	3	1.7E-2	3	1.7E+0	4
Naphthalene	91-20-3	128.2	1	5.9E-2	1	7.5E-6	1	3.30	1	2.0E-2	1	2.3E-1	1	3.1E+1	1
Phenanthrene	85-01-8	178.2	3	3.3E-2	3	7.5E-6	3	4.15	3	2.5E-1	3	2.1E-4	3	1.6E+0	4
Pyrene	129-00-0	202.3	3	2.7E-2	3	7.2E-6	3	4.58	3	2.9E-7	3	4.2E-8	3	1.6E-1	4
OTHER															
PCBs	1336-36-3	290.0	3	1.0E-1	3	1.0E-5	3	5.21	7	1.2E-2	3	0.0E+0	3	2.0E-1	4

See page 72 for references.

APPENDIX 7 *(cont'd)*
CHEMICAL-SPECIFIC DATA FOR DELAWARE UST-RBCA CHEMICALS OF CONCERN (COCs)

Toxicological Parameters

Constituent	Oral Reference Dose (mg/kg/day)	ref	Dermal Reference Dose (mg/kg/day)	ref	Inhalation Reference Concentration (mg/m^3)	ref	Oral Slope Factor $(mg/kg/day)^{-1}$	ref	Dermal Slope Factor $(mg/kg/day)^{-1}$	ref	Inhalation Unit Risk Factor $(\mu g/m^3)^{-1}$	ref	EPA Weight of Evidence	Is Constituent Carcinogen?
VOLATILES														
Benzene	3.0E-3	10	-	-	6.0E-3	10	2.9E-2	1	3.0E-2	11	8.3E-6	1	A	Yes
Toluene	2.0E-1	2	1.6E-1	11	4.0E-1	2	-	-	-	-	-	-	D	No
Ethylbenzene	1.0E-1	1	9.7E-2	11	1.0E+0	1	-	-	-	-	-	-	D	No
Xylene (mixed isomers)	2.0E+0	2	1.8E+0	11	7.0E+0	2	-	-	-	-	-	-	D	No
Isopropylbenzene (Cumene)	1.0E-1	10	8.0E-2	11	4.0E-1	10	-	-	-	-	-	-	D	No
ADDITIVES														
Methyl t-butyl ether (MTBE)	1.0E-2	12	8.0E-3	11	3.0E+0	10	-	-	-	-	-	-	-	No
1,2-Dichloroethane (EDC)	-	-	-	-	1.0E-2	10	9.1E-2	10	9.1E-2	11	2.6E-5	10	B2	Yes
1,2-Dibromoethane (EDB)	-	-	-	-	-	-	8.5E+1	10	1.1E+2	11	2.2E-4	10	B2	Yes
PAH-CARCINOGENIC														
Benzo(a)Anthracene	-	-	-	-	1.0E+0	12	7.3E-1	10	8.2E-1	11	8.8E-5	12	B2	Yes
Benzo(a)Pyrene	-	-	-	-	1.1E+1	12	7.3E+0	1	8.2E+0	11	2.1E-3	1	B2	Yes
Benzo(b)Fluoranthene	-	-	-	-	1.0E+0	12	7.3E-1	10	8.2E-1	11	8.8E-5	12	B2	Yes
Benzo(k)Fluoranthene	-	-	-	-	1.0E-1	12	7.3E-2	10	8.2E-2	11	8.8E-6	12	B2	Yes
Chrysene	-	-	-	-	9.0E-7	12	1.2E+0	2	1.3E+0	11	3.3E-4	2	B2	Yes
Indeno(1,2,3-cd)Pyrene	-	-	-	-	1.1E+0	12	7.3E-1	10	8.2E-1	11	8.8E-5	12	B2	Yes
PAH-NON-CARCINOGENIC														
Acenaphthene	6.0E-2	10	5.3E-2	11	-	-	-	-	-	-	-	-	D	No
Anthracene	3.0E-1	2	2.7E-1	11	-	-	-	-	-	-	-	-	D	No
Fluoranthene	4.0E-2	2	3.6E-2	11	-	-	-	-	-	-	-	-	D	No
Fluorene	4.0E-2	2	3.6E-2	11	-	-	-	-	-	-	-	-	D	No
Naphthalene	4.0E-1	1	3.6E-1	11	1.4E+0	1	-	-	-	-	-	-	D	No
Phenanthrene	3.0E-2	12	2.7E-2	11	-	-	-	-	-	-	-	-	D	No
Pyrene	3.0E-2	10	2.7E-2	11	-	-	-	-	-	-	-	-	D	No
OTHER														
PCBs	7.0E-5	10	-	-	-	-	2.0E+0	10	2.2E+0	11	6.0E-4	10	B2	Yes

See page 72 for references.

APPENDIX 7 *(cont'd)*
CHEMICAL-SPECIFIC DATA FOR DELAWARE UST-RBCA CHEMICALS OF CONCERN (COCs)

Miscellaneous Parameters

Constituent	Maximum Contaminant Level (MCL)		Time-Weighted Average Workplace Criteria (TWA)		Dermal Relative Absorp. Factor		Detection Limit in Groundwater		Detection Limit in Soil		Saturated Zone Half Life	
	(mg/L)	ref	(mg/m3)	ref	(unitless)	ref	(mg/L)	ref	(mg/kg)	ref	(days)	ref
VOLATILES												
Benzene	5.0E-3	52 FR 25690	3.3E+0	1	0.5	1	0.002	13	0.005	13	720	15
Toluene	1.0E+0	56 FR 3526 (30 Jan 91)	1.5E+2	ACGIH	0.5	1	0.002	13	0.005	13	28	15
Ethylbenzene	7.0E-1	56 FR 3526 (30 Jan 91)	4.4E+2	1	0.5	1	0.002	13	0.005	13	228	15
Xylene (mixed isomers)	1.0E+1	56 FR 3526 (30 Jan 91)	4.3E+2	ACGIH	0.5	1	0.005	13	0.005	13	360	15
Isopropylbenzene (Cumene)	-	-	2.5E+2	OSHA	0.5	1	-	-	-	-	16	15
ADDITIVES												
Methyl t-butyl ether (MTBE)	-	-	6.0E+1	NIOSH	0.5	1	-	-	-	-	-	-
1,2-Dichloroethane (EDC)	5.0E-3	52 FR 25690 (08 Jul 87)	4.0E+0	NIOSH	0.5	1	0.0005	13	0.005	13	360	15
1,2-Dibromoethane (EDB)	5.0E-5		1.5E+2	OSHA	0.5	1		-		-	120	15
PAH-CARCINOGENIC												
Benzo(a)Anthracene	-	-	-	-	0.05	1	0.01	14	0.66	14	1360	15
Benzo(a)Pyrene	2.0E-4	57 31776 (17 Jul 92)	2.0E-1	1	0.05	1	0.01	14	0.66	14	1060	15
Benzo(b)Fluoranthene	-	-	-	-	0.05	1	0.01	14	0.66	14	1220	15
Benzo(k)Fluoranthene	-	-	-	-	0.05	1	0.01	14	0.66	14	4280	15
Chrysene	2.0E-4	2	-	-	0.05	1	0.01	14	0.66	14	2000	15
Indeno(1,2,3-cd)Pyrene	-	-	-	-	0.05	1	0.01	14	0.66	14	1460	15
PAH-NON-CARCINOGENIC												
Acenaphthene	-	-	-	-	0.05	1	0.01	14	0.66	14	204	15
Anthracene	-	-	-	-	0.05	1	0.01	14	0.66	14	920	15
Fluoranthene	-	-	-	-	0.05	1	0.01	14	0.66	14	880	15
Fluorene	-	-	-	-	0.05	1	0.01	14	0.66	14	120	15
Naphthalene	-	-	5.0E+1	1	0.05	1	0.01	14	0.01	14	258	15
Phenanthrene	-	-	-	-	0.05	1	0.01	14	0.66	14	400	15
Pyrene	-	-	-	-	0.05	1	0.01	14	0.66	14	3800	15
OTHER												
PCBs	5.0E-4	56 FR 3526 (30 Jan 91)	-	-	0.05	1	0.05	13	-	-	-	-

See page 72 for references.

APPENDIX 7 *(cont'd)*
CHEMICAL-SPECIFIC DATA FOR DELAWARE UST-RBCA CHEMICALS OF CONCERN (COCs)

References

1. ASTM, Standard Provisional Guide for Risk-Based Corrective Action, PS 104-98.
2. ASTM, Emergency Standard Guide for Risk-Based Corrective Action Applied at Petroleum Release Sites, ES 38-94.
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4. Verschueren, Karel, 1983: *Handbook of Environmental data on organic Chemicals,* Second Ed., (Van Nostrand Reinhold Company Inc., New York), ISBN: 0-442-28802-6.
5. Calculated using Fuller et al. method from *Handbook of Chemical Property Estimation Methods,* 1982, W.J. Lyman, (McGraw-Hill, New York), ISBN -0-07-039175-0.
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10. EPA Region III Risk Based Concentration Table, EPA Region 3, March 7, 1995.
11. Texas Natural Resource Conservation Commission (TNRCC), Risk-Based Corrective Action for Leaking Storage Tank Sites, January 1994.
12. Texas Natural Resource Conservation Commission (TNRCC), Risk Reduction Rule Implementation, July 23, 1998 (update to Reference 11).
13. USEPA, *Test Methods for Evaluating Solid Waste,* SW-846, Third Edition, OSWER, November 1986.
14. USEPA, Method 8270C, Revision 3, "Semivolatile Organic Compounds by GC/MS", December 1996.
15. Howard, *Handbook of Environmental Degradation Rates,* Lewis Publishers, Chelsea, MI, 1989
16. Other Acronyms:
    ACGIH = American Conference of Governmental Industrial Hygienists;
    FR = Federal Register;
    NIOSH = National Institute for Occupational Safety and Health;
    OSHA = Occupational Safety and Health Administration.

APPENDIX 8.
DELAWARE'S POLICY DECISIONS

ASTM's *"Standard Guide for Risk-Based Corrective Action at Petroleum Release Sites"* (RBCA) cannot be adopted "as is" without each state first addressing a number of state-specific policy decisions. Delaware's policy decisions are as follows.

1. **Any risk-based approach to leaking underground storage tank sites in Delaware must be a seamless extension of the existing program.**

   This means that any risk-based approach to assessment of leaking underground storage tank sites in Delaware must be capable of addressing both existing and newly identified LUST sites. This ensures comparability of new and historical data and eliminates major changes in established procedures for the regulated community.

2. **A risk-based assessment of leaking underground storage tank sites in Delaware must be based on a prudent conceptual model of mid-Atlantic coastal plain geology.**

   Delaware's conceptual model of mid-Atlantic coastal plain geology is described in Section 1.4. The model defines the most conservative case so that as more and more data become available, any changes in the assessment and remediation of a LUST site can only be less stringent.

3. **A 1 x 10^{-5} incremental cancer risk, or "level of protection," is the goal of any risk-based corrective action program, for reasons of uniformity with other environmental programs in Delaware.**

   The Department of Natural Resources and Environmental Control set this value.

4. **Releases potentially impacting human safety and other emergencies will be stabilized and brought to equilibrium by whatever means are deemed prudent and necessary before being subjected to a risk assessment.**

   This decision tracks with established procedures. Its goal is to minimize potential risks to human safety and direct impacts to receptors such as drinking water supplies.

5. **All reports of petroleum vapors are considered to be emergency responses and are handled in accordance with Decision #4. Thus, contaminant migration pathways through the *air* are not included in site assessments under DERBCAP.**

   This decision tracks with established procedures.

6. **The Department of Natural Resources and Environmental Control, Underground Storage Tank Branch (the "Department") retains all approval authority. No Responsible Party, no contractor, and no consultant have the authority to proceed with a course of action without first obtaining approval from the Underground Storage Tank Branch.**

   Verbal approvals may be given at the Department's sole discretion in order to expedite action at a site. All verbal approvals will be confirmed in writing.

7. **All free-phase product must be removed to the maximum extent technologically feasible.**

   This decision tracks with established procedure.

8. **Petroleum-stained soils that are excavated or which are encountered at the surface must be managed as though they exceed applicable Risk-Based Screening Levels.**

This decision addresses aesthetic concerns and recognizes that petroleum-stained and smelly soils at the surface are unacceptable, whether or not a calculated quantitative health risk exists. This decision also forms the basis for managing surface stockpiles of petroleum-contaminated soils undergoing bioremediation.

9. No further degradation of the environment will be allowed.

Residual contaminant plumes must be shown to be either stable or declining before a LUST site may be closed.

10. Standards adopted from other environmental programs will be used consistent with their original definitions.

For example, (a) a surface water body showing a petroleum sheen due to a leaking underground storage tank will be addressed using Delaware's surface water quality standards, and (b) the lead concentration shown in Table 4 was adopted from Delaware's Site Investigation and Restoration Branch (state "superfund").

APPENDIX 9.
HYDROGEOLOGIC INVESTIGATIONS

A hydrogeologic investigation must be performed whenever an underground storage tank is removed or abandoned in-place and

- the concentrations of petroleum compounds in the surrounding soils exceed Tier 0 action levels, *and*
- the surrounding impacted soils cannot be removed by overexcavation.

A hydrogeologic investigation performed under Tier 1 incorporates chemical-specific but generic geologic information. A pre-calculated lookup table of Risk-Based Screening Levels (RBSLs) is provided to evaluate the results.

A hydrogeologic investigation performed under Tier 2 incorporates both chemical-specific *and* site-specific geologic information. The relevant action levels, now called Site-Specific Target Levels (SSTLs), are individually calculated for each site using the same procedures as for the pre-calculated lookup table of RBSLs. Documentation must be provided for each site-specific geologic parameter that is used.

A hydrogeologic investigation is performed to identify the nature and extent of a release that has taken place at an underground storage tank facility by:

- identifying the source of the release,
- identifying the pathways of possible contaminant migration from the source to potential receptors, and
- identifying possible Points of Exposure (POEs) where the potential exists for an adverse impact to human health and safety, and to the environment.

A hydrogeologic investigation report, *with recommendations,* forms the basis for action to minimize potential risks to human health and safety, and to the environment, by identifying appropriate remedial technologies to contain, control, remove, or minimize the size, concentration and impacts of the release.

A hydrogeologic investigation comprises the components listed in Table A9-1.

Table A9-1. Components of a hydrogeologic investigation.

Number	Component	Comment
1.	Map of site.	An acceptable site map shows all underground storage tanks and *former* tanks, including piping and dispensers, other potential contaminant sources, public and private water-supply wells, monitor wells, soil borings, underground utilities, building basements and other structures, an approximate scale, a "north" arrow, and sufficient other information such that any person who has never visited the site can find it using only this map.
2.	Drilling logs.	Locations, descriptive logs and construction details for all monitoring wells and soil borings.
3.	Field screening results.	The location and readings for all measurements taken with a photoionization detector (PID) or similar instruments.
4.	Site geology.	***For Tier 1:*** Whether or not ground water was encountered and, if so, at what depth; whether the soils are stable or prone to slumping; a qualitative visual classification of exposed soils: sand, silt or clay; any indications of "urban fill" or old land surfaces; direction of ground-water flow, if known or interpreted from site topography; a description of local geology obtained from published reports. ***For Tier 2:*** All of the information listed for Tier 1, plus measurement or calculation of the following site-specific parameters: • site-specific geology, particularly the stratigraphy, • fraction of organic carbon, f_{oc}, in the soil, • ground-water (Darcy) velocity, • width of the contaminant source perpendicular to the direction of ground-water movement, • volumetric air content of the soil (may be estimated from soil type), • volumetric water content of the soil (may be estimated from soil type), • total porosity of the soil (may be estimated from soil type), • effective porosity of the soil (may be estimated from soil type), • distance from the "core" of the plume to each Point of Exposure (POE), • hydraulic conductivity of the soil at the site, and • hydraulic gradient of the ground-water table at the site.
5.	Water quality data.	Determined by analysis of ground-water samples collected from all monitoring wells where there is no free-phase prod-

		uct. A ground-water sample is ***required*** in a Tier 1 assessment unless it can be shown by additional soils samples from progressively greater depths that no chemicals of concern have reached the ground-water table.
6.	Well gauge data.	Depth to liquid in all monitoring wells, to the nearest 0.01 foot. If free-phase product is present, measure the thickness of the product and calculate an adjustment for the elevation of the water table. Actual water level elevations may be calculated relative to mean sea level or relative elevations may be calculated relative to an arbitrary onsite benchmark.
7.	Soils analyses.	Analyses of soils samples collected from wells or soils borings. Two samples per well or boring is the norm. A common sampling scheme is to collect a composite sample of all soils penetrated down to total depth and then a discrete "grab" sample at total depth. An alternative scheme is to analyze the discrete "grab" sample producing the highest reading on a photoionization detector (PID) and then another discrete "grab" sample at total depth.
8.	Plume delineation.	The location and extent of vapor phase, adsorbed phase and dissolved phase contaminant plumes, as well as any free-phase product that may be present, must be determined by monitoring wells, soil borings, or direct push technology.
9.	Plume movement.	An assessment of the potential for movement of contaminant plumes, based on existence of migration pathways, manmade conduits, measurements of contaminant concentrations over area and time, etc.
10.	Identification of Points of Exposure.	Identify the location and characteristics of each Point of Exposure (POE) within 500 feet of the source of the release. Assess the vulnerability of each POE to water contamination, vapor migration or explosion. Assess the vulnerability of "the environment" within the same radius, including surface water bodies and public access areas.
11.	Quality assurance/quality control (QA/QC).	Collection and handling of all samples must follow proper QA/QC procedures and chain of custody forms must be included with all hydrogeologic investigation reports.
12.	Abandonment of monitoring wells and soil borings.	All monitoring wells and soil borings must be properly abandoned in accordance with applicable requirements when they are no longer needed. All wells or borings from which a ground-water sample is collected must be constructed and abandoned by a Delaware-licensed driller.
13.	Recommendations.	Each hydrogeologic investigation report *must* include recommendations in the form of a plan to: • remove all free-phase product to the extent technologically feasible, • remediate impacted soils, • remediate impacted ground water, • remediate vapors, • properly dispose or treat all impacted materials that are

		brought to the surface, whether or not they are moved off-site, • monitor the site periodically if natural attenuation is the proposed remedy that is approved, • monitor the site following a period of active remediation to ensure no contaminant "spike" re-occurs, • document all remedial actions taken.
14.	Approvals	For certain underground storage tank-related tasks in Delaware, professional licenses or other certificates are required. It is the responsibility of individuals performing tank-related work to ascertain and comply with these requirements.

APPENDIX 10. DELAWARE SUBMERGENCE MODEL

GSI Job No. G-2227
Issued: 9/15/99
Page 1 of 10

MEMORANDUM

TO: Delaware Department of Natural Resources and Environmental Control, Underground Storage Tank Branch

FROM: Groundwater Services, Inc.

RE: Derivation of Tier 1 RBSLs for Soils Periodically Submerged by Fluctuating Water Table Conditions

SCOPE AND OBJECTIVES

In preliminary discussions regarding the Delaware Tier 1 RBCA process, representatives of DNREC identified contaminant release from periodically submerged soils to be a key concern with regard to protection of groundwater quality at UST sites. However, the example soil leachate equations presented in Appendix X.2 of the ASTM RBCA Standard E-1739 are directed toward soil contaminant release to infiltrating rainwater and do not correspond to a fluctuating water table condition. To address this concern, Groundwater Services, Inc. (GSI), has developed a supplemental Tier 1 RBCA algorithm designed to provide soil risk-based screening levels (RBSLs) that are protective of underlying groundwater quality in the event of periodic resubmergence due to fluctuating water table conditions. This memorandum presents the derivation of the soil submergence algorithm.

The approach outlined below characterizes the soil-to-groundwater contaminant transport process in a simple and conservative manner consistent with Tiers 1 and 2 of the RBCA evaluation process, and is intended for derivation of initial soil screening levels at sites where groundwater impacts have not been observed. If these soil-to-groundwater screening levels are exceeded, groundwater sampling and testing may be appropriate. At sites where groundwater impacts are confirmed, soil leachate release may have already occurred in many cases, and the need for soil remediation should be assessed as part of the groundwater response program.

NATURE OF GROUNDWATER IMPACTS

Sandy soils and relatively shallow water table conditions (e.g., <10 ft bgs) are encountered throughout much of Delaware. Static water levels in these shallow water-bearing units typically exhibit significant seasonal fluctuation (e.g., $\pm$3 ft). In this hydrogeologic setting, DNREC has identified the seasonal resubmergence of contaminated vadose zone soils to be a potentially significant mechanism for contaminant release to underlying groundwater. At many UST sites, an increase in groundwater contaminant concentrations has been measured immediately following a high water table condition, suggesting a pulse release from resubmerged soils. Given the prevalence of surface pavement at most UST sites, water table fluctuation, rather than rainfall infiltration, represents the more likely mechanism for soil-to-groundwater contaminant release.

Example RBSL calculation methods provided in ASTM Standard E-1739 include an algorithm for soil-to-groundwater leachate release due to rainfall infiltration. This algorithm characterizes the soil leachate mechanism as a two-step process involving: i) continuous equilibrium partitioning of contaminants from the soil to infiltrating rainwater followed by ii) dilution of the contaminated rainwater leachate within the

underlying lateral groundwater flow system. In contrast, contaminated soil resubmergence occurs periodically (not continuously) and does not involve a rainwater/groundwater dilution factor. Consequently, a new model is needed to derive soil RBSLs that are protective of groundwater quality under fluctuating water table conditions. A simple and conservative algorithm suitable for derivation of Tier 1 RBSL values is presented below.

CONCEPTUAL MODEL OF SOIL RESUBMERGENCE EFFECTS

For derivation of Tier 1 soil RBSL values, the impact of contaminated vadose zone soils on underlying groundwater due to the effects of periodic water table fluctuations can be characterized as a recurring cycle of pulse releases, as illustrated on Figure 1. Prior to the onset of water table fluctuations (Step 0), affected soils located above the water table are not in contact with groundwater, resulting in no contaminant release. However, on a periodic basis, the water table may rise (Step 1), contacting the affected soil zone and removing contaminants via dissolution. As shown on Figure 1, during this period of submergence, groundwater flow will move laterally through the submerged soils, causing the affected groundwater zone to extend in the downgradient direction from the soil source zone (Step 2). When the water table returns to normal stage, the contaminated groundwater mass drops down into the underlying groundwater flow system as a pulse release (Step 3), which subsequently spreads downgradient of the source location due to the effects of groundwater advection and dispersion. Steps 1 through 3 are repeated for each water table fluctuation cycle.

The net impact of this soil contaminant release on groundwater quality depends on the nature and concentration of the soil contaminants, the frequency and duration of the water table fluctuation events, and the rate of lateral groundwater flow. Characterization of each of these factors for use in derivation of Tier 1 soil RBSLs is discussed below.

1) Water Table Fluctuation

Periodic water table fluctuations may be idealized as a "square" wave based on upper-bound and lower-bound water table elevations (Figure 2). This step function assumes that water elevations rise to an upper-bound level, h_U, for a specified time period, then suddenly drop back to a typical lower-bound level, h_L, for the remainder of the cycle.

The time to complete one full cycle, called the period, T (days), is expressed as

$$T = t_{hU} + t_{hL} = \frac{365}{f} \qquad (1)$$

where t_{hU} = time at the upper-bound water table elevation (days);
t_{hL} = time at the lower-bound water table elevation (days); and
f = frequency, or number of fluctuation cycles per year (yr^{-1}).

In actuality, water table variations over time can be expected to follow a more gradual (sinusoidal) wave pattern, resulting in a gradational distribution of residual soil contaminants within the zone of water table fluctuation. However, under Tier 1, we are interested in characterizing the allowable mean contaminant concentration in the affected soil zone that will not cause exceedance of the applicable groundwater standard in the underlying water-bearing unit. This allowable mean soil concentration can be estimated assuming a uniform contaminant distribution in the affected soil zone and a step-function water level variation, as described above.

GSI Job No. G-2227
Issued: 9/15/99
Page 3 of 10

2) Soil-to-Groundwater Contaminant Transfer

To derive a soil RBSL that is specific to contaminant release via periodic soil submergence, all other potential sources of groundwater contamination must be ignored in the model, including soil leachate effects and contaminant release from contaminant sources beneath the water table. As a conservative and simplifying measure, soil contaminant release to rising groundwater can be characterized based on instantaneous equilibrium partitioning among the four phases present in the affected soil zone: soil solids, pore water, soil vapor, and residual nonaqueous phase liquid (NAPL) contaminants. On this basis, partitioning of organic contaminants into the rising groundwater contacting the overlying affected soils is estimated as:

$$C_w = K_{sw} C_T \tag{2}$$

$$K_{sw} = \frac{\rho_b}{\theta_{ws} + \theta_{as} H + \theta_N K_N + \rho_b f_{oc} K_{oc}} \tag{3}$$

where C_w = Constituent concentration in water (mg/L);
C_T = Bulk constituent concentration in soil (mg/kg);
f_{oc} = Fraction organic carbon in soil (unitless);
H = Henry's Law constant for constituent (unitless);
K_N = NAPL partitioning coefficient for constituent (dependent on NAPL composition, unitless);
K_{oc} = Organic carbon partition coefficient for constituent (L/kg);
ρ_b = Soil bulk density (kg/L);
θ_{ws} = Volumetric water content in soil (unitless);
θ_N = Volumetric NAPL content in soil (unitless);
θ_{as} = Volumetric air content in soil (unitless).

For organic constituents, K_N will be very large compared to H. Therefore, partitioning to the vapor phase may be neglected, and the partitioning relationship simplifies to:

$$K_{sw} = \frac{\rho_b}{\theta_{ws} + \theta_N K_N + \rho_b f_{oc} K_{oc}} \tag{4}$$

Organic constituents will partition most strongly to the NAPL phase. Therefore, underestimating the $\theta_N K_N$ term will result in an overestimate in K_{sw} and C_w and an underestimate of the allowable soil concentration, C_T. Typical residual saturations reported by Cohen and Mercer (1993) indicate that volumetric NAPL content may range from 0.04 to 0.08 for sandy soils in the vadose zone (based on total porosity of 0.38). Therefore, use of a low θ_N value of 0.03 in Tier 1 will result in a conservative (low) estimate of the allowable soil concentration.

The value of K_N depends on the composition of the NAPL. However, for Tier 1 calculations, typical K_N values may be estimated for the primary constituents of concern of common NAPLs (e.g., BTEX in weathered gasoline). Following the method of Corapcioglu and Baehr (1987), K_N may be estimated by:

$$K_N = \frac{MF}{C_{sol}} \frac{\rho_N}{X} \tag{5}$$

where MF = constituent mass fraction in the NAPL (unitless);

ρ_N = NAPL density (mg/L);

C_{sol} = pure-phase aqueous constituent solubility (mg/L);

X = constituent mole fraction in the NAPL (unitless).

Equation 5 yields the following K_N values for a composition typical of weathered gasoline (Johnson *et al.,* 1990).

Constituent	K_N (unitless)
Benzene	300
Ethylbenzene	4200
Toluene	1200
Xylene (mixed isomers)	3600

All other variables in Equation 4 may be estimated based on soil type (θ_{ws}, ρ_b) or constituent of concern (K_{oc}), or matched to a conservative default value (f_{oc}=0.001).

3) Lateral Transport in the Fluctuation Zone

Step 2 (Figure 1) depicts the lengthening of the affected groundwater pulse resulting from groundwater flow through the submerged soil zone. Based on the constituent travel distance over time t_{hU}, the length of the resulting groundwater pulse, L_{gw} (ft), is estimated by:

$$L_{gw} = L + v' t_{hU} \tag{6}$$

$$v' = \frac{q}{\theta_{eff} + f_{oc} K_{oc} \rho_b} \tag{7}$$

where L = length of NAPL-affected soils parallel to groundwater flow (ft);
ν = retarded groundwater seepage velocity (ft/day);
θ_{eff} = effective porosity (unitless);
q = groundwater Darcy velocity (ft/day).

As a conservative and simplifying measure, attenuation due to dispersion is neglected in this step, resulting in a uniform constituent concentration within groundwater flowing through the affected soil zone.

4) Pulse Release to Groundwater System

In Step 3 of the process, the water table returns to normal stage, resulting in the instantaneous release of a pulse of contaminated groundwater into the underlying groundwater flow horizon. The concentration of this pulse equals the equilibrium concentration of groundwater in the affected soil zone divided by the fluctuation dilution factor, described in the following section. Following the influx of the pulse source, constituent concentrations in this underlying groundwater flow zone may be estimated as a function of distance and time using the principles of one-dimensional advection-dispersion. For a saturated soil column initially free of contaminants, with a constant in-flowing source concentration, C_0, and with no decay, Ogata and Banks (1961) present the solution to the advection-dispersion equation as:

$$\frac{C(x,t)}{C_0} = \left(\frac{1}{2}\right) \mathrm{erfc}\left(\frac{x - v't}{\sqrt{4\alpha_x v' t}}\right) \tag{8}$$

where α_x = longitudinal dispersivity;
erfc = complementary error function.

However, to calculate constituent concentrations leaving a groundwater zone impacted by a pulse release, the initial and boundary conditions are reversed to consider an initial concentration, C_{pulse}, and a zero-concentration inflowing groundwater stream. For this case, where $x=L_{gw}$ for the end of the source zone, the solution takes the form:

$$\frac{C(\tau)}{C_{pulse}} = 1 - \left(\frac{1}{2}\right) \mathrm{erfc}\left(\frac{L_{gw} - v'\tau}{\sqrt{4\alpha_x v' \tau}}\right) \qquad \text{for } 0 = \tau < T \tag{9}$$

where τ = time following a periodic pulse release.

As a conservative measure, it is assumed that mass transfer to the underlying groundwater zone is a one-way process. Consequently, when the water table rises in Step 1, the underlying groundwater is not affected, but rather continues to attenuate via fresh water flushing until the next pulse occurs at time τ=T (when the cycle again reaches Step 3).

Over time, the average groundwater concentration leaving the pulse zone is simply the average concentration over a single period from $\tau = 0$ to T. Normalizing with respect to the contaminant pulse concentration, an averaging factor for groundwater, AF_{gw}, may be calculated by:

$$AF_{gw} = \frac{C_{avg}}{C_{pulse}} = \frac{1}{T}\int_0^T \left[1 - \left(\frac{1}{2}\right)\mathrm{erfc}\left(\frac{L_{gw} - v'\tau}{\sqrt{4\alpha_x v'\tau}}\right)\right] d\tau \tag{10}$$

Although there is no closed-form analytical solution to the integral of Equation 10, AF_{gw} may be computed via numerical integration using a discretized time step.

5) Fluctuation Dilution Factor

As shown in Figure 1, the thickness of the groundwater pulse zone is assumed to vary from one to two times the thickness of the soil submergence zone. The difference in thickness between these two zones results in the dilution of groundwater contaminant concentrations during the transfer of the pulse from the soil zone to the water-bearing unit. To account for the average effect of this dilution over time, the fluctuation dilution factor (FDF) is defined as the ratio of the soil submergence zone thickness to the *average* groundwater pulse zone thickness.

Based on the idealized square-wave water table function described above (Figure 2), the average water level is given by

$$h_{avg} = (h_U t_{hU} + h_L t_{hL})/T \tag{11}$$

and the base of the groundwater pulse zone may be expressed as

$$h_{base} = 2h_L - h_U \tag{12}$$

Thus, the fluctuation dilution factor is calculated as

$$FDF = \frac{h_{avg} - h_{base}}{h_U - h_L} = \frac{2t_{hU} + t_{hL}}{T} \tag{13}$$

6) Calculation of Soil RBSL Values

Based on the instantaneous-pulse algorithm, the RBSL for affected soils in the fluctuation zone may be calculated by:

$$RBSL_{soil} = \frac{RBSL_{gw}\, FDF}{K_{sw}\, AF_{gw}} \tag{14}$$

where $RBSL_{gw}$ = RBSL for groundwater ingestion (mg/L);
AF_{gw} = normalized average groundwater concentration in the groundwater pulse zone(unitless).

With this approach, several conservative measures tend to overpredict the release of contaminants to groundwater. First, the model assumes saturation-level groundwater concentrations over the entire thickness of the fluctuation zone, regardless of the thickness of the affected soils. Second, the pulse length is extended in Step 2 with no account for dilution due to dispersion. This overestimates the total mass of contaminant in each pulse, slows the pulse attenuation within the underlying groundwater flow zone, and overestimates the average groundwater concentration. Third, the model does not account for source mass reduction resulting from the transfer of mass from the affected soil zone to the groundwater with each pulse, i.e., the mass transferred in each pulse remains constant over time. Fourth, contaminant transfer is assumed to be a one-way process, with no mass returning to the soil zone upon a subsequent rise of the water table.

To derive soil RBSL values using this approach, the user must estimate the frequency and duration of the soil submergence events, as well as the other input parameters listed on Figure 3.

SUMMARY

This memorandum presents an instantaneous-pulse soil submergence model as a simple and conservative approach for deriving RBSL values for affected soils periodically submerged by a fluctuating water table. This method is intended for use under Tiers 1 and 2 of the RBCA process as a conservative screening-level model for sites where groundwater impacts have not been observed. If the screening levels are exceeded, groundwater sampling and testing may be appropriate. For sites where groundwater impacts have been confirmed and response measures are underway, the need to remediate overlying soils to prevent further leachate release should be based on site-specific observations (e.g., observed pulse release to expanding groundwater plume) rather than screening levels.

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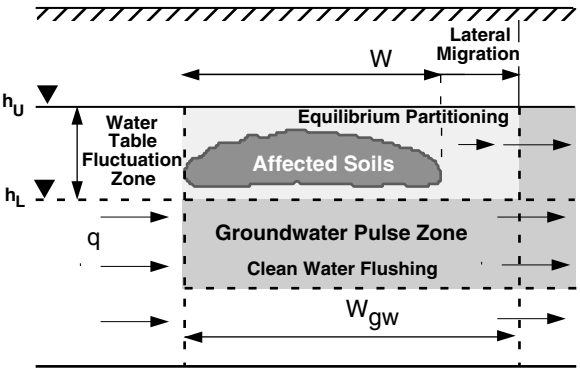
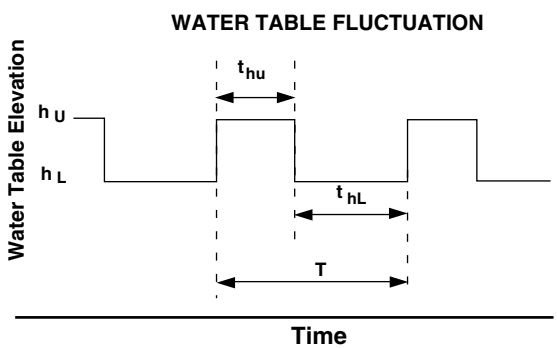
FIGURE 3: SUMMARY OF GROUNDWATER PULSE-SOURCE MODEL





Water Table Fluctuation:

T = (365 days/yr)/f

Equilibrium Partitioning:

$$K_{sw} = \frac{\rho_b}{\theta_{ws} + \theta_N K_N + \rho_b f_{oc} K_{oc}}$$

where $$K_N = \frac{MF \cdot \rho_N}{C_{sol} \cdot X}$$

Lateral Migration (no dispersion):

$$L_{gw} = L + v' \, t_{hU}$$

where $$v' = \frac{q}{\theta_{eff} + f_{oc} K_{oc} \rho_b}$$

Clean Water Flushing (1-D advection-dispersion):

$$AF_{gw} = \frac{1}{T} \int_0^T \left[1 - \left(\frac{1}{2}\right) \mathrm{erfc}\left(\frac{L_{gw} - v' \tau}{\sqrt{4 \alpha_x v' \tau}} \right) \right] d\tau$$

(integrated numerically)

where $\alpha_x = 0.1 \cdot L_{gw}$

Fluctuation Dilution factor:

$$FDF = \frac{2 t_{hU} + t_{hL}}{T}$$

Target Soil Concentration:

$$RBSL_{soil} = \frac{RBSL_{gw} \bullet FDF}{K_{sw} \bullet AF_{gw}}$$

APPENDIX 10. DELAWARE SUBMERGENCE MODEL *(cont'd)*

GSI Job No. G-2227
Issued: 9/15/99
Page 10 of 10

Model Parameters		TIER 1 DEFAULT			TIER 1 DEFAULT
AF_{gw}	Normalized average COC concentration leaving groundwater pulse zone (mg/L)	(see above)	$RBSL_{gw}$	Risk-Based Screening Level in groundwater zone (mg/L)	SS
			S	Aqueous solubility of COC (mg/L)	CS
f	Frequency of water table fluctuations (1/yr)	1	T	Period of water table fluctuation cycle (days)	(see above)
f_{oc}	Fraction of organic carbon (g-C/g-soil)	0.001	t_{hU}	Duration of fluctuation zone submergence (days)	122
K_{oc}	Organic carbon partition coefficient for COC (cm^3-H_2O/g-C)	CS	t_{hL}	Duration of normal water level stage (days)	243
K_N	NAPL-water partition coefficient for COC (mg/L-H_2O/ mg/L-NAPL)	(see above)	X	Mole fraction of COC in source material (mol-COC/mol-NAPL)	CS
K_{sw}	Bulk partition factor for COC (mg/L-H_2O/mg/kg-soil)	(see above)	α_x	Longitudinal groundwater dispersivity (ft)	(see abov)
L	Lateral length of affected soil zone in direction of GW flow (ft)	1500	θ_{eff}	Effective porosity of groundwater zone soils (cm^3-pore-space/cm^3-soil)	0.38
L_{gw}	Length of groundwater pulse zone (fcm)	(see above)	θ_N	Volumetric NAPL content of affected soils (cm^3-NAPL/cm^3-soil)	0.03
q	Groundwater Darcy velocity (cm/yr)	915	θ_{ws}	Volumetric water content of affected soils (cm^3-H_2O/cm^3-soil)	0.35
MF	Mass fraction of COC in source material (kg-COC/kg-NAPL)	CS	ρ_b	Soil bulk density (g-soil/ cm^3-soil)	1.7
$RBSL_{soil}$	Risk-Based Screening Level in fluctuation zone soils (mg/kg)	(see above)	ρ_N	NAPL density (g-NAPL/ cm^3-soil)	0.72

NOTE: SS = Site-specific parameter CS = Chemical-specific parameter

APPENDIX 11.
DEVELOPING AN RBSL FOR MTBE IN DELAWARE

By Pat Ellis

(as published in *Think Tank*, Winter 1999-2000, Number 29)

The Underground Storage Tank Branch recently issued the "final working draft" of the Delaware risk Based Corrective Action Program (DERBCAP) guidance. In developing RBSLs or Risk Based Screening Levels for various chemicals of concern, conservative assumptions were made using generic parameters representative of mid-Atlantic Coastal Plain geology. The following state-wide assumptions were used to develop Tier 0 action levels and Tier 1 RBSLs:

- Grab soil samples are assumed to be collected at the top of the water table,
- Groundwater is assumed to be used for drinking water,
- Current land use is assumed to be residential, and
- Soils are assumed to be well sorted, permeable, fine to medium-grained sand.

The DERBCAP Tier 1 RBSLs are determined by distance from source to a point of exposure (POE) or point of compliance (POC) for each chemical of concern (COC), thus including a fate and transport component in the RBSLs.

RBSLs were calculated using software developed by Groundwater Services, Inc. (GSI). The customized features of the DERBCAP Module to the RBCA Tool Kit for Chemical Releases include variable-distance Tier 1 calculations, Delaware-specific default input parameters and chemical data, and a soil-to-groundwater cross-media transfer model

used to simulate the groundwater impact resulting from the periodic submergence of contaminated soils by a fluctuating water table.

The model calculates natural attenuation of each COC as the sum effect of various physical mechanisms, including natural *dilution*, caused by advection and dispersion, and *attenuation*, caused by sorption, hydrolysis, biodegradation, and other physical/chemical phenomena.

Because the chemical properties of MTBE differ significantly from many of the components of gasoline, and based on experiences with the behavior of MTBE in Delaware soils and groundwater, MTBE Tier 0 action levels and Tier 1 RBSLs are calculated differently than the default method in the GSI Tool Kit.

MTBE is extremely soluble (pure MTBE is about 30 times more soluble than benzene in water), does not sorb well to soils, and is resistant to biodegradation. It also has an extremely low taste and odor threshold.

Because MTBE does not biodegrade easily, the biodegradation factor in the Delaware Module was toggled off when calculating the DERBCAP Tier 0 MTBE action level and Tier 1 MTBE RBSL. Based on experience with MTBE plumes in Delaware and to be sufficiently protective of groundwater not only for potential health effects but also to minimize potential aesthetic impacts to drinking water supplies, the values calculated by the model in this manner were then cut in half. These deviations from the default values allowed the UST Branch to calculate an action level and RBSL for MTBE that should protect against taste and odor impacts to supply wells. Please note that these numbers are action levels, and are not necessarily cleanup levels. Cleanup levels will be assigned to sites on a site-by-site basis based upon distances to actual or potential receptors and the types of receptors.

The Tier 0 Action Level for MTBE is 130 µg/kg (parts per billion) in soil or 0.13 mg/kg (parts per million).

The following table represents the allowable concentrations in source area at varying distances to POE.

Tier 1 RBSLs for MTBE (mg/kg)

Distance to POE	Soil	Groundwater
<50'	0.13	0.18
51-100'	0.16	0.24
101-300'	0.39	0.56
301-500'	2.9	4.2
>500'	7.9	12.0