MINNESOTA POLLUTION CONTROL AGENCY
SITE RESPONSE SECTION

DRAFT GUIDELINES
RISK BASED GUIDANCE FOR THE SOIL LEACHING PATHWAY
USER'S GUIDE

WORKING DRAFT, May 1998

Comment Period Ends December 31, 1998

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NOTICE

THIS DOCUMENT IS A WORKING DRAFT. The Site Response Section of MPCA is developing guidelines for evaluating risks to human health and the environment at sites that may require investigation or response actions pursuant to the Minnesota Environmental Response and Liability Act, Minn. Stat. § 115B.01 to 115B.24 (MERLA).

DEVELOPMENT OF A SITE RESPONSE SECTION SITE EVALUATION MANUAL. The attached document and other documents not yet developed will be incorporated into a Site Response Risk-Based Site Evaluation Manual which will contain guidelines for conducting MERLA-related evaluations, including risk evaluations under the State Superfund program and the MPCA Voluntary Investigation and Cleanup (VIC) Program.

MPCA staff intend to use the policies and procedures in the proposed manual as guidelines to evaluate the need for investigation or remedial actions to address releases and threatened releases of hazardous substances or pollutants or contaminants under MERLA, and the scope and nature of such actions. These policies and procedures are not exclusive and do not have the force and effect of law. MPCA staff may use other policies or procedures to evaluate the need for or adequacy of response actions under MERLA, including procedures set forth in outstanding MPCA Requests for Response Action and Consent Orders. The final standard for all such evaluations is the MERLA statutory requirement that such actions must be reasonable and necessary to protect the public health and welfare and the environment.

APPLICATION TO SITES MUST BE PRE-APPROVED. At this time, Site Response Section staff shall accept only written comments regarding this draft document (see comment period and address above). During guideline development, application of these guidelines or procedures shall be Site-specific, conducted in consultation with and upon approval of MPCA Site Response Section staff assigned to the specific site.

INTERIM CHANGES TO DRAFTS. Document users are responsible for contacting MPCA staff assigned to the site to get the latest unpublished changes to the document.

Distribution List:

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Note: For definitions of terms and concepts, please refer to the RBSE Glossary document.

EXECUTIVE SUMMARY

The Site Response Section (SRS) of the Minnesota Pollution Control Agency (MPCA) developed this Risk Based Guidance For Evaluating The Soil Leaching Pathway as part of a section wide guidance development effort. The document is intended to be used for evaluation of the soil leaching pathway at Voluntary Investigation and Cleanup (VIC) and Superfund sites.

Evaluation of the soil leaching pathway consists of an assessment of the risk posed to ground water and associated receptors from a source of soil contamination in the unsaturated zone. Contaminant and generic soil specific properties are used to predict soil concentration levels that are considered to represent an unacceptable risk to ground water via the leaching pathway. These levels are referred to as Soil Leaching Values (SLVs) and are intended to serve as guidelines for making corrective action decisions. This guidance utilizes a three tiered approach that entails gathering progressively greater amounts of site specific information.

A Tier 1 evaluation of the leaching pathway is designed to screen out contaminants or sources that are not considered to represent a risk and to ground water and to identify sources and contaminants of potential concern (COPC) by comparing a suite of site soil concentration values toa suite of tabulated Tier 1 SLVs. Tier 1 SLVs may be used as cleanup criteria in some instances, although a Tier 2 or Tier 3 evaluation will provide a more realistic estimation of risk to ground water. The rationale is presented for Tier 1 SLVs, and the generic assumptions and equations used to generate these values are discussed. A dilution attenuation factor (DAF) that provides an estimation of the decrease in concentration as leachate enters and mixes with site ground water is available at all Tiers.

At the Tier 2 level additional site data is typically available which allows for a more site specific evaluation. A series of electronic spreadsheets (the Spreadsheet) are provided with supporting guidance to allow users to enter site specific information and develop site specific Tier 2 SLVs. Using the Spreadsheet, Tier 2 SLVs may be generated based on modifications of the Tier 1 partitioning equation or, for a limited number of compounds, using soil leachate concentrations (SLCs, risk values based on leachate alone prior to ground water mixing) developed by MPCA using the Seasonal Soil Compartment Model (SESOIL). A depth to water adjustment is available at Tier 2 expressed by the Contaminant Redistribution Factor (CRF). The Tier 2 SLV thus equals the (SLC)*(DAF)*(CRF). Site specific estimates of the DAF are encouraged utilizing specific site hydrologic characteristics and tabulated estimates of infiltration rates. In most circumstances a Tier 2 evaluation will result in a SLV that is appreciably higher than the Tier 1 value. Site specific inputs used at the Tier 2 level include: soil organic carbon content; soil pH; infiltration rate; depth to ground water; hydraulic conductivity; hydraulic gradient; source length; and mixing depth in aquifer. Development of a site specific soil-water partition coefficient is an option at Tier 2 or Tier 3.

Since both Tier 1 and Tier 2 utilize an equilibrium partitioning equation along with generic site inputs designed principally for unconsolidated glacial or alluvial conditions, some site conditions will not be appropriate for either a Tier 1 or Tier 2 evaluation an may require a Tier 3 evaluation. These conditions include soils in which free phase product serves as a leaching source, karstic conditions and unusual chemical soil environments that may serve to enhance or inhibit contaminant leaching.

A Tier 3 evaluation allows a user to go beyond guidance currently available in this guidance as long as justifiable supporting rationale is provided that is consistent with the risk based policies in Site Response Section. A Tier 3 evaluation will typically evaluate the predicted effect of site specific conditions - such as estimating the effect on leaching due to specific site geology; geochemical environments, hydrology, or biodegradation processes. Tier 3 evaluations may incorporate site specific modeling and may require in some cases special monitoring requirements or treatability studies.

RISK BASED GUIDANCE FOR THE SOIL LEACHING PATHWAY USER'S GUIDE

1.0 INTRODUCTION: PURPOSE AND SCOPE

This document is designed to assist users in properly applying risk based guidance for evaluating the soil-to-ground water leaching pathway (leaching pathway) for sites administered in Site Response Section of the Minnesota Pollution Control Agency (MPCA). The leaching pathway evaluation considers the risk posed by the migration of soil contaminants to ground water. Procedures are presented to estimate soil contaminant concentrations that could remain at a site and not pose an unacceptable risk to ground water. These soil contaminant-specific concentrations, above which an unacceptable risk to ground water is predicted to exist, are referred to as soil leaching values (SLVs) and their utility is structured within a three tiered framework. Additional technical support for the SLVs and their application can be found in the "Working Draft - Risk Based Guidance For Evaluating the Soil Leaching Pathway, Technical Support Document" (Technical Support Document).

2.0 THE TIERED FRAMEWORK

This guidance utilizes a three tiered approach that requires progressively more site specific information and parallels the framework established by the ASTM E-1739 (1995) for risk-based corrective actions (RBCA). Although other risk based exposure pathways are evaluated using a similar three tiered framework, the tiered guidance outlined in this document addresses only the leaching pathway. A Tier 1 evaluation is a screening evaluation in which site soil contaminant concentrations are compared directly to tabulated Tier 1 SLVs. Compounds that exceed their respective Tier 1 SLV are considered compounds of potential concern (COPC) for the leaching pathway and should be further evaluated at the Tier 2 level. A Tier 2 evaluation consists of developing site specific SLVs using site specific information, such as source area dimensions, soil properties, aquifer characteristics and applying them as potential cleanup criteria. A Tier 3 evaluation involves consideration of very site specific conditions and allows the user to make recommendations for corrective active decisions for the leaching pathway that may extend beyond the Tier 2 guidance presented in this document as long as they are properly documented, are justifiable and are consistent with the Site Response risk based policies. This User's Guide focuses primarily on Tier 1 and Tier 2 guidance.

3.0 CONDUCTING A TIER 1 EVALUATION

3.1 Identify and Characterize Source Areas

Prior to conducting a Tier 1 evaluation, a site investigation characterizing potential environmental source areas must be conducted. A source area for the purposes of this guidance is a distinct area of soil contamination at a site where contaminants may leach to ground water. Soil contamination in a source area may be the result of one or multiple release mechanisms. Specific source areas can be identified by a review of historical records and conducting a site walk-over followed by surface and subsurface investigation to verify the extent and magnitude of contamination. For Tier 1 SLVs to be applied as screening criteria at a given source area, hot spots or areas of maximum concentration should be identified and properly sampled.

Table 1 presents a summary of types of site data needed to evaluate the soil leaching pathway at the Tier 1 and Tier 2 levels. Although the collection of site data may be limited to soil analytical data at the Tier 1 level, it may be helpful to be aware of the additional site data that may be required at Tier 2 or Tier 3.

3.2 Use of the Tier 1 SLVs

The Tier 1 SLVs are presented in Attachment A and on the soil leaching spreadsheet (Spreadsheet) designed for conducting both a Tier 1 and a Tier 2 evaluation. The Tier 1 SLVs are designed to screen out, during the initial phase of a site investigation, compounds or source areas that do not require further evaluation for the leaching pathway and to identify chemicals and source areas that may pose a risk to ground water. A summary of the basis for these values and the conceptual site model used to select Tier 1 default site parameters is presented in Section 3.3. A Tier 1 evaluation is conducted by comparing each contaminant soil concentration with its respective Tier 1 SLV which may be facilitated by use of the "Tier 1 SLVs" worksheet on the Spreadsheet. A chemical is considered to have "passed" the Tier 1 evaluation if all sample concentrations for that chemical are at or below the Tier 1 SLV. Chemicals that "pass" the Tier 1 evaluation are determined not to pose potential risk to ground water and require no further evaluation. A chemical is considered to have "failed" the screening if any contaminant concentrations exceed the Tier 1 SLV. Chemicals that "fail" the Tier 1 evaluation at a given source area are considered to pose a potential risk to ground water via the leaching pathway and remain as COPC that should be further evaluated at the Tier 2 or Tier 3 level. There may be certain compounds with tabulated Tier 1 SLVs that are lower than the typical analytical laboratory reporting limits for these compounds. In these cases the laboratory reporting limit may be used as the Tier 1 SLV for these compounds.

A Tier 1 SLV applied as remediation goal will likely result in a more conservative estimation of risk than a Tier 2 or 3 risk evaluation. The cost of collecting additional site data required for a Tier 2 or 3 evaluation may be compared to remediation costs using Tier 1 SLVs as remedial goals. Use of Tier 1 SLVs may be appropriate, for example, at sites where source area contamination exceeds the Tier 1 SLVs, but is volumetrically small and easily excavated or remedied.

3.3 Conceptual Site Model For The Tier 1 SLVs

Tier 1 SLVs presented in Attachment A were calculated using a combination equilibrium partitioning equation and a ground water dilution term as recommended in the United States Environmental Protection Agency Soil Screening Guidance (USEPA, 1996a, 1996b) and shown as Equations 1 and 2 in Table 2. The Dilution Attenuation Factor (DAF) is a unitless factor based on a simple mass flux model that is used to estimate the attenuation of the soil leachate concentration after it has mixed with ground water. Supporting rationale for these equations can be found in the USEPA's Soil Screening Guidance (USEPA, 1996a, 1996b) and in the Technical Support Document for this User's Guide. This guidance uses the shorthand notation, the Soil Leaching Concentration (SLC) to refer to the factor

$$SLC = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right) \qquad \text{[Equation 3]}$$

such that the Tier 1 SLV equation can be more simply expressed as

Tier 1 SLV = (Soil Leaching Concentration)*(Dilution Attenuation Factor), or SLC x DAF

Table 1: Site Specific Inputs For Evaluating the Soil Leaching Pathway

PARAMETER	DATA SOURCE	PURPOSE/USE
Source Dimensions		
Source Length Parallel To GW Flow (L)	Site measurement. Default of 100 feet used at Tier 1.	Required for Tier 2 DAF and Tier 2 mixing zone approximation.
Source thickness (d1)	Site measurement; not used in Tier 1.	Used to evaluate potential risk to ground water; required to calculate Tier 2 contaminant redistribution factor (CRF).
Depth of Source To GW (d2)	Use zero thickness or Site measurement. Assumed to be 0 at Tier 1.	Used to evaluate potential risk to ground water; required to calculate contaminant redistribution factor (CRF).
Soil Characteristics		
Soil Textures	Field description using soil classification. Tier 1 based on defaults for a sandy loam.	Required for Tier 2 evaluation to estimate site specific infiltration rate.
Soil Porosity	Use tabulated estimates in the Spreadsheet for Tier 2. Tier 1 uses 0.4 as a value for total porosity.	Required parameter for Tier 2 partition equation modification.
Site Stratigraphy	Field description, Cross-sections.	Required for developing a Tier 2 conceptual site model.
Soil Moisture Content (θw)	Tabulated estimates for Tier 2 in Tables 4A or 4B and provided in the Spreadsheet.	Required for use of partitioningequation; not required for use of SESOIL-derived Tier 2 SLCs.
Soil Total Organic Carbon (foc)	Laboratory measurement, minimum of 3 samples per source area. Default of 0.2% used at Tier 1.	Used to calculate or modify soil-water partition coefficient for organic compounds. To evaluate sorptive potential of COPC in soil column.
Soil pH	Field/Lab measurement. Neutral pH assumed at Tier 1.	Required if metals/metalloids or ionizable organics are COPC.
Meterological Data		
Average Annual Precipitation Rate/Infiltation Rate Scaling Factor (ISF)	Only used at Tier 2; Use Tables 4A-4C or on the Spreadsheet.	Based on a site's location and soil textures, the ISF is a scaling factor used to develop the adjusted estimated infiltration rate.
Hydrogeologic Characteristics		
Infiltration Rate (I)	For Tier 2 use Tables 4A-4C or the Spreadsheet. Tier 1 default value is 14 cm/yr.	Required for Tier 2 DAF and mixing zone calculation; estimated using soil descriptions, site location and look-up tables.
Hydraulic Conductivity (K)	Field measurement (slug or pump tests) or approved defaults	Required parameter for Tier 2 DAF.
Aquifer Thickness (b)	Field measurement; Only needed if Depth of Mixing Equation used (Table 6, Equation 6).	Required for use in USEPA mixing zone depth approximation at Tier 2.
Ground Water Quality Data		
Depth of Mixing (dm)	Tier 2 site measurements of vertical extent of GW contamination in plume. Optional Tier 2 site measurement.	This empirical estimate of the depth of mixing is optional, but may be used at Tier 2 in determining the site specific DAF.
Receptor survey	Records search, CWI search, interviews, field observations.	Required to evaluate ground water risk .
Extent of GW Plume	Field/Lab measurement	Required to evaluate ground water risk.
Ground water monitoring trends of soil leaching COPCs	Field/Lab measurement	Required to evaluate ground water risk.
Chemical Data		
Kd	Defaults tabulated in the Spreadsheet; Field/Laboratory Study. Other supportable Kd or Koc in the research literature.	Required for soil partitioning equation and Tier 3 soil modeling.

Note: The following additional chemical data may be required for calculating SLVs; defaults selected from standard chemical references are used.		
Henrys Law Constant	Standard chemical references	Required parameter to calculate SLVs for volatile contaminants.
Air Diffusion Coefficient	Literature values or approximation from molecular weight of contaminant.	Required parameter for SESOIL volatilization modeling.
Molecular Weight	Standard chemical references	May be used to approximate air diffusion coefficient; required parameter in SESOIL.
Octonol-Water Partition Coefficient (Kow)	Standard chemical references	Used to approximate some Koc values.
Solubility	Standard chemical references	Required to calculate Soil Saturation Limit values, used to approximate some Kows.

Table 2: Tier 1 Soil Leaching Value (SLV) Equation for the Soil Leaching Exposure Pathway

$$\text{Tier 1 SLV} = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right)(DAF) \qquad \text{[Equation 1]}$$

where

Tier 1 Dilution Attenuation Factor (DAF)

$$= \left[1 + \frac{Kid_m}{IL}\right] \qquad \text{[Equation 2]}$$

Parameter - Definition (units)	Default
C_w - target soil leachate concentration (mg/L)	HRL , HBV or MCL
K_d - soil-water partition coefficient (L/kg)	K_{oc} x f_{oc} for organic compounds; compound specific for metals
K_{oc} - soil-water organic carbon partition coefficient (L/kg)	chemical-specific
f_{oc} - fraction organic carbon in soil (g/g)	0.002 (0.2%)
θ_w - volumetric water content (water-filled soil porosity) (L_{water}/L_{soil})	0.15 appropriate for Loamy Sand
θ_a - air-filled soil porosity (L_{air}/L_{soil})	n - θ_w = .26
ρ_b - dry bulk soil density (kg/L)	1.5
n - total soil porosity (L_{pore}/L_{soil})	0.40
H' - dimensionless Henry's law constant	chemical-specific, assumed zero for inorganic contaminants.
K - saturated Hydraulic conductivity of aquifer beneath source (cm/yr)	157,580 cm/yr (5E-03 cm/s)
i - hydraulic gradient (dimensionless)	0.005
d_m - depth of mixing of leachate within aquifer (cm)	457.2 cm (15 feet)
I - infiltration rate (cm/yr)	14
L - length of contaminant source parallel to ground water flow direction (cm)	3048 cm (based on default of a 100 feet representative of 0.25 acre source area)
DAF - ground water dilution attenuation factor due to leachate-ground water mixing (dimensionless)	10

Note: Refer to Section 4 of the Technical Support Document or the Soil Leaching Spreadsheet for a summary of the chemical specific parameters used in Tier 1 and Tier 2. Most Koc values for organic compounds and Kd values for metals were compiled from standard chemical references (Montgomery, 1996) or the USEPA Soil Screening Guidance (USEPA, 1996a).

A diagram of the Tier 1 conceptual site model used to develop the Tier 1 SLVs and on which the defaults presented in Table 2 are based is illustrated schematically below in Figure 1. A conceptual model and default site inputs were chosen to reflect a physical setting typically encountered at Site Response Section sites, a

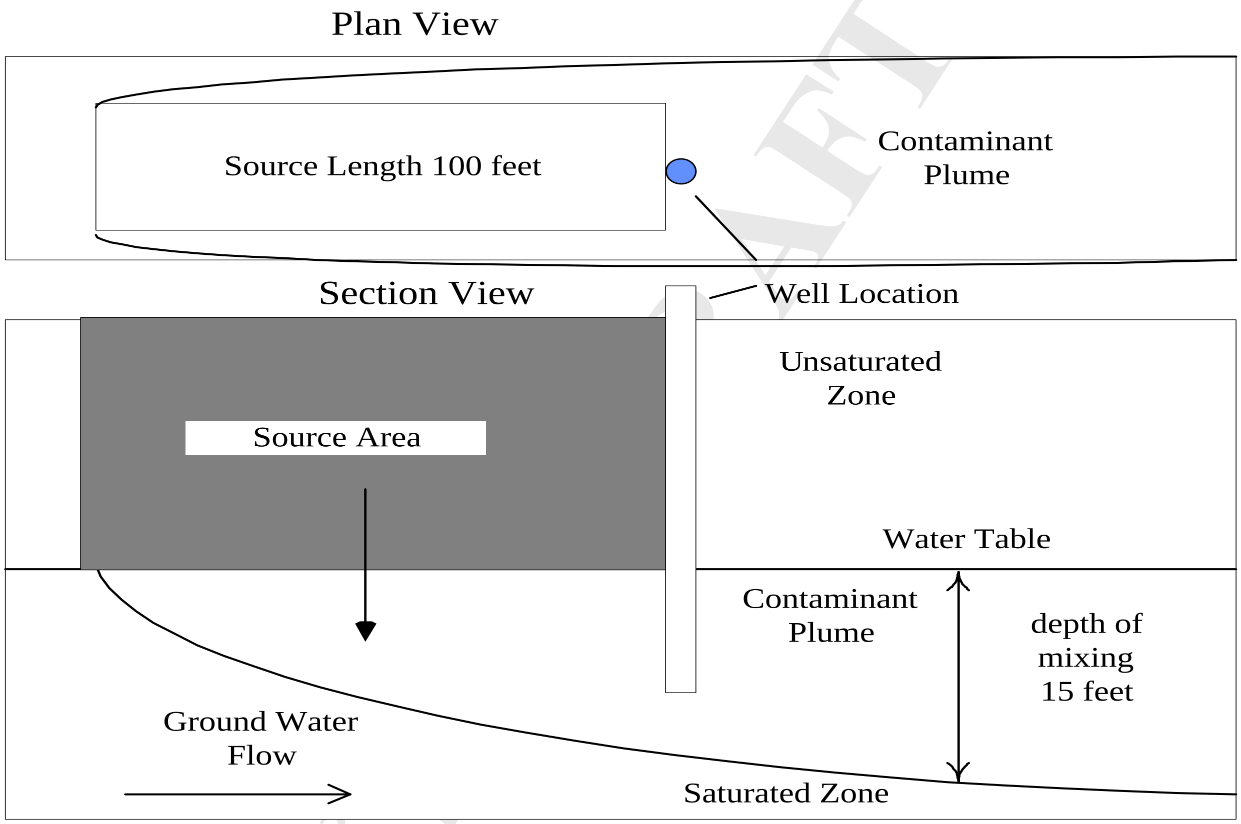

Figure 1: Tier 1 Conceptual Site Model

source area 100 feet in length that is leaching through the soil column to an underlying loamy glacial or alluvial sandy surficial aquifer. This conceptual site model assumes that the soil texture is uniform and that soil contamination in the vadose zone extends to the water table. For Tier 1 the ground water compliance point is a hypothetical well located at the downgradient edge of the source area. Use of these defaults and the DAF equation presented in Figure 1, results in a Tier 1 DAF of 10. This value should be representative for many sites. However for sites where soil textures significantly limits the amount of ground water recharge this default DAF of 10 may be too low. The USEPA found as part of a nationwide study (undertook to model predicted DAFs as a function of source area size, USEPA, 1994) that the 90th percentile DAF value in their study was on the order of 100 or higher for a source area of 1 acre or smaller. For source areas greater than 10 acres, the 90th Percentile for the DAF was 10 or less. Since most of Site Response sites have source areas significantly less than 10 acres, a Tier 1 DAF default value of 10 is generally reasonable and may be used as the minimum DAF value. In addition to length of source area parallel to ground water flow (L), several other hydrologic factors (see Table 2) also control the DAF value including saturated hydraulic conductivity (K) and gradient (i), infiltration rate (I) and depth of mixing (d_m). Tier 2 guidance for developing site specific DAFs is provided in Section 4.2.3.

3.4 Conditions Inappropriate For a Tier 1 Evaluation

The Tier 1 SLVs are based on conservative assumptions; however, under some situations employing them to "screen-out" chemicals or source areas may not be appropriate. If heavy metals are a COPC, the user should conduct a Tier 2 or in some cases a Tier 3 evaluation rather than making a determination that no risk exists solely on the basis of a Tier 1 evaluation. The mobility of heavy metals and metalloids in soils is influenced by various geochemical processes such as acid-base equilibria, complexation with organic and inorganic ligands, precipitation and dissolution of solids, oxidation-reduction, ion-exchange and adsorption to soil particles and organics (McLean and Bledsoe, 1992). The complexity of these processes cannot be adequately addressed at the Tier 1 level and, in many cases, even at Tier 2. The user should be aware that the Tier 1 SLVs for metals are based upon the assumption that the soil pH is neutral - in a range from 6.5 to 7.5. For pH conditions other than neutral, use of the Tier 1 SLVs may significantly under predict the amount of leaching for all metals except chromium III, selenium, and cyanide, whose mobility is predicted to increase with increasing pH (USEPA, 1996a, Meussen, et al., 1994). If metals are a COPC based on the Tier 1 screening evaluation or based on information obtained from a Phase I Investigation, then a minimum of three soil samples for soil pH should be collected in the identified source areas and a Tier 2 evaluation should be conducted.

At sites where non-aqueous phase liquid (NAPL) has been identified in soils or is strongly suspected to be present in the aquifer, a Tier 2 or Tier 3 evaluation should be conducted. In these cases, the remediation of contaminated soils may need to be deferred until the NAPL serving as a continuing source of ground water contamination is addressed. At sites where drums or refuse have been identified or suspected, the site investigation should be expanded and focused to identify containers or drums, to characterize their contents and to define the nature and extent of the refuse, if feasible.

The Tier 1 SLVs are based on an assumption that the site unsaturated zone is comprised of unconsolidated soils, as is commonly the case with soils of glacial and alluvial origin in Minnesota. A Tier 3 evaluation may be required if the unsaturated zone of a site is consolidated bedrock and especially if the bedrock is fractured or in a karst terrain.

A Tier 1 evaluation for the leaching pathway may also be inappropriate at sites where the ground water to surface water is a potential pathway of concern. Some contaminants have more restrictive surface water criteria than the ground water criteria and therefore, the surface water criteria may need to be applied rather than the ground water criteria as part of a Tier 3 evaluation. The surface water chronic standard may be applied as screening criteria at a ground water monitoring well upgradient from a surface water body. At higher Tiers; however, the attenuation of ground water concentrations due to mixing with surface water may be incorporated in order to provide a more realistic estimate of the potential for ground water concentrations to exceed the chronic standards in the surface water body.

Another pathway that may be of concern for contaminated soil and ground water is the contaminant vapor to building migration. The vapor migration pathway may be need to be evaluated where structures are located near areas where highly permeable soils contain elevated concentration of VOCs at shallow depths. If a vapor migration risk of contaminated soils or ground water is suspected, the additional risk posed by further leaching of soil contaminants may need to be evaluated. Neither the Tier 1 or Tier 2 SLVs take into consideration risk posed by vapor migration.

4.0 CONDUCTING A TIER 2 EVALUATION

4.1 Information Required For Conducting a Tier 2 Evaluation

Contaminant concentrations that exceed Tier 1 SLVs may represent a potential risk to ground water and are considered COPC that warrant a Tier 2 evaluation. A Tier 2 evaluation for the leaching pathway utilizes less generic assumptions and more site specific information to make a more realistic estimate of the risk to ground water. At this stage an analysis to compare costs of a Tier 2 or Tier 2 level evaluation verses proceeding with remedial decisions based on the Tier 1 SLVs may be warranted. However, most of the requirements for a Tier 2 investigation can easily be collected during the course of Phase II Investigations. The extent and magnitude of soil and ground water contamination should be determined for each source area accompanied by a thorough ground water receptor survey. Tier 2 SLVs for COPC can be made without information on ground water monitoring data, but site corrective action decisions based on the leaching pathway are best made in association with information about the past and present risk directly posed by ground water contamination. Site data required for the calculation of Tier 2 SLVs are tabulated in Table 1 and include measurement of pertinent soil properties, determination of aquifer characteristics and measurement of source area dimensions. These site data inputs are discussed in further detail below, however this list should not be viewed as exhaustive, but rather as the minimum Tier 2 site data requirements. These data will determine to a large degree how the default Tier 1 assumptions may be modified.

4.1.1 Collect Soil Samples To Evaluate Extent and Magnitude of Soil Impacts

A minimum of three soil borings, probes, or trenches should be conducted in each suspected source area to determine the vertical and horizontal extent of soil contamination in the unsaturated zone. Each sampling location should include logged lithologic descriptions and samples representative of the entire vadose zone. Trenches may substitute for soil borings or probes advanced using Drive Point Technologies (DPT) if the water table can be reached by the backhoe bucket. Additional borings, DPT probes, or trenches should be added as needed to characterize the extent and magnitude of the soil contamination. In addition, a minimum of three soil sampling locations are recommended for the area of highest contamination for each source area. Proper precautions and design of boreholes is critical if concern exists for the vertical cross-contamination or transfer of contaminants.

Soil sampling and descriptions should be continuous from the ground surface to the water table, although this is not practicable in all cases. Soil samples should be screened visually and with appropriate field instruments (e.g. photoionization detector, an organic vapor analyzer, XRF, immunoassay kits or other similar portable instruments) and appropriate field methods. This screening should take place at each logged interval in an effort to identify the relative magnitude and vertical distribution of soil contamination, with emphasis on a) identifying the upper and lower boundaries of contaminated intervals, b) identifying the interval exhibiting the highest level of contamination and c) assessing the magnitude of soil contamination at the water table.

Based upon field screening and physical observations, samples should then be collected for laboratory analysis to verify a) contaminant concentrations in the zone of greatest impacts; b) the vertical extent of contamination and c) the magnitude of vadose zone contamination at the water table. This equates to three or four analytical samples from each boring within the source areas. If no methods are directly available or appropriate for screening other than visual evidence, additional analytical samples may be necessary at certain locations. Refer to the “Site Characterization and Sampling Guidance” for additional information on sampling. If a soil contaminant interval in a borehole is characterized by a sufficient number of properly collected analytical samples, data from these intervals may be used to calculate a depth-weighted average concentration, referred to as normalized leachate concentrations or DWCs, as described in Attachment B.

4.1.2 Determine Source Area Dimensions

Assessment of potential source areas should attempt to measure the areal and vertical extent of each contiguous source area that exceeds Tier 1 SLVs for COPCs. The length of the source area parallel to ground water flow (L) is needed to estimate a site specific DAF. Ground water flow direction measurements should be based on ground water elevation measurements from at least two quarterly sampling events or two seasonal sampling events. If the implied ground water flow direction is variable or indeterminate, then use the longest aerial dimension of the source as the source area length. In addition to source area length, both the average vertical thickness of the soil zone impacted above Tier 1 SLVs and the average vertical thickness from the base of the source zone to the top of the ground water table should be determined. The use of this information is discussed in Section 4.2.

4.1.3 Describe Soil Textures and Soil Characteristics

Soil and sediment textures should be described and logged by a geologist or qualified engineer using either the US Department of Agriculture (USDA, 1951; Brady, 1990) or the Unified Soil Classification System (USCS, described in the American Society for Testing and Materials, ASTM D-2487-93, 1993). The USDA classification is preferred if only one soil classification is used, although the USCS classification may be desired for geotechnical purposes. The descriptions of soils; however, should include lithologic and stratigraphic descriptions of the vertical soil profile to enable the recognition and logging of zones of varying and contrasting permeabilities in both the horizontal and vertical directions. If the unsaturated zone is bedrock, zones of primary porosity should be described along with describing fracture porosity where present.

At least three soil samples should be collected to assess the fraction of total organic carbon (foc) in and beneath the contaminated soil interval. The distribution of organic matter in the soil column at a source area is used to assess the potential for sorption and thus attenuation of organic chemicals. The value of the soil-water partition coefficient (Kd) for organic compounds may be estimated by the relationship Kd = (foc)*(Koc), where Koc is the soil-water organic carbon partition coefficient. Values of Koc for organic compounds were compiled from the research literature (largely Montgomery, 1996) and the USEPA Soil Screening Document (1996a).

In addition to measuring organic carbon levels in soils, if heavy metals are COPC, the average soil pH should be measured along with identifying any unusually high or low soil pH. A Tier 3 evaluation of the potential for leaching of heavy metals may also be recommended in order to evaluate the geochemical factors influencing metal mobility in soils.

4.1.4 Determine Aquifer and Hydrologic Characteristics

Determine the hydraulic gradient, hydraulic conductivity and the extent of the saturated formation beneath the source area. The hydraulic gradient should be based on an average of at least two sets of measurements from a network of permanently installed monitoring wells or piezometers. Hydraulic conductivity estimates are best obtained from pump test results; however, single well response tests or estimates based on aquifer lithologic descriptions may be acceptable. The thickness of the aquifer beneath the source area should be either measured or a reasonable estimate made using published regional or local hydrogeologic sources of information. In addition to aquifer characteristics, estimates of average annual infiltration rates are required in order to determine a site specific DAF. Although site specific measurements may be conducted, estimates may be made using soil lithology descriptions obtained by soil borings or DPT or trenches in association with look-up tables (see Section 4.2.3) for estimated infiltration rates for Minnesota. At Tier 2, these estimates for infiltration rate are further adjusted based on the average annual precipitation rate at the site being evaluated. The rationale for these default tables are provided in the Technical Support Document.

4.1.5 Conduct a Ground Water Investigation

To properly apply Tier 2 SLVs for site corrective action decisions a ground water risk investigation should be conducted. How the Tier 2 SLVs will be applied for corrective action decisions will, in part be controlled by the conclusions of the ground water risk evaluation. The presence and concentration of contaminants in ground water can be used in a qualitative manner to evaluate the risk posed by specific COPC in the unsaturated zone for past and future potential leaching for specific compounds or groups of compounds with similar properties. The absence of specific COPC in ground water that otherwise would have been predicted to have been detected based upon Tier 2 SLVs may be indicative of other attenuation mechanisms not accounted for by the Tier 2 SLVs. Conversely, ground water contaminants not identified as COPC for the leaching pathway could suggest unidentified source areas, poor sampling design, evidence of very mobile and permeable soils or indications of loss of contaminants in the soil column due to volatilization. Refer to the "Ground Water Risk-Based Decision-Making Guidance" for details on conducting a ground water evaluation.

4.2 Calculating a Site Specific Tier 2 SLV

4.2.1 Tier 2 SLV Terminology

The Tier 2 SLV is determined by estimating site specific values for the following variables:

Tier 2 SLV = (SLC)*(DAF)*(CRF) [Equation 4]

The SLC and the DAF, previously described in Section 3.3, represents the Soil Leaching Concentration (mg/kg) and the Dilution Attenuation Factor (unitless), respectively. The DAF is calculated using Equation 2 in Table 2.

The CRF is the Contaminant Redistribution Factor, a unitless factor that may be used to estimate contaminant attenuation at sites due to storage and/or loss of chemicals from a contaminated soil layer to an underlying, nonimpacted layer. It is calculated by the following equation:

$$CRF = \frac{d_1 + d_2}{d_1}\text{, where} \qquad \text{[Equation 5]}$$

- d_1 = the vertical thickness of an upper contaminated soil layer; and
- d_2 = the vertical thickness of a lower uncontaminated soil layer between the base of soil contamination and the first saturated soil zone.

The CRF is based on a relatively simple contaminant mass redistribution approach of estimating the reduced leachate concentration that would result if contaminant mass in an upper contaminated soil interval (referred to Zone 1) is allowed to migrate vertically and redistribute evenly through initially uncontaminated soils in a soil interval between Soil Zone 1 and the water table (referred to as Zone 2). Biodegradation, volatilization, loss of contaminant mass to ground water, and sorptive properties of individual compounds is not considered. This depth attenuation approach using the CRF; however, should provide a conservative, practical, and significant adjustment of the Tier 2 SLV at sites where the source contamination is at a significant distance from the water table. Refer to Section 5 of the Technical Support Document for the mathematical basis of the CRF. For the Tier 1 SLVs, the CRF was assumed to be equal to one.

4.2.2 Overview of Calculating a Tier 2 SLV

The process of calculating Tier 2 SLVs for COPCs consists of making site specific estimates of the variables shown in Equation 4 and is facilitated by use of a series of spreadsheets collected refered to as the Spreadsheet. At the Tier 2 level, there are two options for calculating the SLC: 1) modification of the equation for the SLC (Equation 1 in Table 2); and 2) using SLC values based on model runs conducted and compiled by the MPCA using the Seasonal Soil Compartment Model (SESOIL). SESOIL derived SLC values are not currently available for metals and several organic compounds. Additional SESOIL derived SLC values were developed for 12 commonly biodegradable compounds for which biodegradation factors were readily available. The Spreadsheet includes a worksheet labeled “Tier 2 SLV Worksheet” (Worksheet) which allows one to enter site inputs to determine the Tier 2 SLV in a step-wise manner as outlined in Section 4.2.3. In addition to the Worksheet, the Spreadsheet contains a compilation of chemical data used in Tier 1 and Tier 2 evaluations. Table 3 presents a list of the individual worksheets.

Table 3: List of Individual Worksheets in the Soil Leaching Spreadsheet

SPREADSHEET LABEL	DESCRIPTION
Chemical Data	Soil-organic carbon partition coefficients (Kocs), Henry's Law Constants (H) and diffusion coefficients to be used as defaults for SLVs. These are provided for reference only; the Worksheet uses the Kocs and H from this table but need not be entered by the user.
Metal Kd Values	USEPA (1996a) Kds as a function of pH are default Kd values for metals at Tier 2 are tabulated for reference only. For neutral pH conditions, an alternative set of metal Kd values compiled by Thibault et al. (1990) may be applied if soil and ground water are well characterized.
Ionizable Organics Kocs	Tabulation of Kocs as a function of soil pH for ionizable organic compounds, from USEPA, 1996a for reference only. These values are Tier 2 default and will be selected automatically by the Worksheet based on user soil pH input value.
Tier 1 SLVs	Tabulation of the Tier 1 SLVs. A column is included for user input of soil concentration data.
Tier 2 SLV Worksheet (Worksheet)	The top part of the Worksheet allows a step-wise input of site specific data to calculate Tier 2 SLVs; the lower part displays calculation tables with SLVs using the partition equation and available SESOIL derived SLVs.

Table 3: List of Individual Worksheets in the Soil Leaching Spreadsheet (Continued)

SPREADSHEET LABEL	DESCRIPTION
Tier 2 SLV Results	This worksheet summarizes Tier 2 SLVs determined from completion of the Worksheet. Site concentrations are compared with the Tier 2 SLVs to determine if a risk is posed to ground water by leaching of individual compounds.
Biodegradation-Adjusted SLVs	Tier 2 SLVs that incorporate biodegradation factors for thirteen compounds that readily biodegrade are presented. These calculations use user input from the completed Worksheet.
Soil Saturation Concentrations	Two sets of calculated soil saturation concentrations are compiled based the defaults of soils with foc of 0.2% and of 0.6%.

4.2.3 Using the Soil Leaching Spreadsheet (Spreadsheet)

This section provides instructions in choosing the appropriate site data to enter into the Spreadsheet and in understanding its use and application. For the rationale and technical support for the calculations presented in the Spreadsheet, refer to Sections 4 and 5 of the Technical Support Document.

STEP 1: Estimating Soil Parameters

In Step 1, the user is prompted for inputs for volumetric water content (θw), soil air porosity (θa), fraction of total organic carbon (foc) and soil pH. Soil porosity defaults are available from tables presented on the Spreadsheet for Step 1 (Tables 4A and 4B, below). The two tables are equivalent except that Table 4A presents default soil characteristics for soil textures based on the USDA classification and Table 4B is based on the USCS Classification.

The soil type selected should be the finest grained soil type identified in the unsaturated zone within or below the suspected source interval. It should also represent at least 25 percent of the total soil textures in this interval. If, for example, at least 25 percent of the total interval from the top of the source layer to ground water is a clay loam, the soil characteristics should be selected representative clay loam in Table 4A assuming this is the finest grained soil texture. The interval accounting for this 25 percent need not be contiguous. Note that total soil porosity is calculated by the Worksheet automatically by summing the value for volumetric water content and soil air porosity. The foc is entered in Step 1B by averaging site foc data representative of the area being evaluated or, by entering the Tier 1 default of 0.2 %, if no site data is available.

Step 1C of the Worksheet prompts the user to enter measured values for soil pH. Use of site measured values of pH (as opposed to the use of the default value of 7) is strongly encouraged if metals or ionizable organic compounds are COPCs at Tier 2. This is because the soil-partition coefficient (Kd) values for metals, as developed using a thermodynamic model by USEPA (1996a) exhibit considerable variability based on soil pH. The mobility of ionizable organic compounds, as reflected by the USEPA Koc values for this group, is also somewhat dependent upon soil pH, although to a lesser degree than the metals. A list of the ionizable organic compounds can be found in the Spreadsheet. The Spreadsheet is designed so that it is not necessary for the user to enter the actual Kd (for metals) or Koc (for ionizable organics). By entering a soil pH value the Spreadsheet will automatically select an appropriate value from tabulated values for these compounds. If these two contaminant classes are not COPC, then the default value of 7 may be entered for soil pH. The Worksheet, however, does allow alternative Kd values for metals to be used, if justification is provided. In addition to the Kd values compiled by USEPA (1996a) for metals, tabulated Kd values for several metals compiled from a literature search (compiled by Thibault, et al., 1990) are provided as Table 2 on the "Metal Kd Values" worksheet. These Kd values may be used for neutral soil pH conditions if the source area and the ground water is well characterized at the site.

Table 4A: Tier 2 Default Soil Porosity Inputs and Infiltration Estimates[1] Using USDA Soil Classification

USDA Soil Classification	Default Infiltration Estimates	Default Volumetric Water Content	Default Soil Air Porosity	Default Total Porosity
	cm/yr	Lwater/Lsoil	Lair/Lsoil	Lporosity/Lsoil
Clay	2.5	0.37	0.01	0.38
Clay loam	6.5	0.32	0.09	0.41
Loam	10.0	0.23	0.20	0.43
Loamy sand	15.0	0.11	0.30	0.41
Silt	8.0	0.31	0.15	0.46
Silt loam	8.0	0.29	0.16	0.45
Silt clay	3.5	0.35	0.01	0.36
Silty clay loam	5.0	0.37	0.06	0.43
Sand	17.0	0.08	0.35	0.43
Sandy clay	4.7	0.33	0.05	0.38
Sandy clay loam	9.0	0.25	0.14	0.39
Sandy loam	13.0	0.15	0.26	0.41

Table 4B: Tier 2 Soil Porosity Inputs and Infiltration Estimates[1] Using Unified Soil Classification System (USCS)

USCS Soil Classification	Infiltration Estimates	Default Volumetric Water Content	Default Soil Air Porosity	Default Total Soil Porosity
	cm/yr	Lwater/Lair	Lair/Lsoil	Lporosity/Lsoil
SW/SP: Clean Sand	17.0	0.08	0.33	0.41
SM: Silty Sand	15.0	0.12	0.29	0.41
SC: Clayey Sand	13.0	0.24	0.14	0.38
ML: Sandy Silt	10.0	0.28	0.15	0.43
ML: Silt	8.0	0.31	0.15	0.46
MH: Clayey Silt	8.0	0.25	0.11	0.36
CL: Sandy Clay	4.7	0.34	0.04	0.38
CL: Silty Clay	3.5	0.35	0.01	0.36
CH: Clay	2.5	0.37	0.01	0.38

Table 4C: Infiltration Scaling Factors

MN Annual Precip. Zone[2]	Average Annual Precipitation	Ave. Annual Precipitation in Zone	Average Annual Precip. in Zone	Average Annual Prep. in Zone	Infiltration Scaling Factor [3] (ISF)
	inches/yr	inches/yr	cm/year	cm/year	Unitless
ZONE (1)					
A	32-34	33	81-86	84	1.22
B	30-32	31	76-81	79	1.15
C	28-30	29	71-76	74	1.07
D	26-28	27	66-71	69	1.00
E	24-26	25	61-66	64	0.93
F	22-24	23	56-61	58	0.85
G	20-22	21	51-56	53	0.78
H	18-20	19	46-51	48	0.70

Notes:
1 Values of soil porosity from documentation provided by USEPA (1996a) and Texas Risk Reduction Program (1997).
2 Precipitation zones based on data provided by Minnesota Climatological Working Group from the US Department of Commerce (1992).
3 Infiltration Scaling Factor (ISF) is based upon a precipitation rate of 68 cm/year as calculated by SESOIL during calibration procedure for three SESOIL soil classes for sites in Zone E. Varying infiltration rates were established using SESOIL through calibration with established U.S.G.S. water resources data.

STEP 2: Calculation of the Dilution Attenuation Factor (DAF)

The DAF is calculated by the Worksheet using Equation 2 in Table 2. Step 2A requires an estimation of adjusted infiltration rate. In the Tier 2 SLV calculation for the DAF the variable "I" is the “Adjusted Tier 2 Infiltration Rate” and is estimated using Tables 4A or 4B in association with Table 4C and Attachment C; which are also provided on the Worksheet.

The source length (L), hydraulic conductivity (K) and hydraulic gradient (i) used in the DAF calculation (Step 2B in the Worksheet) should be measured values from the site. The hydraulic conductivity should be estimated by slug tests or pumping tests although default hydraulic conductivity, such as provided in Table 5 may be acceptable under certain circumstances. The use of default values should be noted.

The depth of mixing (d_m) represents the interval through which the leachate mixes with ground water and must be entered as part of Step 2C. This depth may be estimated from the maximum thickness within the aquifer beneath the source that is observed to be contaminated. Alternatively, the depth of mixing may be estimated by means of the equation presented in Table 6. Although the Worksheet prompts the user for the site specific inputs needed to calculate the d_m , the user may override this by inputting a field-based value instead.

Table 5: Default Hydraulic Conductivity Values

(Modified From Table 4.5 of Fetter, 1988)

Aquifer Lithology	Hydraulic Conductivity (cm/sec)
Clays	0.000005
Silt, sandy silts, clayey sands, till	0.0005
Silty sands, fine sands	0.005
Well-sorted sands, glacial outwash, gravels	0.5

Table 6: Equation for Estimation of Mixing Zone Depth

(From USEPA, 1996a, b)

$$d_m = (0.0112L^2)^{0.5} + d_a\{1 - \exp[(-LI)/(Kid_a]\}$$ [Equation 6]

Parameter	Definitions (units)
d_m	mixing zone depth (cm)
L	source length parallel to ground water flow (cm)
I	Infiltration rate (cm/yr)
K	Aquifer Hydraulic Conductivity (cm/yr)
i	Hydraulic Gradient (dimensionless)
d_a	Aquifer Thickness (cm)

STEP 3: Determine Contaminant Redistribution Factor (CRF) if Appropriate

If the soil contamination does not extend to the first saturated zone, a CRF may be calculated that will serve to increase the Tier 2 SLV based upon attenuation of contaminant concentration as predicted using a mass redistribution approach (see Section 4.2.1). The spreadsheet prompts the user to enter the thickness of the vertical thickness of the contaminated soil zone (d_1). This source zone thickness should be the total vertical thickness of the soil column inclusive of all soil layers with contaminant concentrations that exceed the Tier 2 SLV (this interval is referred to as Zone 1). The second thickness (d_2) represents the vertical thickness between Zone 1 and the water table (this interval being referred to as Zone 2). The Contaminant Redistribution Factor (CRF) describes the relative thickness of the sum of Zone 1 and Zone 2 ($d_1 + d_2$) to that of Zone 1 (d_1), CRF = $(d_1 + d_2)/d_1$.

STEP 4: Determine Appropriate Tier 2 SLV

After STEPS 1-3 have been completed by the user on the spreadsheet, the calculation of the Tier 2 SLVs, automatically conducted by the Spreadsheet, may be observed by scrolling past the user entry portion of the Worksheet to view the calculation tables. Within the calculation tables are Tier 2 SLVs calculated based on the partitioning equation on the left and SESOIL-derived SLVs for the appropriate soil type on the right, either of which may be used as the Tier 2 SLV. Table 7 may be used as an aid in determining which of the three SESOIL soil types (sand, silt or clay) is most appropriate. A tabulation of inputs used for Tier 2 and a summary of the Tier 2 SLV results may be found on the "Tier 2 SLV Results" worksheet.

Table 7: Tier 2 SESOIL Soil Classes

SESOIL Soil Class Recommended For Selecting SESOIL-Derived SLCs	USDA Classification	Unified Soil Classification
"SAND"	Sandy loam, loamy sand, sand	Group symbols- SP, SW, GP, GW
"SILT"	Loam, silt loam, silt	Group symbols- ML, SM, GM
"CLAY"	Clay, clay loam, silty clay, sandy clay, silty clay loam, sandy clay loam	Group symbols- OH, CH, MH, OL, CL, SC, GC

The calculated Tier 2 SLVs based on the partition equation in the calculation tables of the Worksheet incorporate modifications of Kd values for organic compounds based on the relationship, Kd = Koc * foc. Similarly, modifications of several of the SESOIL SLCs are available for a range of foc values up to 0.5 % using linear regression analysis of SESOIL modeling runs. Refer to the Technical Support Document Section 5 for supporting rationale for these modifications.

Biodegradation is an important process affecting the attenuation or concentration reduction of many contaminants. Biodegradation is dependent, however, upon a variety of site specific factors including pH; available electron acceptors; microbial consortia; types of enzymes present; contaminants and concentrations; and soil characteristics. This level of complexity allows accurate site specific biodegradation rates to be determined through laboratory microcosm studies as part of a Tier 3 evaluation. For Tier 2 application; however, the SESOIL model was applied with user-supplied, first-order biodegradation rates for 13 monoaromatic hydrocarbons and low molecular weight polyaromatic hydrocarbons assumed to be readily biodegradable under certain conditions, in order to derive generic adjusted SLCs. These compounds are: benzene, xylene, ethylbenzene, toluene, styrene, naphthalene, fluorene, acetone, acenaphthene, methyl ethylketone, phenol, o-cresol, and p-cresol.

As a condition of applying these Tier 2 biodegradation rates the following site conditions must be demonstrated:

- The soil is principally sandy, thus readily allowing oxygen movement through the soil column.
- The ground water beneath and downgradient of the source area generally contains at least 1.0 parts per million oxygen within the upper few feet of the ground water;
- The pH of the soil is between 6.0 and 7.5;
- Metals are not contaminants of concern at the site; and
- Soil organic carbon is at least 0.1 percent.

If these conditions are met the SESOIL-derived Tier 2 SLCs may be used along with the site specific DAF and CRF to arrive at a Tier 2 SLV. Upon completion of Steps 1-3 of the Worksheet, these SESOIL based biodegradation adjusted Tier 2 SLVs appears on the "Biodegradation-Adjusted SLVs" worksheet.

5.0 APPLICATION OF THE TIER 2 SOIL LEACHING VALUES

5.1 Comparison of Tier 2 SLVs With Site Data

At Tier 2 and Tier 3, site sample concentrations are compared directly to the SLVs. Site concentration data may be entered directly in the "Tier 2 SLV Results" worksheet or can be retrieved automatically if data was previously entered on the "Tier 1 SLV" worksheet. Site concentrations that exceed the appropriate SLVs are considered to have failed the Tier 2 evaluation and may indicate soil remediation is necessary. Soil concentrations that are less than its respective Tier 2 SLV require no further evaluation. In some cases, rather than using individual sample concentrations, a depth weighted average concentration (DWC) may be used instead, if sufficient data is available to characterize contaminant concentrations vertically throughout a given borehole location. Prior to applying the DWC as the averaged soil concentration, the distribution of the soil contamination throughout the source area in both the vertical and horizontal directions should be well understood. Refer to the guidelines for calculating and applying the DWC presented in Attachment B.

5.2 Use of the Soil Saturation Concentrations

The soil saturation concentration (Csat) is the contaminant concentration in the soil that corresponds to the adsorptive limits of the soil particles, the solubility limits of the contaminant in soil water and the saturation limits of the contaminant in the soil air. At concentrations above Csat the soil contaminant is predicted to be present in free phase as a NAPL. Tabulated C_{sat} concentrations are presented in Attachment D using Equation 7 (Feenstra, et al. 1991; USEPA, 1996a, b) and the defaults are shown below in Table 8. In Equation 7, the product $(S^i)(\chi^i)$, as defined by Raoult's Law, is the effective solubility (S) of a chemical component found by multiplying the pure-phase solubility (S^i) times the chemical component's mole fraction (χ^i) in the NAPL. For a single-component NAPL, (χ^i) will be 1.0, which is assumed for the tabulated Csat values in Attachment D. A soil contaminant's Csat value will vary as a function of soil textural characteristics expressed as dry soil bulk density, water-filled soil porosity and air-filled soil porosity and will be not a fixed concentration for each contaminant. Two sets of Csat values are presented for sand and clay soil types using an foc of 0.2 and 0.6%. Tier 2 or Tier 3 SLVs should not be used if they are higher than their respective Csat values. Equation 7 may also be used with site specific inputs and estimates for soil porosity and bulk density to calculate site specific Csat values, if desired.

5.3 Risk Based Decisions Using the Tier 2 SLVs

Tier 2 SLVs are designed be applied as criteria to evaluate indirect risk to ground water from future impacts due to contaminant leaching. After the Tier 2 SLVs have been developed using the Spreadsheet the next step is to evaluate their application as site specific remediation goals for the leaching pathway. A flowchart for the tiered risk-based decision framework recommended for the soil leaching pathway is presented in Attachment E. Determining the need for soil corrective action based on the leaching pathway should be based both on comparison of site concentration data to the SLVs as well as information available on the actual risk posed by ground water contamination. The user is referred to the "Ground Water Decision-Making Guidance" for recommendations on evaluating risk posed by ground water contamination. Use of a ground water risk evaluation to determine applicability of the SLVs, however, requires that the extent and magnitude of both soil and ground water be characterized.

Table 8: Default Values For Soil Saturation Concentrations (Csat)

$$C^{i}_{sat} = \frac{S^{i}\chi^{i}}{\rho_b}\left[K_d^{i}\rho_b + \theta_w + H'\theta_a\right]$$ [Equation 7]

Parameter	Definition	Units	Default
Csat	soil saturation concentration	mg/kg	calculated
S^{i}	pure phase solubility	mg/L-water	chemical specific
χ^{i}	mole fraction of component	unitless	1.0; assumed single component
pb	dry soil bulk density	kg/L	1.5
Kd	soil-water partition coefficient	L/kg	Koc * foc
Koc	Soil organic carbon-water partition coefficient	L/kg	chemical specific
foc	fraction organic carbon of soil	g/g	0.2 and 0.6
θ_w	volumetric water content	Lwater/Lsoil	0.37 for clay; 0.08 for sand
H'	dimensionless Henry's Law Constant	unitless	chemical specific
θ_a	air-filled soil porosity	Lair/Lsoil	0.014 for clay; 0.35 for sand

If COPC exceed the Tier 2 SLVs, but these compounds have not been detected in ground water samples at concentrations higher than their respective ground water risk criteria (e.g. HRLs) during long term ground water monitoring, then other contaminant attenuation mechanisms not accounted for at Tier 2 may be occurring. Some researchers (Xing et. al. ,1996; and Xing and Pignatello, 1996) have observed, for example, an increase in adsorption with time is related to physical entrapment of contaminants within soil pore spaces. This suggests that the Kd values applied for the Tier 1 and Tier 2 SLVs may be conservative for older sites. In this light, ground water monitoring data may in some cases provide an empirical basis for evaluating the appropriateness of a Tier 2 SLV.

Similarly, if no risk to ground water receptors is indicated and a ground water plume can be determined to be attenuating, soil corrective action driven by SLVs for the leaching pathway may not be necessary. In the case of very high soil concentrations relative to SLVs, the use of a ground water risk evaluation as corroborative evidence for no action alternative for the leaching pathway without a long term monitoring plan, and possibly a contingency plan, to evaluate long term ground water quality trends is not appropriate.

In the case where the SLVs are not applied as cleanup goals and soil contamination remains on-site without being remediated, a real property notification/affidavit (real property contamination disclosure) may be required to be filed with the county recorder or registrar of titles documenting the presence of the contaminated soils, their concentration and location at the site. If there is a likelihood of someone using ground water resources within the time period it would take for contaminant levels to decrease to less than the risk criteria within the plume area, ground water use restrictions or a Declaration of Restrictions and Covenants may be required.

Remediation of soil contamination may include active measures such as soil vacuum extraction or passive ones such as capping. In the event that engineering controls in the form of an engineered cap, a parking surface or a building to minimize or eliminate leaching are used as a remedy, a mechanism must also exist to ensure maintenance of these controls by means of a contingency plan or an operation and maintenance plan. Engineering controls may also be required to be enforced by means of a legal agreement and a Declaration of Restrictions and Covenants filed with the county recorder or registrar of titles. Refer to the "Guidance Document For Incorporation of Planned Property Use into Site Decisions" for a discussion of "institutional controls." Although institutional and engineering controls do represent acceptable remedies, the Site Response Section of the MPCA has a preference for treatment remedies. The Site Response "Internal Review Draft, Remedy Selection," guidance document states in Section 2.0 that the MPCA prefers detoxification and treatment and that response actions that eliminate or reduce the need for property use restrictions and engineering controls will be given preference.

If soil concentrations or the DWC at a given source area exceeds the Tier 2 or Tier 3 SLV; COPC for the leaching pathway occur in the ground water; and one of the situations as described above cannot be met, then the SLVs functions as a soil cleanup goal for the leaching pathway.

5.4 Reporting Requirements

After completion of a Tier 2 evaluation for the leaching pathway the results, conclusions, rationale and recommendations should be submitted to the MPCA for review and approval. The reporting of the Tier 2 evaluation may be included as part of a larger Phase II Investigation report or as a separate submittal. The Tier 2 evaluation documentation should include at a minimum the following information:

- Tables summarizing:
  - all soil analytical results along with corresponding Tier 1 and Tier 2 SLVs and
  - the site specific inputs used for development of the Tier 2 SLVs.
- Narrative describing:
  - results of the Tier 1 and Tier 2 evaluation, conclusions and corrective action recommendations and
  - site specific physical or chemical conditions or processes of significant to this exposure pathway.
- Figures:
  - site maps drawn to scale, illustrating location of source area(s), buildings, paved areas and utility trenches, monitoring and other ground water wells or probes and
  - geologic cross-sections of the site illustrating major geologic features and stratigraphy and contaminant distribution and wells or probes.

Upon completion of the Worksheet, the table titled “Values Used For Tier 2 SLV Calculations,” at the top of the “Tier 2 SLV Results” worksheet may be copied and formatted as a summary of the site specific inputs used for Tier 2. If metals are a COPC the Kd(s) used in the Tier 2 SLV evaluation should also be reported. If chemical specific parameters (e.g. Henry’s law constant, Koc, etc.) other than those provided in this guidance are used technical support and justification for their use must be provided.

6.0 CONDUCTING A TIER 3 EVALUATION

6.1 Determining the Need For A Tier 3 Evaluation

A Tier 3 evaluation for the leaching pathway is conducted in order to better quantify the potential risk to ground water due to leaching of soil contaminants than is available at Tier 2. One may decide to conduct a Tier 3 evaluation in order to provide support for the adoption of higher, and perhaps more realistic SLVs. Factors that may contribute to Tier 2 SLVs overestimating the amount of leaching at a site may be related to an overestimation of actual infiltration rate; an overestimation of the likelihood for irreversible sorption processes to occur in the soil; underpredicting attenuation due to biodegradation and not accounting for other geochemical oriented sorptive processes. For the most part, the Tier 2 SLVs will be sufficiently conservative to ensure protection of ground water resources, especially for older spill sites. If the spill release is recent, (a few hours or days) the argument that the Tier 2 SLVs are overly conversative may, however, be invalid. Reasons for which a Tier 3 evaluation may be needed include the following:

- to better understand the mobility and toxicity of metals in soil by chemical testing or special modeling;
- to evaluate the effects of secondary or fracture porosity on leaching in contaminated bedrock;
- to provide a more realistic estimate of the attenuation of compounds due to distance of source to ground water than is available by use of the CRF;
- to conduct a more site specific biodegradation study and to develop site specific biodegradation factors; and
- to develop a site specific soil-partition coefficient for COPC.

Detailed Tier 3 guidance is beyond the scope of this document; however, several guidelines may be provided in order to assist the user in conducting a Tier 3 evaluation.

6.2 Guidelines For A Tier 3 Evaluation

A Tier 3 evaluation should focus on answering very specific questions related to predicting risk to ground water resources via the leaching pathway. The objectives and scope of a Tier 3 evaluation should be submitted as a work plan to MPCA technical staff for review and approval. Include sufficient rationale for how and why the Tier 3 evaluation will be conducted and how the results will be evaluated. If a treatability study is proposed as part of the Tier 3 evaluation, details outlining the rationale and the methodologies for the treatibility study should also be included in this workplan.

Both the Tier 1 and Tier 2 SLVs use models to estimate predicted concentrations in ground water as a result of leaching. A Tier 3 evaluation may also consist of additional site specific modeling exercise in order to better estimate risk at a site. The SESOIL model was used extensively for developing Tier 2 SLCs and calibrated base files are available upon request if site specific Tier 3 modeling for organic compounds using the SESOIL model is desired. The SESOIL model, though appropriate for organic contaminants, is less useful for predicting the behavior of metals in soils due to the greater complexity of processes influencing metal behavior such as complexation, cation-exchange, chemical transformations and redox reactions. If adequately supported, one may develop their own calibrations using the SESOIL model or use a different appropriate soil model if approved by the MPCA site project team.

If a modeling approach is to be used for Tier 3, then a proper modeling protocol to promote consistency of reporting and quality of modeling should be followed. Attention should be paid to the following items during planning, implementation and reporting of Tier 3 modeling:

- Develop a conceptual model that verbally and diagramatically describes the system to be modeled and provide this as part of a work plan submitted for MPCA approval;
- Select an appropriate code and provide rationale for its use in the work plan. A computer code should be selected because it can adequately simulate the system described by the conceptual model;
- Provide the basis for the model calibration and the criteria to be used to determine a good fit has been reached;
- Provide sensitivity analysis to describe how model results are affected by changes in parameter values;
- Provide documentation of model runs including a discussion of the limitations of the model and/or uncertainty analysis; and
- Document the results of the modeling and provide a rationale for decisions.

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ATTACHMENT A: TIER 1 SOIL LEACHING VALUES (SLVS), MAY 1998

COMPOUND	CAS No.	TIER 1 SLV mg/kg
INORGANICS		
Antimony	7440-36-0	2.7
Arsenic	7440-38-2	14.6
Barium	7440-39-3	822
Beryllium	7440-41-7	NA
Boron	7440-42-8	NA
Cadmium	7440-43-9	3.0
Chromium III	16065-83-1	1000000
Chromium VI	18540-29-9	19.1
Cobalt	7440-48-4	NA
Copper	7440-50-8	NA
Cyanide	57-12-5	10
Lead	7439-92-1	525
Manganese	7439-96-5	NA
Mercury (as Mercuric Chloride)	7487-94-7	1.0
Molydenum	7439-98-7	30.0
Nickel	7440-02-0	65
Selenium	7782-49-2	1.5
Silver	7440-22-4	2.5
Strontium	7440-24-6	1930
Thallium	7440-28-0	0.4
Tin	7440-31-5	NA
Vanadium	7440-62-2	500
Zinc	7440-66-6	1242
VOLATILE ORGANICS		
Acetone	67-64-1	0.7
Acetonitrile (Methyl cyanide)	75-05-8	0.04
Acrylamide	79-06-1	0.0001
Acrylonitrile	107-13-1	0.001
Benzene	71-43-2	0.034
Benzoic acid	65-85-0	139
Biphenyl	92-52-4	6.3
Bis (2-Chloroisopropyl) ether	108-60-1	0.67
Bromochloromethane (Chlorobromomethane)	74-97-5	0.14
Bromodichloromethane	75-27-4	0.013
Bromoform	75-25-2	0.14
n-Butanol	71-36-3	0.75
Carbon Tetrachloride (tetrachloromethane)	56-23-5	0.023
Chlorobenzene	108-90-7	1.1
Chlorodibromomethane	124-48-1	0.03
Chloroform (trichloromethane)	67-66-3	0.17
Chloromethane (methyl chloride)	74-87-3	0.005

ATTACHMENT A: TIER 1 SOIL LEACHING VALUES (SLVS), MAY 1998 (CONTINUED)

COMPOUND	CAS No.	TIER 1 SLV mg/kg
1,2-Dibromo-3-chloropropane	96-12-8	0.001
1,2-Dichlorobenzene(ortho-)	95-50-1	7.8
1,4-Dichlorobenzene	106-46-7	0.13
Dichlorodifluoromethane (Freon 12)	75-71-8	38
1,1-Dichloroethane	75-34-3	0.18
1,2-Dichloroethane	107-06-2	0.01
1,1-Dichloroethene (Vinylidene chloride)	75-35-4	0.02
cis-1,2-Dichloroethene	156-59-2	0.14
trans-1,2-Dichloroethylene	156-60-5	0.22
Dichloromethane (methylene chloride)	75-09-2	0.07
1,2-Dichloropropane	78-87-5	0.011
1,3-Dichloropropene (cis, trans-, mixture-)	542-75-6	0.01
Epichlorohydrin	106-89-8	0.05
Ethyl ether	60-29-7	1.2
Ethylbenzene	100-41-4	4.7
Hexachlorobutadiene	87-68-3	25
Hexachloroethane	67-72-1	0.04
n-Hexane	110-54-3	18
Isopropylbenzene (cumene)	98-82-8	18
Methyl ethyl ketone (2-butanone)	78-93-3	6.7
Methyl iodide (Iodomethane)	74-88-4	NA
Methyl isobutyl ketone	108-10-1	0.42
Naphthalene	91-20-3	7.5
Styrene	100-42-5	1.9
1,1,2,2-Tetrachloroethane	79-34-5	0.01
1,1,2,2-Tetrachloroethylene	127-18-4	0.07
Tetrahydrofuran (THF)	109-99-9	0.16
Toluene	108-88-3	6.4
1,1,2-Trichlorotrifluoroethane	76-13-1	2580
1,2,4-Trichlorobenzene	120-82-1	0.31
1,3,5-Trichlorobenzene	108-70-3	8.0
1,1,1-Trichloroethane	71-55-6	3.5
1,1,2-Trichloroethane	79-00-5	0.01
1,1,2-Trichloroethylene (TCE)	79-01-6	0.14
Trichlorofluoromethane (Freon 11)	75-69-4	22
1,2,3-Trichloropropane	96-18-4	NA
1,2,4-Trimethylbenzene	95-63-6	NA
1,3,5-Trimethylbenzene	108-67-8	NA
Vinyl chloride (chloroethene)	75-01-4	0.001
Xylenes, Total (o,m,p)	1330-20-7	45
NON/SEMI VOLATILE ORGANICS		
Bis 2-chloroethyl ether	111-44-4	0.001
Diethylhexyl phthalate (Bis-ethylhexyl phthalate)	117-81-7	40
Butyl benzl phthalate	85-68-7	28
2-Chlorophenol	95-57-8	0.27

ATTACHMENT A: TIER 1 SOIL LEACHING VALUES (SLVS), MAY 1998 (CONTINUED)

COMPOUND	CAS No.	TIER 1 SLV mg/kg
Dibutyl phthalate	84-74-2	23
2,4-Dichlorophenol	120-83-2	1.6
Diethyl phthalate	84-66-2	18
Dimethyl phthalate	131-11-3	172
2,4-Dimethylphenol	105-67-9	0.34
1,3-Dinitrobenzene (m-)	99-65-0	0.002
2,4-Dinitrophenol	51-28-5	0.01
Formaldehyde	50-00-0	1.1
Hexachlorobenzene	118-74-1	0.32
Hexachlorocyclopentadiene	77-47-4	4.3
Isophorone	78-59-1	0.16
2-Methylphenol (o-cresol)	95-48-7	0.06
4-Methylphenol (p-cresol)	106-44-5	0.03
2-Nitrophenol	88-75-7	0.60
N-nitroso-diphenylamine	86-30-6	0.88
Pentachlorophenol	87-86-5	0.11
Phenol	108-95-2	7.8
Pronamide (Propyzamide)	23950-58-5	0.25
2,4,6-Trichlorophenol	88-06-2	0.67
PAHS		
Acenaphthene	83-32-9	50
Anthracene	120-12-7	942
Benzo[a]anthracene	56-55-3	0.36
Benzo[a]pyrene	50-32-8	1.0
Benzo[b]fluoranthene	205-99-2	0.55
Benzo[g,h,i]perylene	191-24-2	7.8
Benzo[k]fluoranthene	207-08-9	1.9
Chrysene	218-01-9	1.9
Dibenz[a,h]anthracene	53-70-3	1.8
Fluoranthene	206-44-0	295
Fluorene	86-73-7	47
Pyrene	129-00-0	272
POLYCHLORINATED BIPHENYLS		
Polychlorinated biphenyls (total)	1336-36-3	1.2
DIOXINS AND DIBENZO FURANS		
2,3,7,8-Tetrachlorodibenzofuran (TCDF) 2,3,7,8-TCDD (or 2,3,7,8-TCDD equivalents)(Dioxine)	1746-01-6	0.001
EXPLOSIVES/FLAMMABLE SOLIDS		
2,4-Dinitrotoluene (DNT)	121-14-2	0.001
2,6-Dinitrotoluene (2,6-DNT)	606-20-2	0.001
2,4,6-Trinitrotoluene (TNT)	118-96-7	0.014
PESTICIDES AND HERBICIDES		
Acifluorfen	50594-66-6	0.03
Ametryn	834-12-8	0.42
Carboxin	5234-68-4	4.3
Chloramben	133-90-4	0.13

ATTACHMENT A: TIER 1 SOIL LEACHING VALUES (SLVS), MAY 1998 (CONTINUED)

COMPOUND	CAS No.	TIER 1 SLV mg/kg
Chlorothalonil	1897-45-6	0.86
Dacthal (DCPA)	1861-32-1	404
Dalapon	75-99-0	0.22
Diazinon	333-41-5	0.02
Dimethoate	60-51-5	0.001
Dinoseb (2-sec-butyl-4,6-dinitrophenol)	88-85-7	0.08
Dioxane (1,4-Dioxane)	123-91-1	0.08
Diphenamid	957-51-7	1.0
Diquat	231-36-7	400
Disulfoton	298-04-4	0.004
Diuron	330-54-1	0.11
Endothall	145-73-3	0.14
Fenamiphos	22224-92-6	0.01
Fluometuron	2164-17-2	0.27
Glyphosate (Roundup)	1071-83-6	337
Hexazinone	51235-04-2	0.42
Linuron	330-55-2	0.01
Malathion	121-75-5	0.92
Maleic Hydrazide (Royal Slo-Gro)	123-33-1	5.6
Methanol (Carbinol, Columbian spririts, wood alcohol)	67-56-1	3.2
Methomyl (Lannate)	16752-77-5	0.49
Methyl parathion	298-00-0	0.21
2-(2-Methyl-4-chlorophenoxy)propionic acid (MCPP)	7085-19-0	0.01
Oxamyl (Vydate)	23135-22-0	0.30
Paraquat	4685-14-7	600
Propham (IPC, Chem-Hoe)	122-42-9	0.50
Tebuthiuron (Spike)	34014-18-1	1.3
Terbacil (Sinbar)	5902-51-2	0.19

ATTACHMENT B: USE OF A DEPTH-WEIGHTED AVERAGE CONCENTRATION (DWC)

Part 1 Introduction

Tier 1 evaluations involve direct comparison of soil contaminant concentrations to a Tier 1 SLV ookup value to determine if a potential risk due to leaching is posed or should be further evaluated. For Tier 2 and Tier 3 evaluations the site concentrations that are compared to the Tier 2 or 3 SLV may be compared similarly as in Tier 1, or may be averaged, under certain circumstances. At a boring or point location within a source area a depth-weighted average (DWC) soil concentration may be determined and used as an average soil contaminant concentration that may then be compared with the calculated SLV to estimate the source area's risk to ground water due to leaching. Additionally, multiple DWC's calculated throughout the aerial extent of a source area may then be used to develop an area-weighted average for the entire source area. The minimum conditions for use of the DWC at a site are as follows:

- the horizontal and vertical extent and magnitude of soil contamination has been well characterized,
- continuous soil organic vapor measurements have been collected throughout the soil profile; and
- no ground water receptors exist within a two-year travel time of the source area.

Part 2 Mathematical Basis For a Depth-Weighted Concentration

The total mass of contaminants present in a source can be expressed as

$M_T = (C_t)(\rho_b)(As)(d_{total})$
where
M_T = total mass of contaminant present
C_t = total soil contaminant concentration
ρb = dry soil bulk density
As = source area
d_{total} = source depth or total thickness

If one assumes that soil contamination can be represented as a simple layered soil column such that each layer has uniform soil bulk density and contaminant soil concentration, the mass of contaminant in each layer can be expressed as $M_i = (C_i)(\rho_b)(A_i)(d_i)$ where the i represents the i^{th} layer in the soil column. The total mass in this layered model is equal to

$$M_{T=A_s} \sum_{i=1}^{n} Ci\rho_i / d_{total} \qquad \text{Equation B-1}$$

The total average contaminant concentration is equal to Ctotal = $M_T/\rho_b ave A_s d_{total}$, where $\rho_b$ave is the average soil bulk density for the soil column. The average bulk density expressed as a depth-weighted average can be found using the following relationship:

$$\rho_b ave = \sum_{i=1}^{n} \rho_i d_i / d_{total} \qquad \text{Equation B-2}$$

The depth-weighted average concentration, after simplifying terms, will be equal to

$$DWC = \frac{\sum_{i=1}^{n} C_i \rho_i d_i}{\sum_{i=1}^{n} \rho_i d_i} \qquad \text{Equation B-3}$$

If it is assumed that the soil bulk density is approximately the same throughout the soil column this term can be simplified further by the following expression:

$$DWC = \frac{\sum_{i=1}^{n} C_i d_i}{d_{total}} \qquad \text{Equation B-4}$$

Part 3 Applying the DWC

When using Equation B-4 to calculate a DWC for a particular point within the source area the total depth (d_{total}) refers to the thickness of Zone 1, as defined in Section 4.2.1, to represent an upper contaminated zone in the soil column of thickness d_1, separated from the ground water by an interval of unimpacted soil described as Zone 2, with thickness d_2. Soil within Zone 2 may contain some residual soil contamination as long as it is less than the Tier 2 SLV. The subscript "i" in equations B-1 through B-4, then should not be confused with refering to the total thickness of Zone 1 or Zone 2, but rather refers to individual layers within the upper zone, Zone 1. The vertical interval through with a DWC is determined must be chosen with care. The top of Zone 1 is chosen as the first interval whose soil concentration exceeds the Tier 2 SLV and the base of Zone 1 is chosen as the last interval with a measured soil concentration that exceeds the Tier 2 SLV. Generally Equation B-4 may be used to calculate the DWC unless layers of significantly different soil bulk density characteristics exist within the vertical intervals to be averaged. Vadose zones in which both consolidated and unconsolidated strata occurs or layers containing peat may require the use of Equation B-3 rather than B-4.

Using these guidelines it can be possible for the interval through with the DWC is determined to have soil layers whose contaminant concentrations are less than their respective Tier 2 SLV. Researchers have demonstrated that contamination in the vadose zone rarely moves downward as a uniform wetting front, but tends to preferentially move both horizontally and vertically along zones of relatively higher permeability (i.e. Kueper, et al., 1993). It is not unexpected, therefore that a vertical borehole investigating vadose zone contamination will encounter soil contamination througout a borehole that is not apparently vertically contiguous.

It is critical, considering the potential three-dimensional complexity of the distribution of contamination in the vadose zone that prior to using a DWC a source area has been well characterized Additionally, a DWC should not be used across both an upper contaminated zone and a separate deeper zone of contamination at the water table. This deeper distribution of contaminants may represent a "smear zone" of contamination distributed by natural fluctuations of the water table rather than being attributable directly to downward migration of contamination in the vadose zone.

Since a DWC represents a location specific averaged concentration, t is likely that the DWC and thus the vertically averaged soil concentration in the source will vary, perhaps significantly througout the source area. As a result, a minimum of three DWCs should be calculated for each source area. If DWCs are used rather than using nonaveraged site concentration data for comparison, the user should also evaluate the stratigraphy in a conventional fashion using cross-sections to assess the distribution of soil contamination and look for patterns across the source area. The aerial variation of site DWCs across the source area should then reflect this 3-D interpretation. In addition to applying a DWC at a specific point location, different DWC estimates may be used across a source area to arrive at an estimate of an area-weighted average concentration. Area-averaging of DWC values will result in a better estimate of the average soil concentration through the source area and thus a more realistic estimate of the of the total mass available for leaching. Prior to calculating such an area-weighted average of the soil concentrations within the vadose zone, the stratigraphy, hydrogeology and the contaminant distribution must be very well understood and documented. Because the comparison of a DWC with an SLV implies that the predicted risk to ground water via the leaching pathway is time-averaged, it is also important that the overall ground water risks are well understood and are deemed acceptable. As a result, the DWC and an area-weighted average should only be used upon review and approval of MPCA project technical staff.

Part 4 Example of How To Calculate A DWC for a Site

The example below illustrates how to calculate the DWC at a hypothetical soil boring log.

Depth Below Surface	**USDA Soil Textures**	**PID Screening Results**	**Soil Analytical Data**
(feet)		**(ppm)**	
0 - 5.0	Silty Loam	10	tetrachloroethylene 0.5 mg/kg
5.0-10.0	Loam	14.5	tetrachloroethylene 3.2 mg/kg
10.0 - 15.0	Sandy Loam	35	not sampled
15.0 -20.0	Sand	150	tetrachloroethylene 23 mg/kg
20-25	Sand	460	tetrachloroethylene 125 mg/kg
25-35	Sand, wet, end of boring	330	not sampled

Step 1: First determine the intervals and corresponding concentrations that are to be averaged, moving from the ground surface down. Averaging should begin at the first interval that exceeds the Tier 2 calculated SLVs and continue throughout the contaminated zone. If a clean zone exists below the contaminated zone that portion of the profile should not be used in the calculation of the DWC. In this example we may assume that the Tier 2 SLV has been calculated as 1 mg/kg. The contaminated interval in excess of the SLV extends from 5 feet to 25 feet.

The water table is located at 25 feet. No clean zone or Zone 2 exists in this example. For the example, the following interpretation is made:

Layer	**depth interval (feet)**	**di (feet)**	**Ci mg/kg**
Layer 1	5 to 10	5	3.2
Layer 2	10 to 20	10	23
Layer 3	20 to 25	5	125

Note that in the absence of continuous soil concentration data, a conservative estimation of the extent of soil contamination is made for Layer 2.

Step 2: Calculate the DWC as follows:

di (feet)	**Ci (mg/kg)**	**Step 2a: Determine di x Ci for each layer**
5	3.2	5 x 3.2 =16
10	23	10 x 23 = 230
5	125	5 x 125 = 625
Step 2b: Calculate the Sum of di x Ci		Sum = 16 + 230 + 625 = **871**

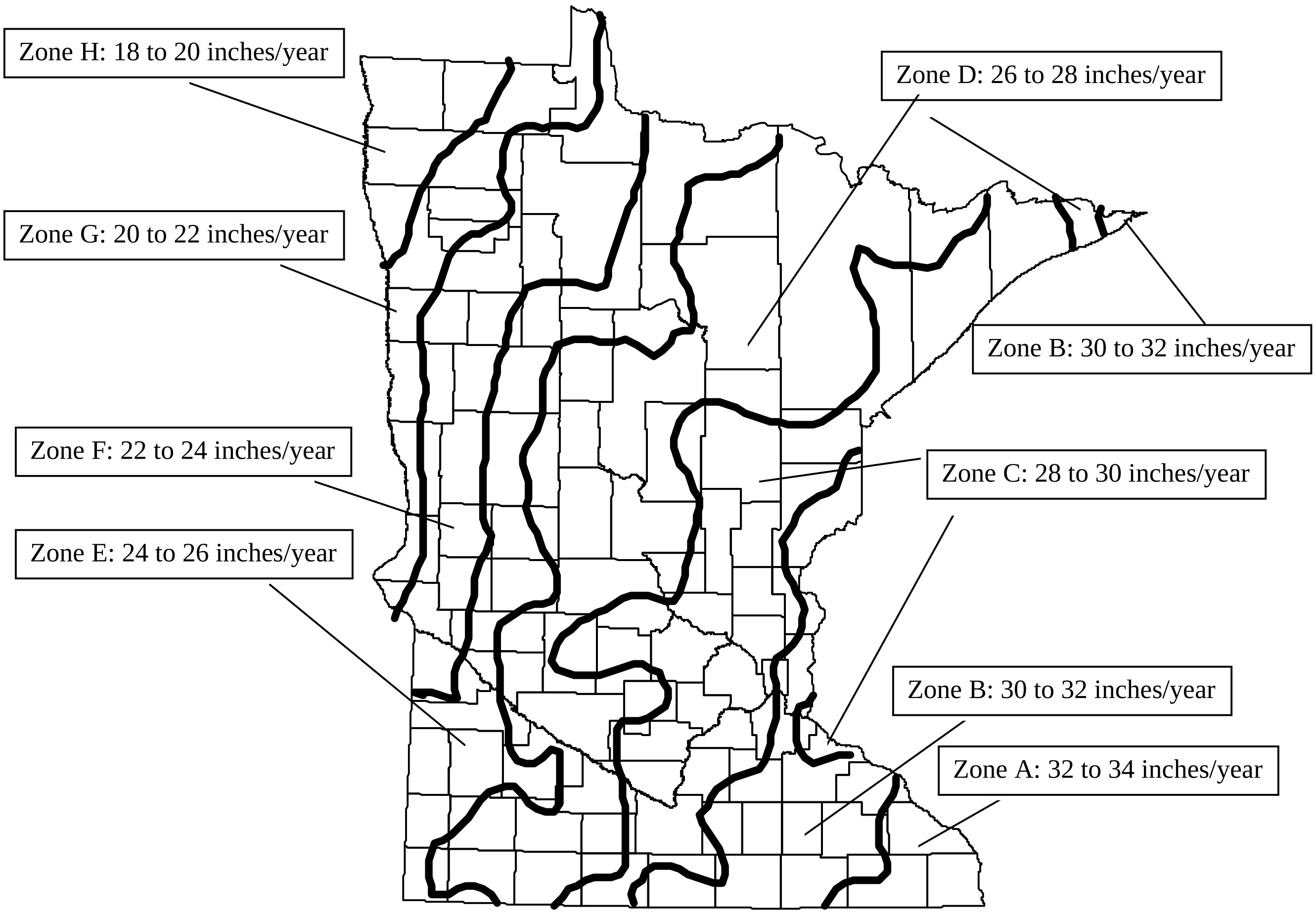
Step 3: Divide the sum of di x Ci by the total contaminated soil interval for which the concentrations are averaged, d(total). In this example, d(total) is 25 - 5 feet = 20 feet.

$$\text{DWC} = \frac{871.0 \text{ mg/kg ft}}{20 \text{ ft}} = 43.6 \text{ mg/kg}$$

This concentration is well above the site specific Tier 2 SLV of 1 mg/kg indicating that leaching of tetrachloroethylene is still of concern at this location and response actions may be necessary. The DWC, however allows soil response actions to potentially focus in on areas of the soil column that will result in a DWC equal to the Tier 2 SLV. An area-weighted contaminant concentration, if based on sufficient representative soil analytical data will also allow a better understanding of the risk to leaching than would otherwise be available by comparing a Tier 2 SLV to sample results without averaging. It may not be practicable to use rigorous statistical methods in order to determine the average concentration of subsurface soils cost effectively. Conservative assumptions as applied in the example above would need to be applied in a similar fashion to develop hypotheses on likely contaminant distributions across the horizontal extent of a source area for determination of an area-weighted average.

ATTACHMENT C: AVERAGE ANNUAL PRECIPITATION RATES IN MINNESOTA

For Use In Determining Adjusted Tier 2 Infiltration Rates



Source for annual precipitation rates for Minnesota:

U.S. Department of Commerce - National Oceanic and Atmospheric, Administration - National Climatic Data Center, 1992, Climatography of the United States, No. 81 - Monthly Station Normals of Temperature, Precipitation, and Heating and Cooling Degree Days - 1961-1990.

ATTACHMENT D: DEFAULT SOIL SATURATION CONCENTRATION (CSAT) ESTIMATES FOR COMPOUNDS

$$\text{Csat} = \frac{S}{\rho_b}\left[K_d \rho_b + \theta_w + H'\theta_a\right]$$

Parameter	Symbol	Units	Default
soil saturation concentration	Csat	mg/kg	calculated
solubility	S	mg/L-water	chemical specific
dry soil bulk density	ρ_b	kg/L	1.5
soil-water partition coefficient	Kd	L/kg	Koc * foc
soil organic carbon-water partition coefficient	Koc	L/kg	chemical specific
fraction organic carbon of soil	foc	g/g	0.2 and 0.6
volumetric water content	θ_w	Lwater/L soil	0.37 for clay; .08 for sand
dimensionless Henry's Law Constant	H'	NA	chemical specific
air-filled soil porosity	θ_a	Lair/Lsoil	0.014 for clay; 0.35 for sand

Note: NC in the Csat table indicate "not calculated" due to insufficient data available.

	CAS	Csat	Csat	Csat	Csat
COMPOUND	Registry#	Clay	Clay	Sand	Sand
		foc=0.2	foc=0.6	foc=0.2	foc=0.6
VOLATILE ORGANICS		mg/kg	mg/kg	mg/kg	mg/kg
Acetone	67-64-1	362682	594682	169705	401705
Acetonitrile (Methyl cyanide)	75-05-8	95176	216903	68321	190048
Acrylonitrile	107-13-1	218411	616255	203202	601046
Allyl Chloride	107-05-1	NC	NC	NC	NC
Benzene	71-43-2	35435	105435	35186	105186
Bromochloromethane (Chlorobromomethane)	74-97-5	84454	245946	81753	243245
Bromodichloromethane	75-27-4	75807	224087	74603	222883
Bromoform	75-25-2	81430	242710	80827	242107
Bromomethane (methyl bromide)	74-83-9	354391	1043092	468827	1157527
1,3 - Butadiene	106-99-0	17872	53219	18155	53502
n-Butylbenzene	104-51-8	7652	22948	7649	22945
sec-Butylbenzene	135-98-8	30515	91460	30500	91444
tert-Butylbenzene (surrogate - n-butylbenzene)	98-06-6	3522	10552	3519	10550
Carbon Disulfide	75-15-0	11184	32937	11284	33038
Tetrachloromethane (Carbon Tetrachloride)	56-23-5	35731	106784	35799	106852
Chlorobenzene	108-90-7	47317	141717	47242	141642
Chlorodibromomethane	124-48-1	43894	130397	43410	129913
Chloroethane (ethyl chloride)	75-00-3	5128	12519	4606	11997
Trichloromethane (chloroform)	67-66-3	130269	386877	129004	385612

ATTACHMENT D: Soil Saturation Concentration (Csat) Estimates For Compounds (Continued)

COMPOUND	CAS Registry#	Csat Clay foc=0.2	Csat Clay foc=0.6	Csat Sand foc=0.2	Csat Sand foc=0.6
Chloromethane (methyl chloride)	74-87-3	25314	73543	24775	73003
1,2-Dibromo-3-chloropropane	96-12-8	29156	86973	28965	86782
1,2 - Dibromoethane (ethylene dibromide)	106-93-4	58164	172358	57353	171547
1,2-Dichlorobenzene(ortho-)	95-50-1	19258	57696	19230	57669
1,3 - Dichlorobenzene	541-73-1	4060	12147	4048	12135
1,4-Dichlorobenzene	106-46-7	9110	27295	9098	27282
Dichlorodifluoromethane (Freon 12)	75-71-8	20447	61112	21486	62150
1,1-Dichloroethane	75-34-3	64003	189491	63286	188774
1,2-Dichloroethane	107-06-2	131609	390617	130038	389046
1,1-Dichloroethene (Vinylidene chloride)	75-35-4	29828	88328	29934	88434
cis-1,2-Dichloroethene	156-59-2	25719	75419	25173	74873
trans-1,2-Dichloroethylene	156-60-5	NC	NC	NC	NC
Dichlorofluoromethane	75-43-4	NC	NC	NC	NC
Dichloromethane (methylene chloride)	75-09-2	29218	81218	26966	78966
1,2-Dichloropropane	78-87-5	27014	79654	26544	79184
Epichlorohydrin	106-89-8	148281	412281	135535	399535
Ethyl ether	60-29-7	58454	141254	45925	128725
Ethylbenzene	100-41-4	8661	25899	8641	25879
Hexachlorobutadiene	87-68-3	642053	1926157	642052	1926156
Hexachloroethane	67-72-1	NC	NC	NC	NC
Isopropylbenzene (cumene)	98-82-8	28478	85410	28475	85407
2-Butanone (methyl ethyl ketone)	78-93-3	957102	2804063	930841	2777802
Methyl iodide (Iodomethane)	74-88-4	NC	NC	NC	NC
Methyl isobutyl ketone	108-10-1	82706	238695	79016	235005
Naphthalene	91-20-3	7392	22160	7386	22154
n-Propylbenzene (surrogate - Cumene)	103-65-1	8946	26809	8940	26802
Styrene	100-42-5	56621	169709	56569	169657
1,1,2,2-Tetrachloroethane	79-34-5	47659	141511	47094	140946
1,1,1,2-Tetrachloroethane	630-20-6	NC	NC	NC	NC
1,1,2,2-Tetrachloroethylene	127-18-4	14971	44811	14966	44806
Tetrahydrofuran (THF)	109-99-9	NC	NC	NC	NC
Toluene	108-88-3	26115	78084	26046	78015
Trichlorotrifluoroethane(1,1,2-)	76-13-1	85887	257069	86260	257442
1,2,4-Trichlorobenzene	120-82-1	99614	298694	99560	298640
1,3,5-Trichlorobenzene	108-70-3	11601	34801	11600	34800
1,1,1-Trichloroethane	71-55-6	47951	143179	47904	143132
1,1,2-Trichloroethane	79-00-5	96564	287508	95746	286690
1,1,2-Trichloroethylene(TCE)	79-01-6	33276	99276	33167	99167
Trichlorofluoromethane (Freon 11)	75-69-4	32476	96804	33243	97571
1,2,3-Trichloropropane	96-18-4	NC	NC	NC	NC
1,2,4-Trimethylbenzene	95-63-6	38653	115932	38645	115925

ATTACHMENT D: Soil Saturation Concentration (Csat) Estimates For Compounds (Continued)

	CAS	Csat	Csat	Csat	Csat
COMPOUND	**Registry#**	**Clay**	**Clay**	**Sand**	**Sand**
		foc=0.2	**foc=0.6**	**foc=0.2**	**foc=0.6**
1,3,5-Trimethylbenzene	108-67-8	6358	19049	6350	19041
Chloroethene (vinyl chloride)	75-01-4	10977	31511	11127	31662
Xylenes (o,m,p)	1330-20-7	6391	19074	6362	19045
SEMI- AND NON-VOLATILE ORGANICS					
Bis 2-chloroethyl ether	111-44-4	265339	787531	262016	784208
Bis chloromethyl ether (sym-Dichloromethyl Ether)	542-88-1	NC	NC	NC	NC
Di-2-ethylhexyl phthalate	117-81-7	NC	NC	NC	NC
Di(2 - ethylhexyl)phthalate (bis-ethylhexyl phthalate)	117-81-7	1	2	1	2
4-Bromophenyl phenyl ether	101-55-3	NC	NC	NC	NC
Butyl benzl phthalate	85-68-7	7396	22187	7395	22186
2-Chlorophenol	95-57-8	1757102	5260445	1752927	5256270
4-Chlorophenyl phenyl ether	7005-72-3	NC	NC	NC	NC
Dibutyl phthalate	84-74-2	3513	10533	3511	10531
Di - n - octyl phthalate	117-84-0	NC	NC	NC	NC
Dibenzofuran	132-64-9	86365930	259097789	86365929	259097788
1,4 - Dibromobenzene	106-37-6	333087	998742	332889	998544
3,3' - Dichlorobenzidine	91-94-1	17911	53730	17910	53730
2,4-Dichlorophenol	120-83-2	3584075	10750004	3583205	10749134
Diethyl phthalate	84-66-2	21434	63770	21226	63562
Dimethoate	60-51-5	NC	NC	NC	NC
Dimethyl phthalate	131-11-3	63878	189504	63043	188669
2,4-Dimethylphenol	105-67-9	191178	569651	189656	568129
2,4-Dimethylphenol	105-67-9	95132	283292	94710	282870
2,4-Dinitrophenol	51-28-5	10611	30457	10072	29917
Dinoseb (2-sec-butyl-4,6-dinitrophenol)	88-85-7	NC	NC	NC	NC
Disulfoton	298-04-4	NC	NC	NC	NC
Hexachlorobenzene	118-74-1	99202	297602	99200	297600
Hexachlorocyclopentadiene	77-47-4	1536	4608	1536	4607
1,3-Dinitrobenzene (m-)	99-65-0	3023	8839	2933	8748
Methomyl (Lannate)	16752-77-5	NC	NC	NC	NC
Methyl parathion	298-00-0	NC	NC	NC	NC
4-Methylphenol (p-cresol)	106-44-5	1949392	5838605	1945641	5834854
3-Methylphenol (m-cresol)	108-39-4	NC	NC	NC	NC
2-Methylphenol (o-cresol)	95-48-7	298831	883666	293804	878639
Isophorone	78-59-1	77127	225461	74808	223142
2-Nitrophenol	88-75-7	42518	126518	42112	126112
N-Nitrosodiphenylamine	62-75-9	5442180	15723763	6562158	16843741
N-nitroso-diphenylamine	86-30-6	4048	12127	4041	12121
Pentachlorophenol	87-86-5	5827	17473	5824	17470
Phenol	108-95-2	796355	2348218	780347	2332210
Pronamide	23950-58-5	NC	NC	NC	NC

ATTACHMENT D: Soil Saturation Concentration (Csat) Estimates For Compounds (Continued)

COMPOUND	CAS Registry#	Csat Clay foc=0.2	Csat Clay foc=0.6	Csat Sand foc=0.2	Csat Sand foc=0.6
2,4,6-Trichlorophenol	88-06-2	171640	514527	171486	514372
2,4,5-Trichlorophenol	95-95-4	384296	1152296	384064	1152064
1,3,5-Trinitrobenzene	99-35-4	NC	NC	NC	NC
PAHs					
Acenaphthene	83-32-9	5230	15687	5229	15687
Anthracene	120-12-7	204	612	204	612
Benzo[a]anthracene	56-55-3	672	2017	672	2017
Benzo[a]pyrene	50-32-8	314	942	314	942
Benzo[b]fluoranthene	205-99-2	165	495	165	495
Benzo[g,h,i]perylene	191-24-2	404	1211	404	1211
Benzo[k]fluoranthene	207-08-9	298	894	298	894
Chrysene	218-01-9	596	1788	596	1788
Dibenz[a,h]anthracene	53-70-3	891	2673	891	2673
Fluoranthene	206-44-0	2023	6068	2023	6068
Fluorene	86-73-7	3052	9156	3052	9156
Ideno(123c-cd)pyrene	193-39-5	15	46	15	46
Pyrene	129-00-0	1836	5507	1836	5507
Polychlorinated biphenyls (total)	1336-36-3	1696	5087	1696	5087
MDA PESTICIDES					
Alachlor	15972-60-8	NC	NC	NC	NC
Aldicarb	116-06-3	NC	NC	NC	NC
Atrazine	1912-24-9	NC	NC	NC	NC
Bentazon (Basagran)	25057-89-0	NC	NC	NC	NC
Carbaryl (Sevin)	63-25-2	76	175	55	155
Carbofuran	1553-66-2	6578	19576	6516	19514
Chlorpyrifos (Lorsban)	2921-88-2	NC	NC	NC	NC
Cyanazine	21725-46-2	NC	NC	NC	NC
Dicambra (Banvel)	1918-00-9	NC	NC	NC	NC
4-(2,4-Dichlorophenoxy)butyric acid (2,4-DB) (Butyrac)	94-82-6	NC	NC	NC	NC
2,4-Dichlorophenoxyacetic acid (2,4-D)	94-75-7	6642	19722	6636	19716
Fonofos (Dyfonate)	944-22-9	NC	NC	NC	NC
2-Methyl-4-chloropphenoxyacetic acid (MCPA)	94-74-6	NC	NC	NC	NC
Metolachlor (Dual)	51218-45-2	19641	58681	19557	58597
Metribuzin	21087-64-9	NC	NC	NC	NC
Pendimethalin	40487-42-1	NC	NC	NC	NC
Phorate (Thimet)	298-02-2	NC	NC	NC	NC
Picloram (Tordon)	1918-02-1	NC	NC	NC	NC
Prometon (Pramitol)	1610-18-0	NC	NC	NC	NC
Propachlor (Ramrod)	1918-16-7	NC	NC	NC	NC
Propazine (Milogard)	139-40-2	NC	NC	NC	NC

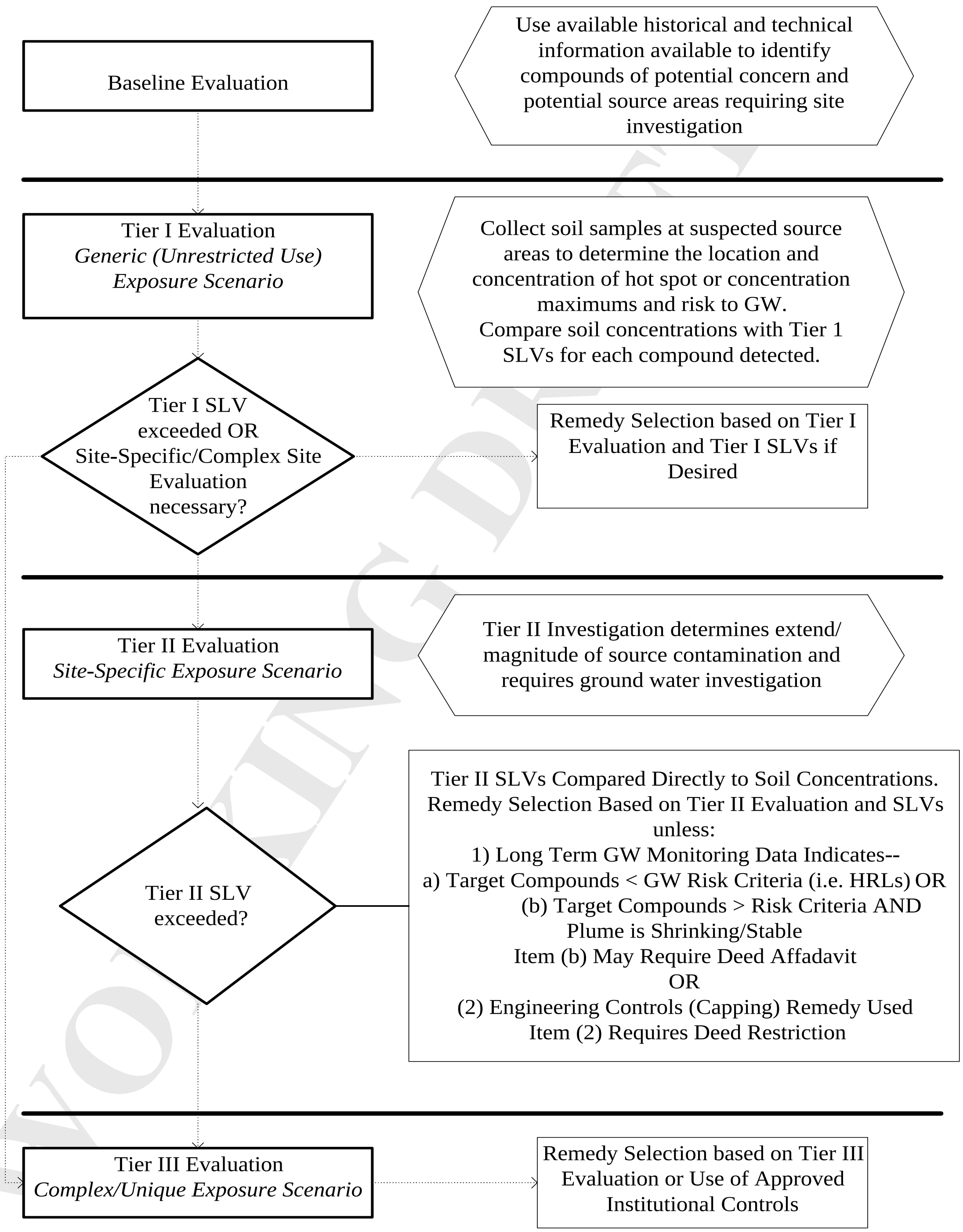
ATTACHMENT D: Soil Saturation Concentration (Csat) Estimates For Compounds (Continued)

	CAS	Csat	Csat	Csat	Csat
COMPOUND	Registry#	Clay	Clay	Sand	Sand
		foc=0.2	foc=0.6	foc=0.2	foc=0.6
Simazine (Princep)	122-34-9	NC	NC	NC	NC
Terbufos	13071-79-9	591	1761	701	1871
Triallate (Far-go)	2303-17-5	NC	NC	NC	NC
Trifluralin (Treflan)	1582-09-8	48059	144059	48013	144013
Dioxins and Dibenzofurans					
2,3,7,8-Tetrachlorodibenzofuran (TCDF) 2,3,7,8-TCDD (or 2,3,7,8-TCDD equivalents) (Dioxine)	1746-01-6	97	290	97	290
1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	19408-74-3	NC	NC	NC	NC
Explosives					
2,4-Dinitrotoluene (DNT)	121-14-2	NC	NC	NC	NC
2,6-Dinitrotoluene (2,6-DNT)	606-20-2	NC	NC	NC	NC
2,4,6-Trinitrotoluene (TNT)	118-96-7	NC	NC	NC	NC
Additional Organics, Pesticides and Herbicides					
Acifluorfen	62476-59-9	NC	NC	NC	NC
Acrylamide	79-06-1	NC	NC	NC	NC
Aldrin	309-00-2	938	2814	938	2814
Ametryn	834-12-8	NC	NC	NC	NC
Benzoic acid	65-85-0	128242	383000	127566	382324
alpha-BHC (alpha-Lindane)	319-84-6	492	1476	492	1476
beta-BHC (beta-Lindane)	319-85-7	6048	18144	6048	18144
sigma-BHC (sigma-Lindane)	319-86-8	8104	24301	8100	24297
gamma-BHC	58-89-9	1457	4367	1456	4366
Biphenyl	92-52-4	NC	NC	NC	NC
Bis(2-Chloroisopropyl)ether	108-60-1	21384	63312	21057	62985
Carbazole	86-74-8	5073	15216	5072	15215
Carboxin	5234-68-4	NC	NC	NC	NC
Chloramben	133-90-4	NC	NC	NC	NC
Chlordane	57-74-9	1344	4032	1344	4032
Chlorothalonil	1897-45-6	NC	NC	NC	NC
Dacthal (DCPA)	1861-32-1	NC	NC	NC	NC
Dalapon	75-99-0	NC	NC	NC	NC
4, 4' - DDD	72-54-8	18000	54000	18000	54000
4, 4' - DDE	72-55-9	107280	321840	107280	321840
4, 4' - DDT	50-29-3	13150	39450	13150	39450
Diazinon	333-41-5	NC	NC	NC	NC
1,3-Dichloropropene(cis, trans-, mixture-)	542-75-6	15830	46070	15743	45983
Dieldrin	60-57-1	835	2504	835	2504
Dioxane (1,4-Dioxane)	123-91-1	NC	NC	NC	NC
Diphenamid		NC	NC	NC	NC
Diquat	231-36-7	NC	NC	NC	NC
Diuron	330-54-1	NC	NC	NC	NC
Endosulfan	115-29-7	218	655	218	655

ATTACHMENT D: Soil Saturation Concentration (Csat) Estimates For Compounds (Continued)

COMPOUND	CAS Registry#	Csat Clay foc=0.2	Csat Clay foc=0.6	Csat Sand foc=0.2	Csat Sand foc=0.6
Endothall	145-73-3	NC	NC	NC	NC
Endrin	72-20-8	615	1845	615	1845
Fenamiphos	22224-92-6	NC	NC	NC	NC
Fluometuron	2164-17-2	NC	NC	NC	NC
Formaldehyde	50-00-0	NC	NC	NC	NC
Glyphosate (Roundup)	1071-83-6	NC	NC	NC	NC
Heptachlor	76-44-8	50760	152280	50760	152280
Heptachlor epoxide	1024-57-3	3328	9984	3328	9984
Hexazinone	51235-04-2	NC	NC	NC	NC
Linuron	330-55-2	NC	NC	NC	NC
Malathion	121-75-5	11686	34989	11659	34961
Maleic Hydrazide (Royal Slo-Gro)	123-33-1	NC	NC	NC	NC
2-(2-Methyl-4-chlorophenoxy)propionic acid (MCPP)	7085-19-0	NC	NC	NC	NC
Methanol (Carbinol, Columbian spririts, wood alcohol)	67-56-1	NC	NC	NC	NC
Methoxychlor	72-43-5	879	2638	879	2638
n-Hexane	110-54-3	NC	NC	NC	NC
nButanol	71-36-3	67767	165273	52870	150376
Oxamyl (Vydate)	23135-22-0	NC	NC	NC	NC
Paraquat	4685-14-7	NC	NC	NC	NC
Propham (IPC, Chem-Hoe)	122-42-9	NC	NC	NC	NC
Propoxur (Baygon)		NC	NC	NC	NC
Tebuthiuron (Spike)	34014-18-1	NC	NC	NC	NC
Terbacil (Sinbar)	5902-51-2	NC	NC	NC	NC
Toxaphene	8001-35-2	38036	114108	38036	114108

APPENDIX E: RISK BASED DECISION MAKING FRAMEWORK AND THE LEACHING PATHWAY



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