Soil Leaching Values
Remediation Division

Introduction

This document provides guidance from the Minnesota Pollution Control Agency (MPCA) Remediation Division for evaluating risks posed by leaching of contaminants in soil to groundwater (soil leaching pathway). The soil leaching pathway can result in degradation of groundwater quality and pose risks to drinking water receptors.

For most programs in the Remediation Division, assessment of whether the soil leaching pathway is a concern will be conducted through the evaluation of groundwater data. Both petroleum and hazardous substance remediation programs have specific program guidance on when a groundwater assessment is required.

At sites where a voluntary party is not investigating groundwater and an evaluation of the soil leaching pathway is needed, soil leaching values (SLVs) may be a tool for evaluating the soil leaching pathway. Any party proposing to use SLVs in lieu of the collection of groundwater data as required by MPCA guidance must obtain prior approval from the MPCA.

Soil leaching values

SLVs are compound-specific, risk-based screening criteria developed by the MPCA to evaluate risks posed to groundwater by soil leaching. The SLV is an estimation of the unsaturated soil contaminant concentration for a given compound above which may result in groundwater contamination in excess of chemical-specific drinking water criteria.

The MPCA SLV conceptual model (Appendix A) is based on an analytic model utilizing a soil partitioning equation and a dilution attenuation factor (DAF), which respectively estimates an equilibrium soil leachate concentration and its concentration reduction based on mixing in groundwater. It is principally based on the U.S. Environmental Protection Agency Soil Screening Guidance (EPA, 1996a, 1996b). The target groundwater criteria used are predominantly the Health Risk Limits established by the Minnesota Department of Health (MDH).

A spreadsheet (the SLV-Spreadsheet) listing the Screening SLVs (formerly referred to as Tier 1 SLVs) accompanies this guidance and can be found on the MPCA's website. The SLV-Spreadsheet also provides means for calculating site-adjusted SLVs (formerly referred to as Tier 2 SLVs) using site-specific information provided by the user (Appendix B).

Chemicals of potential concern

Chemicals that pose the greatest risk to groundwater are those that are both *mobile* and have *lower* target *risk-based criteria for drinking water*. Volatile Organic Compounds, in general, have the greatest potential for soil leaching due to their greater mobility in unsaturated soils and groundwater. Heavier semi-volatile organic compounds typically pose relatively lower risk to groundwater due to their larger compound structure and lower mobility. Heavy metals are typically highly immobile in soils and

groundwater as a result of the wider range of geochemical processes that affect adsorption and precipitation behavior of metals (EPA, 1992), although some metals can be mobilized under specific chemical conditions (e.g., low pH). As a result, metals rarely result in concerns for the soil leaching pathway except at sites with significant releases of metal-bearing wastes. Naturally occurring trace metal concentrations are prevalent in soils, are widely observed at concentrations higher than their respective Screening SLVs, and are not considered to be a contaminant release.

Limitations of soil leaching values

SLVs are based on conservative assumptions and do not consider contaminant mass loss in soils resulting from biodegradation or volatilization. They also cannot account for all of the complex processes resulting in contaminant retention in soils due to the soils being structured and layered, chemical transformations, and rate-limited desorption. As a result, obtaining actual groundwater quality data is often the best way to evaluate future soil leaching. For older soil releases, the absence of contaminants in groundwater at concentrations of concern provides supporting rationale that the soil leaching pathway does not pose a risk under current site conditions. Stated another way, for historical releases, risk-based conclusions drawn from groundwater quality data will always have priority over the use of SLVs alone as a predictive tool for assessing future leaching risks if it is assumed that the leaching conditions at the site remain the same.

While the SLVs are based on conservative assumptions, the Screening SLV conceptual model is not representative of sites where the contaminated unsaturated geology is dominated by karst or fractured clays or bedrock. Such conditions may represent higher soil leaching pathway risks than indicated by the Screening SLV conceptual model which soil-leaching risk evaluations must take into consideration.

The SLVs are based on target groundwater criteria and are not designed to evaluate risks in situations where the groundwater receptor at the site is surface water rather than potential groundwater drinking water receptors.

Regulated and unregulated fill

Screening SLVs are also one of several screening criteria used in determining whether fill generated at remediation sites can be managed as unregulated fill as described in the MPCA document *Best Management Practices for the Off-Site Reuse of Unregulated Fill* (MPCA, 2012). In situations where contaminated soils proposed for off-site reuse do not meet the definition of unregulated fill, refer to the MPCA policies and application procedures described in *Off-Site Use of Regulated Fill Policy* (MPCA, 2012).

Use of Screening Soil Leaching Values

The most conservative screening step is comparing soil contaminant concentrations to compound-specific Screening SLVs. A particular chemical or source area "passes" this screening if the concentrations of contaminant(s) are at or below its Screening SLV. Chemicals or source areas that "pass" this evaluation are determined to not pose a potential risk to groundwater and require no further evaluation for this pathway.

The following additional guidelines outline how the SLVs are to be utilized:

- SLVs are not applicable when (a) there are no groundwater receptors at risk and (b) the groundwater plume has been documented to be stable or shrinking. This situation is applicable to all remedial programs but is especially applicable to petroleum releases, due to the relatively rapid biodegradation of petroleum-related VOCs in both soil and groundwater.

- For older soil releases, if compounds with concentrations in excess of SLVs in soil are not identified in groundwater, these compounds can be determined not to pose a risk for the soil leaching pathway if the leaching conditions at the site remain the same.

- If compounds with concentrations in excess of SLVs in soil are identified in groundwater above target groundwater criteria, the SLVs can be used to identify areas of soil contamination that are contributing to the groundwater contamination. Conversely, if soil remediation is being conducted in lieu of a groundwater investigation and risk-based evaluation of groundwater risks (e.g., some brownfield sites), the use of SLVs as cleanup criteria would address potential risks from soil leaching.

- In cases where SLVs are used as non-risk-based cleanup criteria, Site-adjusted SLVs should provide a more realistic estimation of soil leaching risk.

- SLVs should not be used for inorganic compounds except in cases where significant contaminant sources are suspected (e.g., plating, fly ash, battery wastes, some scrap yards, mining wastes.)

Site-adjusted soil leaching values

Site-adjusted SLVs provide a more realistic estimation of risk associated with the soil leaching pathway rather than relying on Screening SLVs. Site-specific data required for adjusting the Screening SLVs include measurement of source area dimensions, total organic carbon, aquifer hydraulic gradient, hydraulic conductivity, the vertical distance from the base of vadose zone contamination to groundwater, and soil pH for evaluating metals and ionizable organics. If a particular site-specific input parameter is not known, the default value can be used instead. Contaminant concentrations are then compared as before to Site-adjusted SLVs.

If the distribution of soil contaminant concentrations has been well-characterized, a depth-weighted average concentration or an Upper 95 Confidence Limit (UCL) average can be calculated for comparison to Site-adjusted SLVs, rather than comparing individual sample results. For more information on calculating a depth-weighted average concentration, refer to the EPA Soil Screening Guidance (1996b, Section 2.3.3).

Other soil leaching pathway evaluation tools

In lieu of using an analytical equation to calculate Site-adjusted SLVs, a leach test may be used as an empirical means of evaluating leaching potential. Leach tests can be useful especially when inorganics or other nonvolatile compounds are the contaminant(s) of concern, although this technique is not applicable for VOCs. If used, the recommended test method is the EPA Synthetic Precipitation Leaching Procedure, Method SW-846 Method 1312 (EPA, 1996b; NJDEP, 2008), although other leach tests can be considered if appropriate for site-specific conditions. Leach test analytical results are applied by multiplying the result by the site-specific DAF and then comparing the result with the target groundwater criteria. Test results suggest there is a soil leaching risk when sample concentrations or average concentrations exceed the leach test result as adjusted by the DAF. The use of numerical models (e.g., SESOIL) or the development of site-specific soil-water partition coefficient for compounds of concern may be considered but are beyond the scope of this guidance.

Documentation for the Soil Leaching Pathway Evaluation

The results of the soil leaching pathway risk evaluation should be incorporated in Remedial or Phase II Investigation reports if the SLVs are applicable. The reporting should include a summary tabulation of all soil contaminant concentrations compared to Screening SLVs and, if applicable, Site-adjusted SLVs. If Site adjusted SLVs are calculated, documentation should also include the SLV inputs if they differ from default parameters, representative soil concentrations, basis for use of depth weighted average or Upper 95 UCL values, and groundwater risk evaluation results.

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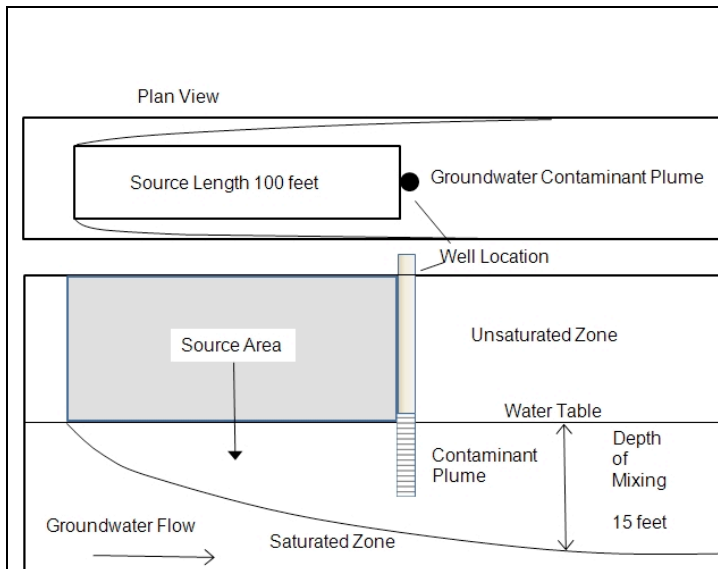# Appendix A: Conceptual site model for soil leaching values

Figure A. Graphic Description of SLV Conceptual Site Model

Soil Leaching Value (SLV) =

Soil Leaching Concentration x Dilution Attenuation Factor X Contaminant Reduction Factor,

Soil Leaching Concentration (SLC) =

$$C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right)$$

Dilution Attenuation Factor (DAF) =

$$DAF = \left(1 + \frac{Kid_m}{IL}\right)$$

Contaminant Redistribution Factor (CRF) =

$$CRF = \left(\frac{d_1 + d_2}{d_1}\right)$$

$$SLV = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right)\left(1 + \frac{Kid_m}{IL}\right)\left(\frac{d_1 + d_2}{d_1}\right)$$

TABLE A. SCREENING SLV DEFAULT PARAMETERS

Parameter - Definition (units)	Default
C_w - target soil leachate concentration (mg/L)	MDH drinking water criteria (HRL, HBV or RAA), EPA long-term health advisory, 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})	0.30 (see EPA 1996a, Section 2.5.2)
θ_a - air-filled soil porosity (L_{air}/L_{soil})	n - θ_w = .26
ρ_b - dry bulk soil density (kg/L)	1.5
Ps − soil particle density (kg/L)	2.6
n - total soil porosity (L_{pore}/L_{soil}) 1-ρb/ρs	0.41
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 ft)
I - infiltration rate (cm/yr)	14
L - length of contaminant source parallel to groundwater flow direction (cm)	3048 cm (based on default of a 100 ft representative of 0.25 acre source area)
DAF -groundwater dilution attenuation factor due to leachate-groundwater mixing (dimensionless)	20
d_1	15 feet
d_2	0 feet

The MPCA Soil Leaching Values Conceptual Model

The SLVs are based on a soil-contaminant-water partitioning equation and a leachate-groundwater dilution attenuation factor (DAF) as presented in the United States Environmental Protection Agency Soil Screening Guidance (EPA, 1996b). The derivation of the three-phase (leachate, sorbed/solid and air phases) partitioning equation is provided in EPA Technical Background Document (1996a, Section 2.5). The DAF is a unitless factor based on a simple mass flux mixing model used to estimate the attenuation of the soil leachate concentration after it has mixed with groundwater. A diagram of the conceptual site model used to develop the Screening SLVs is illustrated schematically in figure A and the values are provided in the accompanying table. The conceptual site model and default site inputs reflect a physical setting with a source area 100 feet in length with a soil column and underlying aquifer comprised of unconsolidated loamy glacial or alluvial sand. It is assumed that the soil texture is uniform and soil contamination in the vadose zone extends to the water table. For the groundwater compliance point a hypothetical well is located at the downgradient edge of the source area. The conceptual model and default site inputs reflect a conservative physical setting but one representative of site situations encountered at MPCA remediation sites. The most influential parameters predicting the leachate concentration is the compound's soil-water partition coefficient, the amount of organic matter in the soil column, and soil type as an influence on infiltration rate.

The calculation of the DAF is a function of the length of source area parallel to groundwater flow (L), saturated hydraulic conductivity (K), hydraulic gradient (i), infiltration rate (I) and depth of mixing (dm). The default DAF of 20 is based on studies conducted by EPA (1996a, Appendix E) that this value is protective for most sites with a source area of 0.5 acre or less. In addition to length of source area parallel to groundwater flow (L), several other hydrologic factors, including saturated hydraulic conductivity (K) and gradient (i), infiltration rate (I) and depth of mixing (dm), influence the DAF value.

The target groundwater risk values used in the SLV calculation are applicable Minnesota groundwater drinking water criteria and include the Health Risk Limits (HRLs) or health-based values (HBVs) developed by MDH, risk-based EPA long-term health advisories (EPA, 2012), or the EPA Maximum Contaminant Levels (MCLs). Chemical data used to calculate the SLVs are provided on the "*Chemical Data*" worksheet tab of the SLV-Spreadsheet. The hierarchy used for the principal chemical parameters — soil-organic partition coefficients (Koc) for organic compounds, soil-water partition coefficients (Kd) for metals, and the Henry Law Constants—is the same as used by EPA in its "Regional Screening Levels for Chemical Contaminants at Superfund Sites" and sources are provided in the notes section on the Chemical Data tab. Soil-water partition coefficients (Kd) for several common metals and soil organic carbon-water partition coefficients (Koc) for a group of ionizable organic compounds as a function of pH were developed by EPA (1996a) using the thermodynamic MINTEQA2 model.

Soil porosity defaults are utilized for the SLVs and are tabulated for soil textures using both the U.S. Department of Agriculture classification and the USCS classification and include default values for average annual infiltration rates as a function of soil type. The estimated infiltration rates provided for use on the SLV-Spreadsheet are based on Sesoil modeled calibration of three hydrologic water balance investigations conducted by the U.S. Geologic Survey. Tabulated soil parameter defaults were estimated through a combination of the soil parameter models of Brooks and Corey (1964), Carsel and Parrish (1988), and Clapp and Hornberger (1978) and as discussed in EPA (1988, 1996b) and Connor, J.A. et al. (1997) and using MPCA modeled infiltration rates.

The Contaminant Redistribution Factor (CRF) is a unitless factor based on the Soil Attenuation Model (SAM) described by Connor, JA et al. (1997) which calculates leachate attenuation resulting from a theoretical mass redistribution from an upper contaminated soil layer to an underlying, non-impacted layer. The CRF is the only analytical component of the SLV model that is not incorporated in the EPA model. The CRF incorporate depth-to-groundwater attenuation effects by estimating the reduced leachate concentration that would result if contaminant mass in an upper contaminated soil interval (referred to Zone 1 with thickness d1) 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 of thickness d^2). It is calculated as CRF = $(d_1 + d_2)/(d_1)$. For the Screening SLVs, it is assumed that the contaminated soil lies directly on the groundwater and the CRF is given a value of one.

Appendix B. Technical support for calculated site-adjusted SLVs

Information to assist in calculating a Site-adjusted SLV is provided below. Additional step-by-step instructions are provided on the "*SLV Worksheet*" tab of the SLV-Spreadsheet.

Step 1: Estimation of soil parameters

Values for volumetric water content (θ_w) and total porosity are entered using Table 1 or Table 2 provided on the SLV worksheet. Based on the chosen values, volumetric air porosity (θ_a) is calculated automatically. Measured or default values for fraction of total organic carbon (foc) and dry soil bulk density are entered. The foc value should either be based on representative sampling results for the site or be the default value of 0.2 percent (0.002). If metals or ionizable organics are being evaluated, a site-specific soil pH can be entered; otherwise, the default pH value of 7 should be entered. The soil type selected from Table 1 or Table 2 should be the finest soil type identified in the unsaturated zone within or below the contaminated area, provided that it comprises at least 25 percent of the total soil textures. The interval accounting for this 25 percent need not be contiguous. These compounds and their tabulated modeled values are provided, for reference, respectively, in the two SLV worksheet tabs labeled "pH-based Metal Kds" and "Kocs-Ionizable Organics." Other metal Kd values and organic compound Koc and Henry Law constant values used in the SLV model are documented in the tab labeled "Chemical Data." The Kd for organic compounds on the SLV-Spreadsheet is estimated by Koc x foc.

Step 2: Calculation of Dilution Attenuation Factor

An estimated infiltration rate (I) and Infiltration Scaling Factor (ISF) are used in the Dilution Attenuation Factor (DAF) calculation. These values are chosen by the user from Tables 1 or 2 and Figure 1, respectively, on the "SLV Worksheet" tab of the SLV-Spreadsheet. The default average annual infiltration rates are derived from MPCA modeled estimates representative of different soil types, although these defaults may be replaced by other estimates or site infiltration measurements if available. The ISF is used to normalize the default infiltration rates provided in Tables 1 and 2 based on the average annual precipitation at the site. At sites with an impervious or semi-impervious surface, such as paving or sidewalks overlying contaminated soil, the infiltration value used in the Site-adjusted SLV calculation can be further adjusted by assuming a runoff factor of 90 percent, thus entering an infiltration rate that is 10 percent of the tabulated value in Tables 1 and 2. Other values required for the DAF calculation are the hydraulic conductivity (K) and measured hydraulic gradient (i) of the uppermost saturated zone, and the length of source parallel to groundwater flow direction (L).

The DAF calculation also requires an estimated value for the depth of contaminant leachate mixing (d_m) in the aquifer. This value can either be obtained using the EPA depth of mixing equation provided in the spreadsheet or from site-specific groundwater sampling results (e.g., vertical profiling) which document the maximum extent of vertical mixing of contamination in the aquifer. The mixing equation uses the values previously entered by the user for L, I and i and the aquifer thickness. Either the calculated DAF value or the minimum default value of 20 is used for the Site-adjusted SLV calculation, whichever value is greater.

Step 3: Calculation of Contaminant Redistribution Factor

If the soil contamination does not extend to the uppermost saturated zone, the Site-adjusted SLV provides an additional estimate of contaminant attenuation based on an assumption of sorptive redistribution of contamination to soils underlying the contaminated soil zone. This contaminant redistribution factor (CRF) is calculated from the vertical thickness of the contaminated soil zone (d_1) and the vertical thickness from the base of the contaminated soil zone to the water table (d_2). These zones of interest are illustrated schematically on Figure 2 of the "SLV Worksheet" tab. The source zone thickness (d_1) should be based on the total vertical thickness of the soil column inclusive of all soil layers with contaminant concentrations that exceed Screening SLVs.

A summary tabulation of the Site-adjusted SLV user inputs and the resulting computed SLV values are provided on the "Site Adjusted SLVs" worksheet tab on the SLV-Spreadsheet.