# EPD Stakeholder Input Request
# Land Protection Branch
# Draft Leaching Guidance

The Georgia Environmental Protection Division (EPD) Land Protection Branch (LPB) has developed the attached draft guidance document:

**FAQs for Evaluating the Soil-to-Groundwater Pathway**

This document will be applicable for use in Georgia under a variety of regulatory frameworks including RCRA, CERCLA, Hazardous Site Response Act, Voluntary Remediation Program Act, and Georgia Brownfield Act.

As part of the guidance development process, LPB is soliciting input from the public and impacted organizations regarding this document. Feedback will be accepted through December 14, 2018 by mail or by e-mail at the following addresses. You may also call with questions. Depending on the feedback received, EPD will revise and finalize the document or provide a forum for further stakeholder input:

Mail: David Hayes, Response and Remediation Program
Land Protection Branch, EPD
2 Martin Luther King, Jr. Drive, SE
Suite 1054
Atlanta, Georgia 30334
RE: FAQs for Evaluating the Soil-to-Groundwater Pathway

E-mail: david.hayes@dnr.ga.gov
Subject: FAQs for Evaluating the Soil-to-Groundwater Pathway

Phone: (404) 657-8672

EPD will be participating in a workshop hosted by Georgia Industry and Environmental Coalition on December 4, 2018 at the Southern Company Gas offices in Atlanta. This workshop will include a presentation and roundtable discussion on the topic, thereby affording an additional option for individuals to learn more and to provide feedback.

GEORGIA
DEPARTMENT OF NATURAL RESOURCES

ENVIRONMENTAL PROTECTION DIVISION

**LAND PROTECTION BRANCH**
**Hazardous Waste Corrective Action Program**
**Hazardous Waste Management Program**
**Response and Remediation Program**
2 Martin Luther King, Jr. Dr. SE
Suite 1054
Atlanta, Georgia 30334

# Frequently Asked Questions for Evaluating the Soil-to-Groundwater Pathway

**October 15, 2018**

**Technical Guidance Document**

**Disclaimer: This is an external review draft to assist stakeholders in providing feedback as part of a guidance development process.  Final agency approval of this document is pending.**

## Acknowledgement

The following staff of the EPD Land Protection Branch participated in the development of this document:

- Heather Clark (Hazardous Waste Management, DoD Unit)
- Jill Clark (Risk Assessment Unit)
- Gary Davis, P.G. (Response & Remediation, Brownfields Unit)
- David Hayes (Response & Remediation, Voluntary Remediation Unit)
- Allan Nix, P.G. (Response & Remediation, Response Development Unit 1)
- Allison Keefer, P.G. (Hazardous Waste Corrective Action, Remedial Sites 1 Unit)

Additional EPD staff and management provided technical review of this document.

# Disclaimer

This document is intended to provide guidance to stakeholders regarding the evaluation of the soil-to-groundwater pathway for sites regulated under the Hazardous Waste Corrective Action, Hazardous Waste Management, and Response and Remediation Programs of the Land Protection Branch. This document reflects the current thinking of the referenced programs regarding the subjects discussed herein. Comments are welcome at any time. This document may be revised in the future based on comments and/or new information. This document does not create or confer any rights for or on any person or operate to bind the public. An alternative approach to those discussed in this document may be used if the approach satisfies the requirements of applicable statutes and regulations. The use of trade names does not constitute endorsement by EPD.

## Contents

## Purpose

The purpose of this document is to provide guidance for evaluating the soil-to-groundwater pathway at regulated sites in Georgia in a convenient question-and-answer format. This document is intended for use with sites that are subject to regulation by the Georgia Environmental Protection Division (EPD) under the following Georgia statutes and regulations:

**Statutes:**

- Hazardous Site Response Act (OCGA 12-8-90)
- Brownfield Act (OCGA 12-8-200)
- Hazardous Waste Management Act (OCGA 12-8-60)
- Voluntary Remediation Program Act (OCGA 12-8-100)

**Regulations:**

- Rules for Hazardous Site Response (Chapter 391-3-19)
- Rules for Hazardous Waste Management (Chapter 391-3-11)

Programs within the EPD Land Protection Branch administer regulatory oversight of these statutes and regulations. These programs and their contact information are shown in Table 1. For more information about Land Protection Branch programs, click here.

**Table 1: Contact Information for Relevant EPD Regulatory Programs.**

| EPD Regulatory Program | Phone |
|---|---|
| Hazardous Waste Management Program | 404.656.2833 |
| Hazardous Waste Corrective Action Program | 404.656.7802 |
| Response and Remediation Program | 404.657.8600 |

## Frequently Asked Questions (FAQs)

### 1. What is the soil-to-groundwater pathway?

The soil-to-groundwater pathway is the pathway along which contaminants migrate from the vadose, or unsaturated, zone (soil) to the saturated zone (groundwater) by a process known as "leaching." During leaching, soil contaminants are released into the pore-waters of the soil, forming "leachate", which then percolates down into the underlying groundwater. If contaminants are present in free phase, they may migrate independently of pore water movement. The purpose of evaluating the soil-to-groundwater pathway is to determine acceptable contaminant concentrations in soil that will not cause contaminant concentrations in groundwater to exceed acceptable levels. A conceptual model of the soil-to-groundwater pathway is shown in Figure 1.

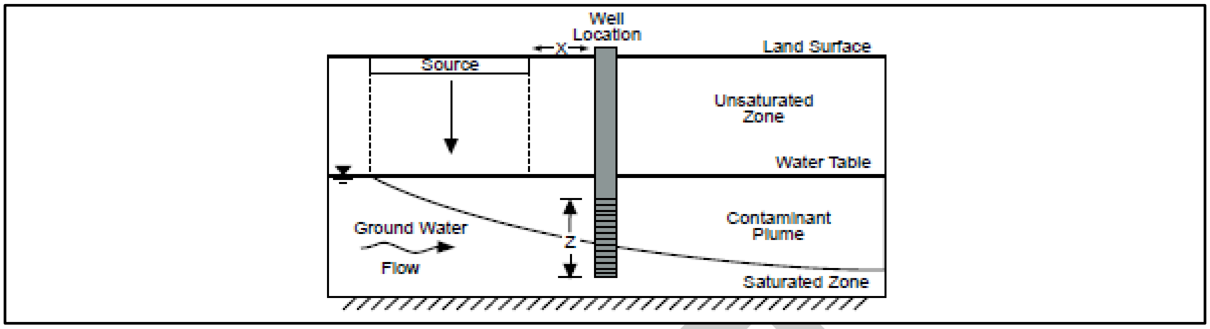

**Figure 1: Conceptual model of the soil-to-groundwater pathway. Source: EPA 1996b.**

## 2. Is an evaluation of the soil-to-groundwater pathway required at my site?

The soil-to-groundwater pathway is evaluated as part of determining site-specific soil cleanup standards. Generally, an evaluation of the pathway will be needed at sites undergoing investigation and corrective action for soil contamination. An exception would be cases where default soil cleanup standards that already account for protection of groundwater are used in accordance with applicable statutes or regulations, such as the Type 1 or 3 Risk Reduction Standards provided by the Rules for Hazardous Site Response. Contact the EPD program with regulatory oversight for more information about when an evaluation of the soil-to-groundwater pathway is required.

## 3. How do I evaluate the soil-to-groundwater pathway?

The soil-to-groundwater pathway may be evaluated using a laboratory leaching test and/or a fate and transport model approved by EPD. Laboratory tests may also be used to obtain site-specific parameters for input in fate and transport models.

EPD recommends beginning the evaluation of the soil-to-groundwater pathway with Equation 10 of the United States Environmental Protection Agency (USEPA) *Soil Screening Guidance: User's Guide* (USEPA 1996a). This equation is referred to as the "Partition Equation" in this document. The Partition Equation is a conservative screening level model that can often be used with limited site-specific data. If desired, a more site-specific evaluation can then be performed by incorporating site-specific parameters in the Partition Equation, by using laboratory leaching tests, or by using a more advanced fate and transport model with site-specific input parameters.

Note: When using a model to develop soil leaching values, the assumptions of the model should be clearly stated, and the selection/determination of any input parameters should be justified and documented.

## 4. How do I use the Partition Equation to evaluate the soil-to-groundwater pathway?

This section discusses the use of the Partition Equation to develop soil screening criteria for evaluating the soil-to-groundwater pathway. Note that the USEPA *Regional Screening Levels for Chemical Contaminants at Superfund Sites* provides tabulated "Protection of Groundwater" screening levels that are calculated with the Partition Equation at conservative risk levels, using default input parameters and particular target leachate concentrations:

https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

For cases in which it can be demonstrated that the inputs and risk levels used to calculate the Protection of Groundwater Regional Screening Levels (RSLs) align with the requirements of the regulatory program providing oversight, the RSLs may be applicable for use as preliminary screening criteria for the soil-to-groundwater pathway. Site managers with an interest in using the RSLs for screening purposes should review the RSL table User's Guide (available at the above-referenced website), which provides the basis for the development of the Protection of Groundwater RSLs, to determine their potential applicability. The appropriateness of the RSLs for use as screening criteria should be confirmed with the regulatory program under which the site is managed.

### 4.1 Introduction to the Partition Equation

The Partition Equation is presented as (USEPA 1996a):

$$C_t = C_w\left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b}\right) \qquad \text{(Equation 1)}$$

**Table 2: Parameters for Equation 1.**

| Parameter | Definition | Units | Default | Comment |
|---|---|---|---|---|
| $C_t$ | acceptable soil concentration | mg/kg | --- | --- |
| $C_w$ | target leachate concentration | mg/L | --- | see Step 2 |
| $K_d$ | soil-water partition coefficient | L/kg | chemical-specific, $K_d = K_{oc} \times f_{oc}$ (organics) | see Step 3 |
| $K_{oc}$ | soil organic carbon-water partitioning coefficient | L/kg | chemical-specific | see Step 3 |
| $f_{oc}$ | fraction of soil organic carbon | kg/kg | 0.002 | see Step 4 |
| $\theta_w$ | water-filled soil porosity | $L_{water}/L_{soil}$ | 0.3 | --- |
| $\theta_a$ | air-filled soil porosity | $L_{air}/L_{soil}$ | 0.13 | $\theta_a = \eta - \theta_w$ |
| $\eta$ | total soil porosity | $L_{pore}/L_{soil}$ | 0.43 | $\eta = 1 - \rho_b/\rho_s$ |
| $\rho_b$ | dry soil bulk density | kg/L | 1.5 | --- |
| $\rho_s$ | soil particle density | kg/L | 2.65 | --- |
| H' | dimensionless Henry's Law Constant | unitless | chemical-specific | see Step 4 |

The Partition Equation is a screening level model used to determine an acceptable contaminant concentration in soil based on the acceptable contaminant concentration in groundwater. The acceptable groundwater concentration is typically the groundwater cleanup standard for the site. Two fundamental processes are accounted for in the Partition Equation: 1) partitioning of the contaminant between soil particles, pore air, and pore water (leachate) and 2) leachate dilution in groundwater. The acceptable groundwater concentration is used to determine the target leachate concentration ($C_w$). The target leachate concentration is the maximum leachate concentration that, after dilution in groundwater, will not cause the groundwater concentration to exceed the acceptable level. The target leachate concentration is then used in the Partition Equation to determine the associated soil concentration due to soil-water partitioning.

When using the Partition Equation, the assumptions upon which the equation is based should be considered to determine if they are appropriate for site conditions. The following assumptions used in the Partition Equation are presented in the *Soil Screening Guidance: Technical Background Document* (USEPA 1996b):

- The source is infinite (i.e., steady-state concentrations will be maintained in groundwater over the exposure period of interest).
- Contaminants are uniformly distributed throughout the zone of contamination.
- Soil contamination extends from the surface to the water table (i.e., adsorption sites are filled in the unsaturated zone beneath the area of contamination).
- There is no chemical or biological degradation in the unsaturated zone.
- Equilibrium soil/water partitioning is instantaneous and linear in the contaminated soil.
- The receptor well is at the edge of the source (i.e., there is no dilution from recharge downgradient of the site) and is screened in the plume.
- The aquifer is unconsolidated and unconfined (surficial).
- Aquifer properties are homogeneous and isotropic.
- There is no attenuation (i.e. adsorption or degradation) of contaminants in the aquifer.
- Non-aqueous phase liquids (NAPLs) are not present at the site.

It is highly recommended that users of the Partition Equation review relevant sections of the *Soil Screening Guidance*, which includes the *User's Guide*, the *Technical Background Document*, and the *Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites* (USEPA 1996a, 1996b, 2002). These documents are available at the following website:

https://www.epa.gov/superfund/superfund-soil-screening-guidance

## 4.2 Steps to Using the Partition Equation

The following methodology is recommended for using the Partition Equation to evaluate the soil-to-groundwater pathway:

1. Delineate the source area

   The source area consists of contaminated soils located above the uppermost water-bearing unit, and can act as a reservoir for migration of regulated substances to groundwater. The source area for a contaminant may be delineated by the contaminant background concentration, the practical quantitation limit, or an alternate value approved by EPD. The value used for source area delineation is generally established by the program under which the evaluation is being performed. Contact the regulatory program overseeing the site investigation for additional information.

2. Determine the target leachate concentration, $C_w$

   Determination of the target leachate concentration is discussed in Section A.1 of the Appendix.

3. Determine the soil-water partition coefficient, $K_d$

   Literature values or site-specific values may be used for $K_d$. Determination of the soil-water partition coefficient is discussed in Section A.3 of the Appendix.

4. Determine other parameters

   a. Fraction of organic carbon, $f_{oc}$

      The default $f_{oc}$ value for use in the Partition Equation is 0.002 kg/kg. A site-specific value may also be used. Determination of a site-specific value for $f_{oc}$ is discussed in Section A.4 of the Appendix.

   b. Dimensionless Henry's Law Constant, H'

      Values for the dimensionless Henry's Law Constant should be taken from the most recent version of the USEPA Regional Screening Levels for Chemical Contaminants at Superfund Sites, Chemical Specific Parameters Table, which is available at (USEPA 2018a):

      https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

      The dimensionless Henry's Law Constant should not be confused with the Henry's Law Constant, which has units of (atm x $m^3$/mol).

   c. Porosity [total ($\eta$), water-filled ($\theta_w$), and air-filled ($\theta_a$)]

      The default values for total, water-filled, and air-filled porosity are 0.43, 0.3, and 0.13, respectively. These values may be adjusted based on site-specific geotechnical data.

   d. Dry soil bulk density, $\rho_b$

The default value for dry soil bulk density is 1.5 kg/L. This value may be adjusted based on site-specific geotechnical data.

5. Calculate the acceptable soil concentration, $C_t$

   Once values for all parameters have been identified, the Partition Equation (refer to Equation 1) is used to calculate the acceptable soil concentration, which is considered a conservative estimate of the maximum contaminant concentration in soil that will not result in an exceedance of the acceptable groundwater concentration.

## 5. What laboratory leaching tests are acceptable for evaluating the soil-to-groundwater pathway?

Two USEPA laboratory tests, the Toxicity Characteristic Leaching Procedure (TCLP, SW-846 Method 1311) and the Synthetic Precipitation Leaching Procedure (SPLP, SW-846 Method 1312), are generally accepted as stand-alone tests for evaluating the soil-to-groundwater pathway. These tests simulate leaching in soil samples, allowing a correlation to be made between the total contaminant concentration in a soil sample and the resulting leachate concentration. These tests are similar, but they use different extraction fluids to simulate different types of environmental conditions. The TCLP test was developed as a waste characterization test to assess the leaching of contaminants in a municipal solid waste landfill (USEPA 1996a). To simulate the conditions present in a municipal solid waste landfill, the TCLP test employs a buffered organic acid as the extraction fluid (TNRCC 1998).

The SPLP test employs a non-buffered inorganic extraction fluid that is intended to simulate leaching in typical soil, where pore water is present due to infiltration from precipitation (TNRCC 1998). For the purpose of evaluating the soil-to-groundwater pathway, the use of the TCLP test should be limited to sites where conditions reflect those of a municipal solid waste landfill.

The TCLP test remains the sole test for evaluating the toxicity characteristic for waste determination (i.e., solid vs. hazardous waste) purposes. *The SPLP test better simulates the field conditions at most regulated sites (other than municipal solid waste landfills), and therefore is the preferred laboratory leaching test for evaluating the soil-to-groundwater pathway.* Other leaching tests may be considered on a site-specific basis.

## 6. What are the sample collection and reporting recommendations associated with the SPLP and TCLP tests?

### 6.1 Sample Collection Recommendations

1. For general soil sampling information, refer to the USEPA Region 4 Science and Ecosystem Support Division (SESD) *Soil Sampling Operating Procedure*, which is available at (USEPA 2014):

   https://www.epa.gov/quality/soil-sampling

2. The number of samples needed to adequately support the estimation of soil leaching thresholds using laboratory leaching tests will depend on the size and complexity of the site, as well as the method selected to evaluate the leaching test data.

   Generally, sites with larger source areas and/or a greater degree of subsurface heterogeneity will require more samples to remain adequately representative of spatial contaminant concentration variability and differences in leaching potential due to soil properties where more than one major soil type is present.

   In order to generate a data set that is more likely to support the requirements of the methods presented in this guidance, EPD recommends that a minimum of (10) samples be collected and analyzed per source area. If more rigorous statistical methods or models are used to evaluate leaching test results, the number of samples collected should be commensurate with the requirements of the model, at the desired level of confidence.

3. Each soil sample collected for leaching analysis should comprise one (1) aliquot for total concentration analysis and one (1) aliquot for the leaching procedure. An additional aliquot should be collected for the purpose of pH measurement for samples that are to be analyzed for inorganics or ionizing organics.

4. Soil samples should be collected across the range of contaminant concentrations (including higher, mid-range, and lower concentrations) found throughout the volume of soil found within the source area to increase the likelihood of bracketing the soil leaching threshold.

5. Soil samples should be collected from each major soil type and/or soil horizon found in the source area to assess differences in leaching potential due to soil properties.

6. Sampling Considerations for Inorganics and Semi-volatiles:

   a. Samples collected for inorganics or semi-volatiles should be thoroughly homogenized to ensure that the aliquot used for totals analysis and the aliquot used for the leachate procedure are representative of the same sample matrix.

   b. At least one duplicate totals aliquot should be collected and analyzed. The totals aliquot and the duplicate totals aliquot should be taken from the same homogenized soil sample. For more information regarding quality control sampling, see the USEPA Region 4 SESD *Field Sampling Quality Control Operating Procedure* at (USEPA 2017):

      https://www.epa.gov/quality/field-sampling-quality-control

7. Sampling Consideration for Volatiles:

   a. Soil samples for volatiles should not be homogenized due to the potential for volatile loss. Since the individual aliquots must be collected and containerized separately (See SESD soil sampling protocol), care should be taken to collect the aliquot for totals analysis as close to the aliquot for the leaching procedure as practicable, so that they are as representative of similar soil conditions as possible.

b. Field chemical preservatives should not be used when collecting the aliquot to be used for the leaching procedure. These preservatives can cause contaminants to leach from soil, which can lead to inaccurate laboratory leaching test results. The leaching test aliquot should be collected in a laboratory-approved container (e.g., En Core® sampler). Care should be taken to minimize voids and completely fill the container (zero headspace). For consistency, it is recommended that the aliquots for totals analysis also be collected using methods that do not require field chemical preservatives.

c. At least one duplicate totals aliquot should be collected and analyzed. The duplicate totals aliquot should be collected as close as possible to the location of the totals aliquot of the original sample. As indicated above, additional information regarding quality control sampling can be found at:

https://www.epa.gov/quality/field-sampling-quality-control

### 6.2 Reporting Recommendations

The following should be reported when using SPLP or TCLP tests to evaluate the soil-to-groundwater pathway:

1. A narrative description of sampling and test methods
2. Laboratory analytical data
3. A site map (with scale), showing the location of each soil sample
4. A table, listing the following information for each soil sample:
   a. Sample identification;
   b. Depth of the soil sample;
   c. Soil classification (i.e. silty sand, clay, etc.);
   d. Soil pH (only needed for inorganics and ionizing organics);
   e. Total contaminant concentration in soil (dry weight basis) (mg/kg);
   f. Leachate concentration (mg/L);
   g. Volume of leachate (L);
   h. Dry weight of soil used for leaching test (kg); and
   i. Leachate pH.

Note: Consider consulting with the laboratory prior to submitting soil samples for analysis to ensure that the desired information will be reported.

## 7. I performed SPLP or TCLP tests to evaluate the soil-to-groundwater pathway. How do I analyze the test results?

The following methodology is recommended for analyzing SPLP or TCLP results to evaluate the soil-to-groundwater pathway. This methodology has been adapted from the New Jersey Department of Environmental Protection (NJDEP) document, *Development of Site-Specific*

*Impact to Ground Water Soil Remediation Standards Using the Synthetic Precipitation Leaching Procedure* (NJDEP 2013):

1. Delineate the source area

   Source area delineation is discussed in Section 4.2.

2. Determine the target leachate concentration

   Determination of the target leachate concentration is discussed in Section A.1 of the Appendix.

3. Calculate the soil-water partition coefficient, $K_d$, for each leaching test

   The calculation of $K_d$ for a leaching test is discussed in Section A.3.3.2 of the Appendix.

4. Estimate the field leachate concentration for each leaching test

   The field leachate concentration can be estimated using the following equation:

$$C_L = \frac{C_T}{K_d + \frac{\theta_w + \theta_a H'}{\rho_b}} \qquad \text{(Equation 2)}$$

**Table 3: Parameters for Equation 2**

| Parameter | Definition | Units | Default |
|---|---|---|---|
| $C_L$ | field leachate concentration | mg/L | --- |
| $C_T$ | total contaminant concentration in soil | mg/kg | --- |
| $K_d$ | soil-water partition coefficient | L/kg | chemical-specific,<br>$K_{oc}$ x $f_{oc}$=$K_d$ (organics) |
| $\theta_w$ | water-filled soil porosity | $L_{water}/L_{soil}$ | 0.3 |
| $\theta_a$ | air-filled soil porosity | $L_{air}/L_{soil}$ | 0.13 |
| $\rho_b$ | dry soil bulk density | kg/L | 1.5 |
| H' | dimensionless Henry's Law Constant | unitless | chemical-specific |

5. Determine the acceptable soil concentration

   Three methods are presented that allow for the determination of the acceptable soil concentration. Methods 1 and 2 can be used to directly determine the acceptable soil concentration. Method 3 involves using a site-specific soil-water partition coefficient, $K_d$, in a fate and transport model to determine the acceptable soil concentration. Any of these methods may be used, provided that consideration is given to the individual method recommendations.

   a. Method 1: Determine an Acceptable Soil Concentration by Direct Comparison

This method allows for the determination of an acceptable soil concentration by direct comparison of field leachate concentrations to the target leachate concentration. This method is described as follows:

i. Prepare a table of total soil concentrations in ascending order with the corresponding field leachate concentration and the target leachate concentration.

ii. If none of the field leachate concentrations exceed the target leachate concentration, the highest total soil concentration may be used as the acceptable soil concentration. In these cases, EPD may request additional sampling to confirm the leaching test results.

iii. If some, but not all, of the field leachate concentrations exceed the target leachate concentration, the highest total soil concentration for which the field leachate concentration does not exceed the target leachate concentration may be used as the acceptable soil concentration, as long as the field leachate concentrations of all lower total soil concentrations do not exceed the target leachate concentration.

iv. If all of the field leachate concentrations exceed the target leachate concentration, none of the soil concentrations should be used and additional sampling is recommended.

The use of Method 1 is illustrated in the following example:

**Table 4: Example of Method 1.**

| sample identification | total contaminant concentration in soil (mg/kg) | field leachate concentration (mg/L) | target leachate concentration (mg/L) |
|---|---|---|---|
| Sample 1 | 0.5 | 0.04 | 0.1 |
| Sample 2 | 0.8 | 0.04 | 0.1 |
| Sample 3 | 2 | 0.002 | 0.1 |
| Sample 4 | 12 | 0.03 | 0.1 |
| Sample 5 | 30 | 0.09 | 0.1 |
| Sample 6 | 75 | 0.3 | 0.1 |
| Sample 7 | 120 | 0.2 | 0.1 |
| Sample 8 | 150 | 0.08 | 0.1 |
| Sample 9 | 180 | 0.5 | 0.1 |
| Sample 10 | 300 | 2 | 0.1 |

In this example, the acceptable soil concentration would be 30 mg/kg because the field leachate concentrations of this and all lower total soil concentrations are below the target leachate concentration. Note that even though the field leachate concentration of Sample 8 is below the target leachate concentration, the field leachate concentrations of Samples 6 and 7 (with lower soil concentrations) exceed the target leachate concentration. Therefore, the total soil concentration of Sample 8 should not be used as the acceptable soil concentration.

b. Method 2: Determine an Acceptable Soil Concentration using Linear Regression

This method allows for the determination of an acceptable soil concentration by linear regression analysis of the leaching test results. This method is described as follows:

i. Determine if the data qualify for this method:

1. At least half of the total soil concentration data points should be at or above the midpoint of the range of total soil concentration values.
2. The target leachate concentration should be within the range of field leachate concentrations.

ii. Prepare a scatterplot of total contaminant concentration in soil (y-axis) versus field leachate concentration (x-axis) using a computer program such as Microsoft Excel®. Apply a linear trend line to the data and display the trend line equation and the coefficient of determination ($R^2$) value on the graph. If the $R^2$ value is 0.8 or greater, continue to the next step. If the $R^2$ value is less than 0.8, a different method is recommended to determine the acceptable soil concentration.

iii. The acceptable soil concentration may be determined using the following equation:

$$C_t = m(C_w) + b \qquad \text{(Equation 3)}$$

**Table 5: Parameters for Equation 3.**

| Parameter | Definition | Units |
|---|---|---|
| $C_t$ | acceptable soil concentration | mg/kg |
| $C_w$ | target leachate concentration | mg/L |
| b | y-intercept of the linear trend line | mg/kg |
| m | slope of the linear trend line | L/kg |

The use of Method 2 is illustrated in the following example:

**Table 6: Example data for Method 2.**

| sample identification | total contaminant concentration in soil (mg/kg) | field leachate concentration (mg/L) | target leachate concentration (mg/L) |
|---|---|---|---|
| Sample 1 | 20 | 0.01 | 0.2 |
| Sample 2 | 40 | 0.02 | 0.2 |
| Sample 3 | 75 | 0.12 | 0.2 |
| Sample 4 | 100 | 0.06 | 0.2 |
| Sample 5 | 120 | 0.23 | 0.2 |
| Sample 6 | 170 | 0.2 | 0.2 |
| Sample 7 | 215 | 0.45 | 0.2 |
| Sample 8 | 185 | 0.28 | 0.2 |
| Sample 9 | 250 | 0.35 | 0.2 |
| Sample 10 | 300 | 0.5 | 0.2 |

Note that half of the total soil concentrations are above the midpoint of the range of soil concentrations (160 mg/kg) and the target leachate concentration is within the range of field leachate concentrations. These are recommended conditions to proceed to the next step. The data are placed on a scatterplot, a linear trend line is applied, and the trend line equation and the $R^2$ value are displayed on the graph:

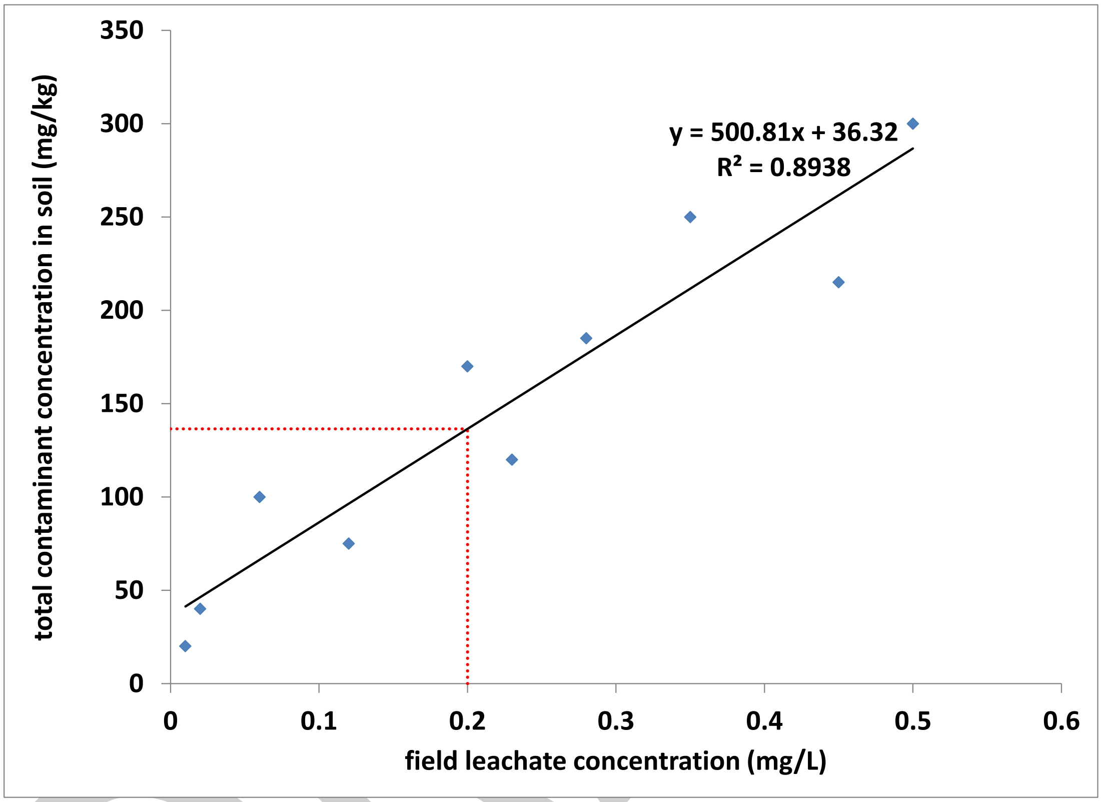

**Figure 2: Example scatterplot for Method 2.**

The $R^2$ value is greater than 0.8, so we can proceed to the next step. Plugging in the appropriate values to Equation 3 gives:

$$C_t = 500.81(0.2) + 36.32 = 136.48\frac{mg}{kg}$$

In this example, the acceptable soil concentration would be 136.48 mg/kg.

c. Method 3: Use a Site-Specific $K_d$ in a Fate and Transport Model

Determination of a site-specific $K_d$ from SPLP or TCLP results is discussed in Section A.3.3.2 of the Appendix. The use of other leaching tests to determine $K_d$ may be considered. A site-specific $K_d$ can be used as an input parameter in the Partition Equation (Equation 1) or in a more advanced fate and transport model.

## 8. What fate and transport models are acceptable for evaluating the soil-to-groundwater pathway?

Fate and transport models capable of evaluating the soil-to-groundwater pathway range from simple, such as the Partition Equation, to more advanced computer programs. Advantages of more advanced models include the ability to more accurately model site conditions, such as contaminant distribution and soil property variability, and the ability to consider more complex fate and transport processes, such as contaminant attenuation and degradation. EPD generally accepts models that are accepted or supported by the USEPA or the USGS. Other models may be accepted on a case-by-case basis. EPD encourages the use of public domain models that have been subject to extensive peer review. Some examples of public domain vadose zone models include SESOIL, VLEACH, and VS2DT.

When using a fate and transport model to evaluate the soil-to-groundwater pathway, at a minimum, a vadose zone model should be used to show that leachate concentrations reaching groundwater will not exceed the acceptable groundwater concentration. Vadose zone models may be used in conjunction with groundwater models to account for contaminant dilution and attenuation in groundwater. Some cases may require the use of both vadose zone and groundwater models, such as when the potential for contaminant migration to a particular receptor well is being assessed.

Conservative parameters should be used in cases where reliable site-specific parameters are not available. EPD may require calibration of model parameters and field validation of model projections.

## 9. How are measured soil concentrations compared to calculated soil concentrations protective of the soil-to-groundwater pathway to demonstrate compliance?

The USEPA Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites (2002) provides three methods for comparing measured site soil concentrations to calculated concentrations that are protective of the soil-to-groundwater pathway. These methods are discussed below, along with considerations for their use:

a. Using maximum measured soil concentrations

   The simplest approach is to compare the maximum measured soil concentration to a calculated value that is protective of the soil-to-groundwater pathway. If the maximum concentration is less than or equal to the calculated value, the soil would be considered to be protective of the soil-to-groundwater pathway.

b. Using the mean concentration in soil borings

   When soil sample results are available from multiple depths within a borehole, the mean contaminant concentration of each contaminant from the impacted zone within the borehole may be compared to calculated values protective of the soil-to-groundwater pathway. However, the use of this method is contingent upon various aspects of the Conceptual Site Model (CSM) and may not be appropriate for use at some sites. In general, this method may be considered when a clean layer of soil exists between the bottom of the impacted soils and the water table and sufficient sample data are available over the vertical extent of the impacted soils to characterize contaminant concentrations in the subsurface. Particular attention should be given to the vertical delineation of the impacted interval when calculating mean concentrations for a soil boring. Clean samples from non-impacted intervals should not be included in the calculation of the mean. Additionally, the number of soil borings advanced within the area of contamination should be sufficient to characterize subsurface contamination.

c. Using a 95% upper confidence limit (UCL) of the mean

If sufficient data is available, a 95% UCL of the mean contaminant soil concentration within the contaminated area may be compared to a calculated value protective of the soil-to-groundwater pathway. As with using soil boring averaging, a clean layer of soil should exist between the zone of contamination and the water table, and clean samples collected outside the area of contamination should not be included in the calculation of the 95% UCL of the mean.

**10. What additional lines of evidence can be used to support an evaluation of the soil-to-groundwater pathway?**

Users of this guidance are generally expected to evaluate the potential for soil leaching based on a comparison of measured contaminant concentrations in site soils to calculated soil concentrations protective of the soil-to-groundwater pathway developed using an EPD-approved method. However, EPD recognizes that these quantitative methods may not account for all factors with the potential to influence the soil-to-groundwater pathway at a particular site. In cases where the soil release occurred many years ago and groundwater has not been impacted by leaching, EPD may consider the use of these and other lines of evidence to demonstrate that the existing soil concentrations are protective of groundwater on a case-by-case basis. These lines of evidence may include, but are not limited to:

- Age of the release: The age of the soil release should be on the order of decades old, such that the effect of any expected leaching would be observable in groundwater. This is a critical line of evidence for using this method.
- Groundwater concentration trends: Sufficient groundwater data should demonstrate that groundwater has not been impacted by leaching. This is a critical line of evidence for using this method. In some cases, ongoing groundwater monitoring may be appropriate to confirm that the soil concentrations remain protective of groundwater.
- Magnitude of the release: consideration of the magnitude of soil contaminant concentrations that exceed calculated soil concentrations protective of the soil-to-groundwater pathway
- Horizontal and vertical extent of the release: consideration of the extent of the soil release, including the frequency of soil contaminant concentrations that exceed calculated soil concentrations protective of the soil-to-groundwater pathway

- Depth of groundwater: consideration of the depth of groundwater in relation to soil contamination
- Ground cover: consideration of how past ground cover (e.g., paved surface) may have influenced past leaching and how current/future soil cover may influence future leaching
- Area groundwater use: consideration of groundwater use in the surrounding area

## References

Indiana Department of Environmental Management (IDEM). 2007. Determining the Fraction of Organic Carbon. OLQ-General ID-0119. September. https://semspub.epa.gov/work/05/424375.pdf

NJDEP. 2013. Development of Site-Specific Impact to Ground Water Soil Remediation Standards Using the Synthetic Precipitation Leaching Procedure. Version 3.0. November. http://www.nj.gov/dep/srp/guidance/rs/splp_guidance.pdf

Ohio EPA. 2008a. Voluntary Action Program Derived Leach-Based Soil Values. Technical Guidance Document. Revision 3. October. http://www.epa.state.oh.us/portals/30/vap/docs/sec-g-att.pdf

Ohio EPA. 2008b. Voluntary Action Program Derived Leach-Based Soil Values. Appendix Technical Support Document. October. Revision 3. http://www.epa.state.oh.us/portals/30/vap/docs/sec-g-attapp.pdf

Texas Natural Resource Conservation Commission (TNRCC). 1998. When to use Toxicity Characteristic Leaching Procedure (TCLP) Test or Synthetic Precipitation Leaching Procedure (SPLP) Test to demonstrate the leaching potential of contaminants. Interoffice Memorandum. October. https://www.tceq.texas.gov/assets/public/remediation/trrp/tclpsplp.pdf

USEPA. 1987. DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings. USEPA Publication 600287035. http://nepis.epa.gov/Simple.html

USEPA. 1996a. Soil Screening Guidance: User’s Guide. USEPA Publication 9355.4-23. July. https://www.epa.gov/superfund/superfund-soil-screening-guidance

USEPA. 1996b. Soil Screening Guidance: Technical Background Document. USEPA Publication EPA/540/R95/128. May. https://www.epa.gov/superfund/superfund-soil-screening-guidance

USEPA. 2002. Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites. OSWER 9355.4-24. December. https://www.epa.gov/superfund/superfund-soil-screening-guidance

USEPA. 2017. Field Sampling Quality Control Operating Procedure. Region 4 Science and Ecosystem Support Division. Effective Date: April 26, 2017. https://www.epa.gov/quality/field-sampling-quality-control

USEPA. 2014. Soil Sampling Operating Procedure. Region 4 Science and Ecosystem Support Division. Effective Date: August 21, 2014. https://www.epa.gov/quality/soil-sampling

USEPA. 2018. Regional Screening Levels for Chemical Contaminants at Superfund Sites. Generic Tables. https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

USEPA. 2018. Regional Screening Levels for Chemical Contaminants at Superfund Sites. User’s Guide. https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide

Washington Administrative Code (WAC). 2018. Deriving soil concentrations for groundwater protection. Section 173-340-747. http://apps.leg.wa.gov/wac/default.aspx?cite=173-340-747

# Appendix

## A.1 Determining the Target Leachate Concentration

There are two cases to consider when determining the target leachate concentration:

1. The contaminant is not present in groundwater upgradient of the source area, and
2. The contaminant is present in groundwater upgradient of the source area.

In both cases, the target leachate concentration should not exceed the water solubility of the contaminant.

### A.1.1 Case 1: The Contaminant is Not Present in Upgradient Groundwater

If groundwater upgradient of the source area has not been impacted by the contaminant, the target leachate concentration is calculated by multiplying the acceptable groundwater concentration by the dilution-attenuation factor ("DAF") (USEPA 1996a):

$$C_w = C_f \times DAF \qquad \text{(Equation 4)}$$

**Table 7: Parameters for Equation 4.**

| Parameter | Definition | Units |
|---|---|---|
| $C_w$ | target leachate concentration | mg/L |
| $C_f$ | acceptable groundwater concentration | mg/L |
| DAF | dilution-attenuation factor | unitless |

#### A.1.1.1 Determining DAF Values

The DAF is defined as "the ratio of contaminant concentration in soil leachate to the concentration in groundwater at the receptor point" (USEPA 1996b). The DAF quantifies the reduction in the contaminant concentration from soil leachate to the receptor point due to physical, chemical, and biological processes (USEPA 1996a). DAF values may be determined using either default values or by calculating a site-specific value.

##### A.1.1.1.1 Default DAF Values

A default DAF of 20 may be used in most cases when the source area is 0.5 acre or less and upgradient groundwater has not been impacted. However, EPD may not approve the use of a default DAF of 20 if site conditions indicate that it is not appropriate. Conditions where a default DAF of 20 may not be appropriate include fractured bedrock and karst aquifers (USEPA 1996b). For soil source areas greater than 0.5 acre, a default DAF of 1 may be used, or a site-specific DAF may be calculated.

#### A.1.1.1.2 Calculating a Site-Specific DAF

A site-specific DAF may be calculated using the following relationships (USEPA 1996a):

$$DAF = 1 + \frac{Kid}{LI} \qquad \text{(Equation 5)}$$

where:

$$d = \left(0.0112 \cdot L^2\right)^{0.5} + d_a\left[1 - \exp\left(\frac{-LI}{Kid_a}\right)\right] \qquad \text{(Equation 6)}$$

**Table 8: Parameters for Equations 5 and 6.**

| Parameter | Definition | Units |
|---|---|---|
| DAF | dilution-attenuation factor | unitless |
| K | hydraulic conductivity | ft/yr |
| i | hydraulic gradient | unitless |
| I | infiltration rate (groundwater recharge rate) | ft/yr |
| d | mixing zone depth (cannot exceed $d_a$) | ft |
| L | source length parallel to groundwater flow | ft |
| $d_a$ | aquifer thickness | ft |

The dilution-attenuation factor calculated using Equation 5 is based solely on leachate dilution in groundwater and does not consider the effects of any other attenuation mechanisms. Note that the mixing zone depth (d) cannot be greater than the aquifer thickness ($d_a$). Equation 5 is appropriate for determining the DAF by which "concentrations are reduced when leachate mixes with a clean aquifer" (USEPA 2002).

### A.1.2 Case 2: The Contaminant is Present in Upgradient Groundwater

If the contaminant is present in upgradient groundwater, the target leachate concentration may be calculated using Equation 4 with a DAF of 1 or using the Summers Model to account for the upgradient (background) contaminant concentration in the aquifer (Ohio EPA 2008a, 2008b). When expressed in terms of the parameters in Equation 5, the Summers Model can be presented as:

$$C_w = \left(1 + \frac{Kid}{LI}\right)C_f - \left(\frac{Kid}{LI}\right)C_i \qquad \text{(Equation 7)}$$

**Table 9: Parameters for Equation 7.**

| Parameter | Definition | Units |
|---|---|---|
| $C_w$ | target leachate concentration | mg/L |
| $C_f$ | acceptable groundwater concentration | mg/L |
| $C_i$ | upgradient groundwater concentration | mg/L |
| K | hydraulic conductivity | ft/yr |
| i | hydraulic gradient | unitless |
| I | infiltration rate (groundwater recharge rate) | ft/yr |
| d | mixing zone depth (see Equation 6) | ft |
| L | source length parallel to groundwater flow | ft |

Note that when the upgradient groundwater concentration is zero, Equation 7 is equivalent to Equation 5.

## A.2 Determining Groundwater Recharge Rates

Groundwater recharge rates may be estimated according to hydrogeologic setting using values from the USEPA publication, *DRASTIC: A Standardized System for Evaluating Groundwater Pollution Potential Using Hydrogeologic Settings* (USEPA 1987). When a range of groundwater recharge rates is presented for a hydrogeologic setting, the maximum rate should be used to calculate a site-specific DAF. Note that the DRASTIC publication presents groundwater recharge rates in units of inches per year, which requires conversion to units of feet per year for use in Equations 5 - 7. Other methods to determine the groundwater recharge rate may also be considered.

## A.3 Determining the Soil-Water Partition Coefficient, $K_d$

### A.3.1 Determining $K_d$ for Organics Using Literature Values

For organics, $K_d$ may be determined using the following relationship (USEPA 1996b):

$$K_d = K_{oc} \times f_{oc} \qquad \text{(Equation 8)}$$

**Table 10: Parameters for Equation 8.**

| Parameter | Definition | Units | Default |
|---|---|---|---|
| $K_d$ | soil - water partition coefficient | L/kg | chemical-specific |
| $K_{oc}$ | soil organic carbon - water partition coefficient | L/kg | chemical-specific |
| $f_{oc}$ | fraction of soil organic carbon | kg/kg | 0.002 |

Literature values of $K_{oc}$ may be used in Equation 8 along with the default $f_{oc}$ value of 0.002 to determine a literature-based value for $K_d$. Literature values of $K_{oc}$ should generally be taken from the most recent version of the USEPA Regional Screening Levels for Chemical Contaminants at Superfund Sites, Chemical Specific Parameters Table, which is available at (USEPA 2018a):

https://www.epa.gov/risk/regional-screening-levels-rsls-generic-tables

It should be noted that $K_{oc}$ values have been shown to vary as a function of pH for a class of organics known as ionizing organics. Ionizing organics include benzoic acid, 2-chlorophenol, 2,3-dichlorophenoxyacetic acid, 2,4-dichlorophenol, 2,4-dinitrophenol, pentachlorophenol, 2,3,4,5-tetrachlorophenol, 2,4,6-tetrachlorophenol, 2,4,5-trichlorophenol, and 2,4,6-trichlorophenol. Values of $K_{oc}$ as a function of pH for ionizing organics are presented in Exhibit C-2 of the *Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites* (USEPA 2002), which is available at:

https://semspub.epa.gov/work/HQ/174067.pdf

### A.3.2 Determining $K_d$ for Inorganics Using Literature Values

Literature values of $K_d$ for selected inorganics are listed in the "Soil to Groundwater" section of the *USEPA Regional Screening Levels User's Guide* (USEPA 2018b), which is available at:

https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide

Literature values of $K_d$ as a function of pH for selected inorganics are listed in Exhibit C-4 of the *Supplemental Guidance for Developing Soil Screening Levels at Superfund Sites* (USEPA 2002):

https://semspub.epa.gov/work/HQ/174067.pdf

The $K_d$ value for inorganics can be affected by a variety of factors, including "pH, oxidation-reduction conditions, iron oxide content, soil organic matter content, cation exchange capacity, and major ion chemistry" (USEPA 1996b). Therefore, it is recommended that laboratory leaching tests be used when possible to evaluate the soil-to-groundwater pathway for inorganics, as described in Question 7. It is particularly recommended that laboratory leaching tests be used when the subsurface pH has been impacted by a release, such as when there has been a release of an acid.

### A.3.3 Determining a Site-Specific $K_d$

#### A.3.3.1 Determining a Site-Specific $K_d$ for Organics Based on the Fraction of Soil Organic Carbon, $f_{oc}$

For organics, a site-specific $K_d$ may be determined by multiplying a literature-based $K_{oc}$ and a site-specific value for $f_{oc}$ in Equation 8. Determination of a site-specific $f_{oc}$ value is discussed in Section A.4 of the Appendix.

### A.3.3.2 Determining a Site-Specific $K_d$ Using a Laboratory Leaching Test

A site-specific $K_d$ for organics or inorganics can be determined through the use of a laboratory leaching test. For a description of laboratory leaching tests, sampling and reporting recommendations, and recommended data reduction, see Questions 5, 6, and 7.

This method allows for the determination of a site-specific soil-water partition coefficient, $K_d$, using leaching test results. The soil-water partition coefficient can be used in a fate and transport model such as the Partition Equation to determine an acceptable soil concentration. When linear partitioning is assumed, $K_d$ is defined as (NJDEP 2013):

$$K_d = \frac{C_S}{C_L} \qquad \text{(Equation 9)}$$

**Table 11: Parameters for Equation 9.**

| Parameter | Definition | Units |
|---|---|---|
| $K_d$ | soil - water partition coefficient | L/kg |
| $C_S$ | equilibrium contaminant concentration sorbed to soil | mg/kg |
| $C_L$ | equilibrium contaminant concentration in leachate | mg/L |

Using the results of a leaching test, a sample-specific $K_d$ can be calculated using the following relationship (NJDEP 2013):

$$K_d = \frac{C_T M_S - C_{SPLP} V_L}{M_S C_{SPLP}} \qquad \text{(Equation 10)}$$

**Table 12: Parameters for Equation 10.**

| Parameter | Definition | Units |
|---|---|---|
| $K_d$ | soil - water partition coefficient | L/kg |
| $C_{SPLP}$ | SPLP or TCLP leachate concentration | mg/L |
| $V_L$ | volume of leachate | L |
| $C_T$ | total contaminant soil concentration (prior to leaching test) | mg/kg |
| $M_S$ | dry weight of soil used for leaching test | kg |

The lowest calculated $K_d$ value can generally be used as a conservative estimate of $K_d$ for the source area. If statistical methods are considered to determine a representative $K_d$, it is recommended that consideration be given to the population distribution, the variance of the observed values, and the limitations of using small numbers of observations to conduct statistical analysis.

## A.4 Determining the Fraction of Organic Carbon, $f_{oc}$

The default value for $f_{oc}$ is 0.002 kg/kg, or 0.2%. However, a site-specific $f_{oc}$ may also be determined by measuring site-specific soil organic carbon. Sample collection, analytical methods, and reporting recommendations for soil organic carbon measurement are discussed in the following sections.

### A.4.1 Sample Collection Recommendations

1. A minimum of ten (10) soil samples should be collected. The total number of samples needed and the horizontal and vertical distribution of sample locations are dependent on the heterogeneity of the subsurface and should be evaluated on a site-specific basis.
2. When possible, samples should be collected at least two (2) feet below the ground surface (i.e., below the root zone) in uncontaminated soil that is representative of soil through which contaminants are likely to migrate (WAC 2018). Totals analysis, using the appropriate analytical method, for organic constituents of concern should be used to show that the soil used for organic carbon measurement has not been impacted by organic contaminants. Soil samples collected from surficial soils (where the greatest amount of organic carbon is typically located) or from soil impacted with organic contaminants may result in an overestimation of the ability of subsurface soil to adsorb contaminants.

### A.4.2 Analytical Methods

The Walkley-Black Method (dichromate oxidation) is the recommended method for measuring soil organic carbon. Other methods may be considered on a site-specific basis. Note that ASTM D2974 provides a measurement of soil organic *matter* as opposed to soil organic carbon. For more information, see the Indiana Department of Environmental Management (IDEM) guidance document, *Determining the Fraction of Organic Carbon* (IDEM 2007).

### A.4.3 Reporting Recommendations

1. A site map (with scale), showing the location of each soil sample
2. Laboratory analytical data
3. A narrative describing the sampling methods used
4. A table, listing the following information for each sample:
   a. Sample identification;
   b. Depth of the soil sample;
   c. Total soil contaminant concentration (mg/kg);
   d. Soil classification (i.e. silty sand, clay, etc.); and
   e. Total soil organic carbon (dry weight basis) (mg/kg).

When soil organic carbon is reported in units of mg/kg, the fraction of organic carbon (kg/kg) is calculated using the following conversion:

$$f_{oc} = \frac{TOC}{10^6} \qquad \text{(Equation 11)}$$

**Table 13: Parameters for Equation 11.**

| Parameter | Definition | Units |
|---|---|---|
| $f_{oc}$ | fraction of soil organic carbon | kg/kg |
| TOC | total soil organic carbon | mg/kg |

The lowest calculated $f_{oc}$ value can generally be used as a conservative estimate of $f_{oc}$ for the source area. If statistical methods are considered to determine a representative $f_{oc}$, it is recommended that consideration be given to the population distribution, the variance of the observed values, and the limitations of using small numbers of observations to conduct statistical analysis.