

GUIDANCE DOCUMENT

**DEVELOPMENT OF SITE-SPECIFIC IMPACT TO GROUND WATER SOIL
REMEDICATION STANDARDS USING THE SYNTHETIC PRECIPITATION
LEACHING PROCEDURE**

Version 3.0 - November 2013

New Jersey Department of Environmental Protection
Trenton, New Jersey

Table of Contents

I. Introduction	1
II. Instructions for Soil Sampling and Conducting the SPLP Test	2
A. Sampling, Extraction and Analysis – Semivolatile Organic Chemicals and Inorganics	2
B. Sampling, Extraction and Analysis – Volatile Organic Chemicals	3
III. Determination of the Leachate Criterion	5
A. Selecting a Default Leachate Criterion	5
B. Developing a Site-Specific Leachate Criterion	6
IV. Results Processing and Reporting	7
A. Calculation of Field Leachate Concentrations	7
B. Using Field Leachate Concentrations to Determine a Site-Specific Impact to Ground Water Soil Remediation Standard	9
Option 1. Determination of a Site-Specific Soil Remediation Standard from Field Leachate Concentrations Arranged in Tabular Format	9
Option 2. Determination of a Site-Specific Soil Remediation Standard using a Site- Specific K_d Value	11
Option 3. Determination of a Site-Specific Soil Remediation Standard using SPLP Results and Linear Regression Analysis	12
C. Submission Requirements	13
V. Other Considerations	14
APPENDIX A Background Information on the Synthetic Precipitation Leaching Procedure	17
APPENDIX B Default Leachate Criteria for Class II Ground Water ($\mu\text{g/L}$)	19
APPENDIX C Calculation of Leachate Concentrations under Field Conditions Using the Results of the Synthetic Precipitation Leaching Procedure	23
References	29

I. Introduction

The Synthetic Precipitation Leaching Procedure (SPLP) is a United States Environmental Protection Agency (USEPA) SW-846 test method that can be used with soil samples from a contaminated site to estimate the site-specific adsorption-desorption potential of a contaminant that may impact ground water. The SW-846 methods are available online (<http://www.epa.gov/osw/hazard/testmethods/sw846/index.htm>). The SPLP test is listed as SW-846 Method 1312, and details on conducting the SPLP test may be found at the following link:

<http://www.epa.gov/osw/hazard/testmethods/sw846/pdfs/1312.pdf>

The procedure consists of a batch equilibrium experiment in which contaminant is partitioned between soil solids and an extracting solution, using a 20:1 ratio of solution to solid. The resulting solution is known as the leachate. Method 1312 directs the user to compare contaminant concentrations in the SPLP leachate to “appropriate criteria” to determine whether the contaminated soil represents an unacceptable leaching threat. For determination of New Jersey Impact to Ground Water Soil Remediation Standards (IGWSRS), the results from this test are first used to estimate the leachate concentration of a contaminant in soil solution under natural conditions in the field. Then, the estimated field leachate concentration is compared to an appropriate leachate criterion (LC), to determine whether the contaminated soil represents a potential threat to ground water quality. If the estimated field leachate concentration exceeds the leachate criterion, the NJDEP has developed procedures to determine a site-specific impact to ground water soil remediation standard using results from the SPLP test.

The SPLP procedure may often be the method of choice for determining cleanup standards for inorganic and low mobility organic compounds (see Appendix A). Low mobility organic compounds may be conveniently defined as those with K_{oc} values greater than 20,000 L/kg (Roy and Griffin, 1985), and these values may be looked up in the chemical properties table in the Inhalation Soil Standards Basis and Background Document, or at the following link:

<http://www.nj.gov/dep/srp/guidance/rs/chemproperties.pdf>

Volatile organic contaminants may also be tested using the SPLP procedure. Soil samples collected for SPLP extraction must be collected using an Encore[®] sampler (or equivalent) as discussed below. Volatile contaminants are defined as those with Henry’s law constants greater than 10^{-5} atm m⁻³ mol⁻¹ and vapor pressures greater than 1 mm Hg at 25°C (NJDEP 2013). These are identified in Appendix B.

Included in the necessary calculations for processing the results of the SPLP test is the determination of a site-specific soil-water partition coefficient (K_d). This parameter is used to estimate field leachate concentrations of the contaminant and to calculate site-specific remediation standards from SPLP test results. Details on these procedures are discussed in Section IV below. The K_d parameter may also be used in other options, such as in the SESOIL model, to develop site-specific impact to ground water soil remediation standards.

The SPLP option may be used at any time during the remediation process, provided that sufficient site data and information are available on which to base a standard. The Department has provided a spreadsheet that will enable the person conducting the remediation to quickly and easily generate soil remediation standards that will be protective of ground water for any given site:

http://www.nj.gov/dep/srp/guidance/rs/splp_spreadsheet.xls

The spreadsheet carries out all the necessary calculations using the SPLP test results and calculates the site-specific remediation standard. The Department strongly recommends that the person conducting the remediation use this spreadsheet and include printouts of the spreadsheet in the appropriate submitted report.

Methanol or any other preservation cannot be used with any soil samples collected for SPLP extraction because it affects contaminant desorption.

Prior to implementing this procedure, the user should review the additional considerations discussed in Section V of this document.

Additional background information regarding this test method is provided in Appendix A of this guidance.

In 2012, the Department established a Committee to review and update the guidance for the Synthetic Precipitation Leaching Procedure for developing site-specific impact to groundwater soil remediation standards. The Committee included Stakeholders and NJDEP staff. This Guidance represents the work of the Committee and it supersedes any previous Department guidance issued on this topic. The following people were on the Committee that prepared this document:

Dr. Swati Toppin, Chair	NJDEP
George Blyskun	NJDEP
Ann Charles	NJDEP
Dr. Barry Frasco	NJDEP
MaryAnne Kuserk	NJDEP
Dr. Paul Sanders	NJDEP
Matthew Turner	NJDEP
Michael Gonshor	Roux Associates, Inc.
Stephen Posten	AMEC Environment and Infrastructure

II. Instructions for Soil Sampling and Conducting the SPLP Test

A. Sampling, Extraction and Analysis – Semivolatile Organic Chemicals and Inorganics

Ensure that a sufficient volume of soil is collected so that the SPLP test (100g soil required), total contaminant analysis (5 or 25g of soil required) and soil moisture tests can be conducted. Leachate concentrations and total contaminant concentrations are interrelated and the correlation

of these data can be used when developing site-specific remediation standards. Before the samples are split for SPLP and total contaminant analysis, the samples must be thoroughly mixed to yield uniform contaminant concentrations.

1. Collect a minimum of three soil samples for each area of concern. (One exception to this requirement is when small fuel oil or diesel cases are being investigated – see the Extractable Petroleum Hydrocarbon guidance):

http://www.nj.gov/dep/srp/guidance/srra/eph_protocol.pdf

The number of samples collected shall be determined by the size of the area initially being investigated pursuant to soil remediation standards guidance. The samples should include the highest suspected concentrations of the contaminants on site. Samples that represent a range of contaminant concentrations will be useful in conducting the procedures described below if some or all of the SPLP results exhibit unacceptable leachate concentrations. The samples should be representative of the variation in soil conditions over the area of concern, including variation with soil depth. Additional information regarding required field sampling techniques may be found in the NJDEP Field Sampling Procedures Manual:

<http://www.nj.gov/dep/srp/guidance/fspm/>

After thoroughly mixing, split each sample and analyze as described below.

2. One sub-sample must be analyzed for total contaminant concentrations using appropriate methods as discussed in appropriate NJDEP rules and guidance.
3. One sub-sample must be applied to the SPLP procedure described in USEPA SW-846, Analytical Method 1312.
4. One sub-sample must be used for soil moisture determination, to enable soil analytical results to be reported on a dry weight basis.
5. Measure the pH of the leachate sample at the conclusion of the SPLP extraction procedure.
6. Analyze the leachate for the contaminants of concern using appropriate methods as discussed in appropriate NJDEP rules and guidance.

B. Sampling, Extraction and Analysis – Volatile Organic Chemicals

When assessing soil contaminated with volatile organic chemicals, significant loss of these contaminants may occur during sample collection, preparation and analysis. These contaminants are identified in Appendix B. It is recommended that soil samples be taken from intact soil cores obtained using direct push methods or split- spoon methods. Direct push methods collect soil cores in plastic liners. It is recommended that plastic liners be used with split spoon equipment

as well, to minimize the potential volatile loss. Samples must be taken immediately (to avoid volatile loss) from the side of the core.

When sampling a sidewall after excavation, collection of soil using direct push or split spoon methods may not be practical, but samples should be taken as soon as possible after the soil is exposed. To the degree practical, it is recommended that a hand coring device be used in order to collect a sample a few inches lateral to the sidewall surface.

The NJDEP SPLP procedure requires samples for both total and SPLP analysis, and sample collection is more problematic for volatiles than for metals and semivolatile organic chemicals. Since a single soil sample cannot be collected, mixed and split without a large loss of volatiles, separate samples must be taken for total and SPLP analysis. The samples should be taken from immediately adjacent locations in an area of uniform soil type, to ensure that the total contaminant concentrations in each sample are equivalent. A 5 or 25 gram sample is needed for total contaminant analysis (depending on the method), a 25 gram sample must be taken to use in the SPLP extraction test, and a third sample is taken for soil moisture determination. The 25 gram sample taken for the SPLP test must be taken using an Encore[®] sampler (or equivalent), since methanol preservation may not be used on this sample and volatile loss must be prevented. It is also recommended that the sample for total VOC analysis be taken using an Encore[®] sampler, but methanol preservation techniques may be used.

When using the Encore[®] sampler, the plunger should not be withdrawn prior to sample collection, as this will cause pressurized air in the sampler to pass back through the soil sample as it is being collected, with resultant volatile loss. Instead, allow the soil to depress the plunger as the sampler is filled, as per instructions for this sampling device. When sampling from smaller diameter cores (e.g. 1.5”), the 25 gram sampler cannot be filled with one coring operation because it is too large relative to the diameter of the core. Therefore, two rapid coring operations should be conducted on immediately adjacent locations from an area of uniform soil type.

1. Collect a minimum of three sets of soil samples for each area of concern. A sample set consists of one sample for total contaminant analysis (5 or 25 g), one Encore[®] sample for SPLP testing (25 g), and a sample for soil moisture determination. (One exception to collecting three sets of soil samples is when small fuel oil or diesel cases are being investigated – see the Extractable Petroleum Hydrocarbon guidance):

http://www.nj.gov/dep/srp/guidance/srra/eph_protocol.pdf

The number of samples collected shall be determined by the size of the area initially being investigated pursuant to soil remediation standards guidance. The samples should include the highest suspected concentrations of the contaminants on site. Samples that represent a range of contaminant concentrations will be useful when employing the procedures described below if some or all of the SPLP results exhibit unacceptable leachate concentrations. The investigator should use their professional judgment when selecting samples for SPLP testing for weakly adsorbed chemicals, such as volatile organic contaminants, as it may be expected that samples with higher total volatile

organic contaminant concentrations will have SPLP results which show exceedances of the Leachate Criteria. Therefore, for weakly adsorbed chemicals such as volatile organic contaminants, it is especially important to select samples with a range of concentrations. The samples should be representative of the variation in soil conditions over the area of concern, including variation with soil depth. Additional information regarding required field sampling techniques may be found in the NJDEP Field Sampling Procedures Manual:

<http://www.nj.gov/dep/srp/guidance/fspm/>

2. One sample (5 or 25 gram sample) must be analyzed for total contaminant concentrations using appropriate methods as discussed in appropriate NJDEP rules and guidance.
3. One sample (25 gram Encore[®] sample) must be applied to the SPLP procedure described in USEPA SW-846, Analytical Method 1312. For volatile organic chemicals, this requires the use of a Zero-Headspace Extraction Vessel (500-600 mL volume) as described in the method. The soil sample must be directly transferred from the Encore[®] sampler to the vessel, and the extraction vessel must be sealed and headspace eliminated immediately to avoid loss of volatiles.
4. One sub-sample must be used for soil moisture determination to enable soil analytical results to be reported on a dry weight basis.
5. Analyze the leachate for the contaminants of concern using appropriate methods as discussed in appropriate NJDEP rules and guidance.

III. Determination of the Leachate Criterion

A leachate criterion for each contaminant being evaluated is necessary when using the SPLP test. Default leachate criteria have been developed by the Department for regulated contaminants. Alternatively, site-specific leachate criteria may be developed as discussed below.

A. Selecting a Default Leachate Criterion

For Class II ground water, the person conducting the remediation may select the Leachate Criterion from the table of Default Leachate Criteria provided in Appendix B of this guidance. The Department recommends that the Leachate Criterion in Appendix B be used when very little or no site specific information is available. This table includes:

1. Health-based ground water quality criteria for organic and inorganic contaminants from the Ground Water Quality Standards, N.J.A.C. 7:9C, for Class II ground water;
2. Health-based Leachate Criteria, which are the health-based ground water quality criteria multiplied by a default dilution-attenuation factor (DAF) of 20;

3. Aqueous Practical Quantitation Levels (PQLs) from the Ground Water Quality Standards, N.J.A.C. 7:9C; and
4. Higher of the health-based Leachate Criteria or the PQL. This value is used as the Leachate Criterion. For some contaminants, the Leachate Criterion is limited by the water solubility in order to avoid non-aqueous phase contamination (residual saturation).

For chemicals listed in Appendix B, steps 1-4 above are incorporated into the SPLP spreadsheet provided by the Department. The user only needs to select the chemical.

For chemicals not listed in Appendix B, New Jersey Ground Water Quality Criterion and PQLs should be used, if available. If not, the Department must first develop ground water quality criteria pursuant to N.J.A.C. 7:9C. Then follow the steps above. Step 3 is skipped if no PQL is available. The Leachate Criterion should not exceed the water solubility of the contaminant unless a listed PQL is above the water solubility (Inorganic contaminants do not have unique water solubilities so this step does not apply.) It is recommended that the NJDEP spreadsheet for unlisted chemicals be used, which calculates the leachate criterion after the required parameters are entered.

For Class I and Class III ground water, the Department must first develop ground water quality criteria pursuant to N.J.A.C. 7:9C. Then follow the instructions described above for chemicals not listed in Appendix B.

B. Developing a Site-Specific Leachate Criterion

The person conducting the remediation may develop a site-specific Leachate Criterion using a site-specific DAF. The Department has provided guidance and a spreadsheet for the development of a site-specific DAF:

<http://www.nj.gov/dep/srp/guidance/rs/daf.pdf>

http://www.nj.gov/dep/srp/guidance/rs/daf_calc.xls

To develop a site-specific Leachate Criteria once a site-specific DAF is developed, the following procedure should be followed:

1. Determine the health-based ground water quality criterion from the Ground Water Quality Standards, N.J.A.C. 7:9C. (for Class II ground water, these are provided in Appendix B);
2. Multiply the health-based ground water quality criterion by the site-specific DAF;
3. Select the higher of the Leachate Criteria or the aqueous PQL from the Ground Water Quality Standards, N.J.A.C. 7:9C; and

4. Ensure that the Leachate Criteria does not exceed the water solubility of the contaminant (unless a listed PQL is above the water solubility). Inorganic contaminants do not have unique water solubilities and this step does not apply.

For chemicals listed in Appendix B, steps 1-4 above are automatically calculated using the SPLP spreadsheet provided by the department. The user need only select the chemical and enter the site-specific DAF.

For chemicals not listed in Appendix B, New Jersey Ground Water Quality Criterion and PQLs should be looked up, if available. If not, the Department must first develop ground water quality criteria pursuant to N.J.A.C. 7:9C. Then follow the steps above. Step 3 is skipped if no PQL exists. The Leachate Criterion should not exceed the water solubility of the contaminant unless a listed PQL is above the water solubility (Inorganic contaminants do not have unique water solubilities so this step does not apply.) It is recommended that the NJDEP spreadsheet for unlisted chemicals be used, which calculates the leachate criterion after the required parameters, including the site-specific DAF, are entered.

For Class I and Class III ground water, the Department must first develop ground water quality criteria pursuant to N.J.A.C. 7:9C. Then follow the instructions described above for chemicals not listed in Appendix B.

IV. Results Processing and Reporting

The Department recommends the use of the NJDEP SPLP spreadsheet to enter and report sample data and SPLP results. In addition to being a convenient method of reporting results, the spreadsheet also does all necessary calculations discussed below, including the determination of estimated field leachate concentrations, alternative cleanup standards, and sample-specific and site-specific soil-water partition coefficients. The NJDEP SPLP spreadsheet may be found at the following link:

http://www.nj.gov/dep/srp/guidance/rs/splp_spreadsheet.xls

A. Calculation of Field Leachate Concentrations

Leachate concentrations measured in the SPLP test are not equivalent to those that would be observed under field conditions because the relative amounts of soil and water used in the SPLP test are completely different from those in a natural soil system. (For a detailed explanation of the issues involved, refer to Appendix C.) For this reason, field leachate concentrations must be calculated for each sample using the SPLP leaching test results and its corresponding measured total soil concentration. The procedure to calculate field leachate concentrations is described below.

1. For each sample, calculate a soil water-partition coefficient (K_d) for each contaminant:

$$K_d = \frac{(C_T M_S - C_{SPLP} V_L) / M_S}{C_{SPLP}} \quad (1)$$

where

K_d = is the soil-water partition coefficient (L/kg)

C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

M_S = the total weight of the soil sample submitted for SPLP analysis (~0.1 kg for inorganic chemicals and semivolatiles, or ~0.025 kg for volatiles)

C_{SPLP} = the concentration of contaminant in the SPLP leachate (mg/L)

V_L = the volume of the SPLP leachate (~2 L for inorganic chemicals and semivolatiles, or ~0.5 L for volatiles)

NOTE: C_{SPLP} in Equation 1 must have units of mg/L

The derivation of Equation 1 is provided in Appendix C.

NOTE: For weakly adsorbed chemicals, the mass of contaminant leached may sometimes be greater than the total mass of contaminant, due to sampling and experimental error. This will result in a negative K_d value. In these cases, a K_d of 0.0001 should be used in Equation (2) below. When using the SPLP spreadsheet, this adjustment is included if necessary.

- For each sample, substitute the K_d value in the following equation to calculate the estimated field leachate concentration:

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

where

ρ_b = bulk density of the soil (1.5 kg/L)

θ_w = soil moisture content (0.23)

θ_a = soil air content (0.18)

H' = the dimensionless Henry's law constant

C_L = field leachate concentration (mg/L).

Equation 2 is a simple rearrangement of the USEPA Soil Screening Guidance soil-water partition equation. It is derived in Appendix C.

- Use the field leachate concentrations as C_L as needed in the options below.

B. Using Field Leachate Concentrations to Determine a Site-Specific Impact to Ground Water Soil Remediation Standard

The three options provided below allow the person responsible for conducting the remediation to determine a site-specific impact to ground water soil remediation standard using the estimated field leachate concentrations. When multiple options are employed, the option that gives the highest value may be taken as the alternative remediation standard. The Department has provided a spreadsheet on its web site that will calculate the site-specific impact to ground water soil remediation standards using the field leachate concentrations results for each suitable option listed below, depending on the nature of the dataset.

http://www.nj.gov/dep/srp/guidance/rs/splp_spreadsheet.xls

Option 1. Determination of a Site-Specific Soil Remediation Standard from Field Leachate Concentrations Arranged in Tabular Format

Prepare a table of total contaminant concentrations in ascending order, along with the corresponding field leachate concentrations. Compare the field leachate concentration for each sample to the Leachate Criterion as follows:

1. If all field leachate concentrations are at or below the Leachate Criterion, the highest total contaminant concentration tested can be used as the site-specific soil cleanup remediation standard. If this site-specific soil cleanup remediation standard is the highest concentration of the contaminant for the AOC, then no further investigation is required for the impact to ground water pathway for that AOC.
2. If one or more of the field leachate concentrations are above the Leachate Criterion, select the highest total contaminant concentration for which this, and all other samples with lower contaminant concentrations in soil, exhibit field leachate concentrations at or below the Leachate Criterion. This concentration can be used as a site-specific soil remediation standard.

Two examples are provided below to illustrate this approach:

Example 1
Area of Concern 1

Sample Number	Total Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L ($\mu\text{g/L}$)	Leachate Criterion LC ($\mu\text{g/L}$)
Sample 1	5	900	2600
Sample 2	10	1200	2600
Sample 3	30	2280	2600
Sample 4	50	1680	2600
Sample 5	75	2700	2600

where

C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

C_L = Contaminant field leachate concentration ($\mu\text{g/L}$)

LC = Leachate Criterion

In Example 1 above, the Leachate Criterion for the contaminant of concern is 2600 $\mu\text{g/L}$. The total contaminant concentration for sample 4 (50 mg/kg) and all lower total contaminant concentrations tested resulted in field leachate concentrations below the leachate criterion. Therefore, the impact to ground water soil remediation standard for Area of Concern 1 is 50 mg/kg.

Example 2
Area of Concern 2

Sample Number	Total Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L ($\mu\text{g/L}$)	Leachate Criterion LC ($\mu\text{g/L}$)
Sample 1	5	900	1950
Sample 2	10	1200	1950
Sample 3	30	2280	1950
Sample 4	50	1680	1950
Sample 5	75	2700	1950

In Example 2 above, the Leachate Criterion for the contaminant of concern is 1950 $\mu\text{g/L}$. Sample 2 has the highest total contaminant concentration in soil (10 mg/kg) for which all this and all lower contaminant concentrations in soil resulted in field leachate

concentrations that are at or below the leachate criterion. Even though the Sample 4 field leachate concentration is below the LC, a sample with a lower total contaminant concentration (Sample 3) yielded a field leachate concentration above the LC. Therefore, the impact to ground water soil remediation standard for Area of Concern 2 is 10 mg/kg.

Option 2. Determination of a Site-Specific Soil Remediation Standard using a Site-Specific K_d Value

Sample-specific K_d values can be calculated using the total contaminant concentration in a soil sample (C_T) and the SPLP leachate concentration (C_{SPLP}). These sample-specific K_d values may be used to determine a site-specific K_d value. This site-specific value is then used to determine a site-specific soil remediation standard as follows:

1. Use the total contaminant concentration in a soil sample (C_T), and the corresponding SPLP leachate concentration (C_{SPLP}) in Equation 1 above to calculate a sample-specific soil-water partition coefficient (K_d).
2. Prepare a table of the calculated K_d values.
3. If the K_d values of all the samples vary by less than an order of magnitude, calculate the average K_d . If the K_d values of all the samples vary by more than an order of magnitude, select the lowest calculated K_d .
4. Substitute the site-specific partition coefficient (K_d) into Equation 3 to calculate a site-specific soil cleanup criterion:

$$IGWSRS = LC \left\{ [K_d] + \frac{\theta_w + \theta_a H'}{\rho_b} \right\} \quad (3)$$

where

$IGWSRS$ = Impact to Groundwater Soil Remediation Standard (mg/kg)

LC = Leachate criterion (mg/L)

K_d = is the average, or lowest, calculated sample specific soil-water partition coefficient (L/kg)

θ_w = the volume fraction of water in the original soil sample (0.23)

θ_a = the volume fraction of air in the original water sample (0.18)

H' = the dimensionless Henry's law constant for the contaminant of interest

ρ_b = the dry soil bulk density (1.5 kg/L)

Equation 3 is equivalent to the soil-water partition coefficient described in the USEPA Soil Screening Guidance document (USEPA, 1996). The Leachate Criterion (health-based ground water criteria x DAF) is equivalent to EPA's target leachate concentration. Henry's law constants may be found in the Inhalation Soil Standards Basis and Background Document or at the following link: <http://www.nj.gov/dep/srp/guidance/rs/chemproperties.pdf>

Option 3. Determination of a Site-Specific Soil Remediation Standard using SPLP Results and Linear Regression Analysis

A linear regression technique may be used to determine a site-specific soil remediation standard if an adequate linear correlation exists between field leachate concentrations and the corresponding total contaminant concentrations in soil. Conduct the linear regression as follows:

1. For all samples where both the total contaminant concentration in soil and the field leachate concentration are above the PQL, plot the field leachate concentration data (in units of $\mu\text{g/L}$) on the y-axis as the dependent variable versus the contaminant concentration in soil concentrations for all samples (in units of mg/kg) on the x-axis as the independent variable;
2. Determine if the data qualifies for a linear correlation test:

At least half of the total soil concentration data points must lie at or above the midpoint of the range of total soil concentrations;

The calculated Leachate Criterion (LC) must lie within the range of measured field leachate concentrations; and

The R-Square value for the linear least-squares regression analysis of the plotted points must be 0.7 or higher.

Note: For Option 3, since at least half of the total soil concentration data points must lie at or above the midpoint of the range of total soil concentrations, the investigator should use their professional judgment in selection of samples for SPLP analyses to in order to ensure this condition is met.

3. Calculate the site-specific soil remediation standard using Equation 4 below:

$$IGWSRS = \frac{LC - b}{m} \quad (4)$$

where

$IGWSRS$ = the impact-to-ground water soil cleanup criterion (mg/kg)

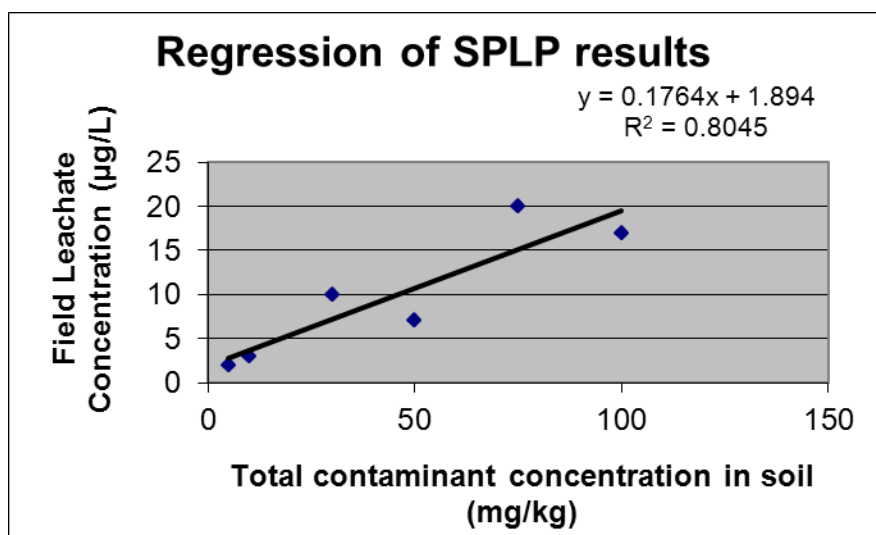
LC = the Leachate Criterion ($\mu\text{g/L}$)

m = the slope of the best fit line obtained via linear regression analysis ($(\mu\text{g/L})/(\text{mg/kg})$)

b = the intercept of the best fit line obtained via linear regression ($\mu\text{g/L}$)

Example 3
Area of Concern 3

Sample Number	Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L (µg/L)	Leachate Criterion LC (µg/L)
Sample 1	5	2	10
Sample 2	10	3	10
Sample 3	30	10	10
Sample 4	50	7	10
Sample 5	75	20	10
Sample 6	100	17	10



$$\text{IGWSRS} = (10\mu\text{g/L} - 1.89\mu\text{g/L}) / 0.176(\mu\text{g/L}) / (\text{mg/kg}) = 46 \text{ mg/kg}$$

Using the example data in Equation 4, the soil remediation standard for area of concern 3 would be 46 mg/kg.

C. Submission Requirements

In order for the Department to efficiently review proposed site-specific soil remediation standards, it is recommended that the person responsible for conducting the remediation use the spreadsheet provided by the Department at

http://www.nj.gov/dep/srp/guidance/rs/splp_spreadsheet.xls.

The spreadsheet does all necessary calculations, including the determination of alternative cleanup standards using the three options discussed above. It also calculates the field leachate concentrations, displays calculated sample-specific K_d values, and determines a site-specific K_d value that may be used in other methods for calculating alternative remediation standards.

The following parameters should be reported for each sample and for each contaminant of concern:

- Sample number
- The total contaminant concentration in the soil (C_T)
- The SPLP leachate concentration (C_{SPLP})
- The field leachate concentration (C_L)
- The final pH of the leachate
- The volume of the leachate (V_L)
- The dry weight of the soil-sub sample used in the SPLP test (M_S)

It is also strongly suggested that other properties and information related to the soil samples be reported if they are available (e.g. depth of sample, soil texture information, soil organic carbon content, etc.)

V. Other Considerations

The following issues are frequently encountered when conducting an SPLP investigation:

1. Need for additional soil sampling

Additional soil samples may need to be collected for SPLP testing if:

- Delineation conducted subsequent to earlier SPLP testing determines that soil contamination extends to a different soil type or depth not yet evaluated. Because soil properties often vary with depth, subsurface soil samples should be included if the contamination extends below the surface soil.
- Delineation conducted subsequent to earlier SPLP testing determines that soil contaminant concentrations are higher than concentrations initially measured.

2. Total contaminant concentrations in soil are below detection limit

If the total contaminant concentration in a soil sample is below the detection limit, SPLP calculations are not able to be conducted on that sample. Furthermore, the sample is considered uncontaminated. Contaminated soil needs to be sampled and tested.

3. Concentrations in an SPLP leachate sample are below the detection limit

If the total contaminant concentration in a soil sample is detectable, but the corresponding SPLP leachate concentration is below the detection limit, the results can still be used in SPLP options 1 and 2. The aqueous reporting limit is used as the SPLP leachate concentration. The resulting standards calculated using Options 1 and 2 would be conservative, since SPLP leachate concentrations are actually less than the reporting limit. Option 3 cannot be used, since this requires a regression analysis of actual field leachate concentrations. The SPLP spreadsheet automatically checks for this condition.

4. Manually calculated remediation standard is higher than tested concentrations

If this situation occurs, the highest contaminant concentration actually tested becomes the remediation standard. The reason for this is that the adsorption capacity of the soil may be exceeded at higher concentrations, and the SPLP calculations do not take this into account. The SPLP spreadsheet automatically makes this adjustment if necessary.

5. All field leachate concentrations are below leachate criterion, but contaminant concentrations in soil on site are higher than those tested

In situations where all SPLP samples give field leachate concentrations below the leachate criterion, the highest total concentration tested may be used as an alternative remediation standard. The situation may arise where this alternative standard is below the highest concentration on site because the highest concentration was not tested. If a higher remediation standard is desired, a soil sample with a higher contaminant concentration should be collected and submitted for SPLP testing. However, in some cases, a repeat visit to a site to collect SPLP samples from areas with the previously observed highest concentrations will result in new total contaminant concentration results that are somewhat lower than those initially measured. Professional judgment should be used to determine whether sufficient effort has been made to resample the area containing the previously observed highest concentration. If this is judged to be the case, and if all of the newer field leachate concentration results are below the leachate criterion, the newer sample results are used to set the maximum concentration observed on site and the alternative remediation standard. This should be explained in the report sent to the Department.

6. Sites with minimal and/or scattered contamination near the reporting limit

In cases where the impact to ground water soil screening criterion is at or near the soil reporting limit, results from several samples may be below the reporting or detection limit, and it may be difficult to obtain 3 samples with contaminant concentrations above this level. If this is judged to be the case, results from one or two samples may be acceptable. This should be explained in the report submitted to the Department. The regression option may not be used with less than three sample results.

7. Samples with soil concentrations below the impact to ground water soil screening level

On occasion, samples collected may exhibit total soil concentrations of the contaminant of concern that are below the IGWSSL. This situation may occur when the contamination only slightly exceeds the IGWSSL. These sample results may still be used. However, unless at least one soil sample has a total contaminant concentration above the screening level, it will not be possible to calculate an alternative standard above the default screening level.

APPENDIX A

Background Information on the Synthetic Precipitation Leaching Procedure

The Synthetic Precipitation Leaching Procedure (SPLP) test uses Method 1312 from the USEPA SW-846 compendium of analytical and test methods (<http://www.epa.gov/osw/hazard/testmethods/sw846/index.htm>). Method 1312 measures the leaching potential of a contaminant in soil, and thus offers a quick and inexpensive method to assess chemical mobility. A particularly useful aspect of the SPLP procedure is that it measures desorption, rather than adsorption, of contaminants from soil. It is well known that desorption of many contaminants to soil decreases as contact time increases (Riley et al., 2010; Sander et al., 2006; Fendorf et al., 2004; Lock and Janssen, 2003, Loehr and Webster, 1996). In some cases, a portion of the contaminant may become irreversibly adsorbed to soil and therefore immobile. Defaults values for soil adsorption coefficients (K_{oc} or K_d values) used in the USEPA SSL partition equation do not consider these processes. While the USEPA partition equation could be used with desorption, rather than adsorption coefficients, values for desorption coefficients are not generally available and appear to be site-specific. For metals, an additional complication arises in that the K_d values used in the USEPA soil-water partition coefficient for default screening levels assume that the most mobile species of the contaminant is present (USEPA 1996). This is necessary because standard analytical methods usually measure total metals, so the actual species (redox state, salt, or complex) is not typically known. Because different species of a metal have widely varying mobility, the assumption of a mobile species is made in order to be adequately protective of all situations that may occur.

The SPLP procedure directly measures the current desorption (leaching) potential of the contaminant, because it uses actual aged, contaminated soil from the site. For metals, the leaching potential of the species present in the soil will be determined, whether or not it is actually known. While a detailed assessment of the results of this test may be complex when mixtures of different species of the same metal are present, the procedure nonetheless provides a much-improved estimate of leaching tendency over predictive methods using lookup K_{oc} or K_d adsorption constants.

The conditions of the SPLP test simulate actual environmental precipitation, in that the leaching solution is a simulation of mid-Atlantic rainfall (pH 4.2). Thus, the test more realistically estimates the leaching potential of contaminants that may occur under field conditions in New Jersey (Brown et al., 1996; Lackovic et al., 1997).

Since the SPLP test exhibits several advantages over other methods to determine the leaching potential of contaminants, and because it can be conducted in a time and cost efficient manner during a site investigation, the use of this test is often recommended prior to pursuing other options when determining alternative impact to ground water remediation standards at contaminated sites.

The limitations of the SPLP test are as follows. First, because leachate is filtered through a 0.6 - 0.8 μm filter, the concentration of colloidal inorganics above this pore size may be underestimated. Second, because the oxidation/reduction potential of the sample is not preserved

when the test is conducted, interconversion of metal species with multiple oxidation states may occur.

APPENDIX B

Default Leachate Criteria for Class II Ground Water (µg/L)

Contaminant	CAS Number	Health-based Ground Water Quality Criterion	Impact to GW Health Based Leachate Criterion	Aqueous PQL	Higher of the Health-based Leachate Criterion or PQL (Rounded)
Acenaphthene	83-32-9	400	8,000	10	4,200*
Acenaphthalene	208-96-8	NA	NA	NA	NA
Acetone (2-propanone)**	67-64-1	6,000	120,000	10	120,000
Acetophenone	98-86-2	700	14,000	10	14,000
Acrolein**	107-02-8	4	80	5	80
Acrylonitrile**	107-13-1	0.06	1.2	2	2
Aldrin	309-00-2	0.002	0.04	0.04	0.04
Aluminum	7429-90-5	200	4,000	30	4,000
Anthracene	120-12-7	2,000	40,000	10	43*
Antimony	7440-36-0	6	120	3	120
Arsenic	7440-38-2	0.02	0.4	3	3
Atrazine	1912-24-9	3	60	0.1	60
Barium	7440-39-3	6,000	120,000	200	120,000
Benzaldehyde	100-52-7	NA	NA	NA	NA
Benzene**	71-43-2	0.2	4	1	4
Benzidine	92-87-5	0.0002	0.004	20	20
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.05	1	0.1	1
Benzo(a)pyrene	50-32-8	0.005	0.1	0.1	0.1
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	205-99-2	0.05	1	0.2	1
Benzo(ghi)perylene	191-24-2	NA	NA	NA	NA
Benzo(k)fluoranthene	207-08-9	0.5	10	0.3	0.8*
Beryllium	7440-41-7	1	20	1	20
1,1'-Biphenyl	92-52-4	400	8,000	10	6,000*
Bis(2-chloroethyl)ether**	111-44-4	0.03	0.6	7	7
Bis(2-chloroisopropyl)ether	108-60-1	300	6,000	10	6,000
Bis(2-ethylhexyl)phthalate	117-81-7	2	40	3	40
Bromodichloromethane (Dichlorobromomethane)**	75-27-4	0.6	12	1	12
Bromoform**	75-25-2	4	80	0.8	80
Bromomethane (Methyl bromide)**	74-83-9	10	200	1	200
2-Butanone (Methyl ethyl ketone) (MEK)**	78-93-3	300	6,000	2	6,000
Butyl benzyl phthalate	85-68-7	100	2,000	1	2,000
Cadmium	7440-43-9	4	80	0.5	80
Caprolactam	105-60-2	3,500	70,000	5,000	70,000
Carbazole	86-74-8	NA	NA	NA	NA
Carbon disulfide**	75-15-0	700	14,000	1	14,000
Carbon tetrachloride**	56-23-5	0.4	8	1	8
Chlordane (alpha and gamma)	57-74-9	0.01	0.2	0.5	0.5
Chlorobenzene**	108-90-7	50	1,000	1	1,000
Chloroethane (Ethyl chloride)**	75-00-3	NA	NA	NA	NA

Contaminant	CAS Number	Health-based Ground Water Quality Criterion	Impact to GW Health Based Leachate Criterion	Aqueous PQL	Higher of the Health-based Leachate Criterion or PQL (Rounded)
Chloroform**	67-66-3	70	1,400	1	1,400
Chloromethane (Methyl chloride)**	74-87-3	NA	NA	NA	NA
2-Chlorophenol (o-Chlorophenol)**	95-57-8	40	800	20	800
Chrysene	218-01-9	5	100	0.2	2*
Cobalt	7440-48-4	100	2,000	0.5	2,000
Copper	7440-50-8	1,300	26,000	4	26,000
Cyanide	57-12-5	100	2,000	6	2,000
4,4'-DDD	72-54-8	0.1	2	0.02	2
4,4'-DDE	72-55-9	0.1	2	0.01	2
4,4'-DDT	50-29-3	0.1	2	0.1	2
Dibenz(a,h)anthracene	53-70-3	0.005	0.1	0.3	0.3
Dibromochloromethane (Chlorodibromomethane)**	124-48-1	0.4	8	1	8
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.4	0.02	0.4
1,2-Dibromoethane (ethylene dibromide)**	106-93-4	0.0004	0.008	0.03	0.03
1,2-Dichlorobenzene (o-dichlorobenzene)**	95-50-1	600	12,000	5	12,000
1,3-Dichlorobenzene (m-Dichlorobenzene)**	541-73-1	600	12,000	5	12,000
1,4-Dichlorobenzene (p-Dichlorobenzene)**	106-46-7	75	1,500	5	1,500
3,3'-Dichlorobenzidine	91-94-1	0.08	1.6	30	30
Dichlorodifluoromethane**	75-71-8	1000	20,000	2	20,000
1,1-Dichloroethane**	75-34-3	50	1,000	1	1,000
1,2-Dichloroethane**	107-06-2	0.3	6	2	6
1,1-Dichloroethene (1,1-Dichloroethylene)**	75-35-4	1	20	1	20
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)**	156-59-2	70	1,400	1	1,400
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)**	156-60-5	100	2,000	1	2,000
2,4-Dichlorophenol	120-83-2	20	400	10	400
1,2-Dichloropropane**	78-87-5	0.5	10	1	10
1,3-Dichloropropene (cis and trans) (summed)**	542-75-6	0.4	8	1	8
Dieldrin	60-57-1	0.002	0.04	0.03	0.04
Diethylphthalate	84-66-2	6,000	120,000	1	120,000
2,4-Dimethylphenol	105-67-9	100	2,000	20	2,000
Di-n-butyl phthalate	84-74-2	700	14,000	1	11,000*
4,6-Dinitro-2-methylphenol (4,6-Dinitro-o-cresol)	534-52-1	0.7	14	1	14
2,4-Dinitrophenol	51-28-5	10	200	40	200
2,4-Dinitrotoluene	121-14-2	NA	NA	NA	NA
2,6-Dinitrotoluene	606-20-2	NA	NA	NA	NA
2,4-Dinitrotoluene/2,6-Dinitro Dinitrotoluene (mixture)	25321-14-6	0.05	1	10	10
Di-n-octyl phthalate	117-84-0	100	2,000	10	20*
1,2-Diphenylhydrazine	122-66-7	0.04	0.8	20	20
Endosulfan I and Endosulfan II	115-29-7	40	800	0.1	510*

Contaminant	CAS Number	Health-based Ground Water Quality Criterion	Impact to GW Health Based Leachate Criterion	Aqueous PQL	Higher of the Health-based Leachate Criterion or PQL (Rounded)
Endosulfan sulfate	1031-07-8	40	800	0.02	800
Endrin	72-20-8	2	40	0.03	40
Ethyl benzene**	100-41-4	700	14,000	2	14,000
Fluoranthene	206-44-0	300	6,000	10	210*
Fluorene	86-73-7	300	6,000	1	2000*
alpha-HCH (alpha BHC)	319-84-6	0.006	0.12	0.02	0.1
beta-HCH (beta-BHC)	319-85-7	0.02	0.4	0.04	0.4
Heptachlor	76-44-8	0.008	0.16	0.05	0.2
Heptachlor epoxide	1024-57-3	0.004	0.08	0.2	0.2
Hexachlorobenzene	118-74-1	0.02	0.4	0.02	0.4
Hexachloro-1,3-butadiene	87-68-3	0.4	8	1	8
Hexachlorocyclopentadiene	77-47-4	40	800	0.5	800
Hexachloroethane	67-72-1	2	40	7	40
Indeno(1,2,3-cd)pyrene	193-39-5	0.05	1	0.2	0.2 [#]
Isophorone	78-59-1	40	800	10	800
Lead	7439-92-1	5	100	5	100
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	0.03	0.6	0.02	0.6
Manganese	7439-96-5	50	1,000	0.4	1,000
Mercury	7439-97-6	2	40	0.05	40
Methoxychlor	72-43-5	40	800	0.1	45*
Methyl acetate**	79-20-9	7,000	140,000	0.5	140,000
Methylene chloride (Dichloromethane)**	75-09-2	3	60	1	60
2-Methylnaphthalene	91-57-6	30	600	10	600
2 methylphenol (o-cresol)	95-48-7	NA	NA	NA	NA
4 methylphenol (p-cresol)	106-44-5	NA	NA	NA	NA
Methyl tert butyl ether (MTBE)**	1634-04-4	70	1,400	1	1,400
Naphthalene	91-20-3	300	6,000	2	6,000
Nickel (Soluble salts)	7440-02-0	100	2,000	4	2,000
2-Nitroaniline	88-74-4	NA	NA	NA	NA
Nitrobenzene	98-95-3	4	80	6	80
N-Nitrosodimethylamine	62-75-9	0.0007	0.014	0.8	0.8
N-Nitrosodi-n-propylamine	621-64-7	0.005	0.1	10	10
N-Nitrosodiphenylamine	86-30-6	7	140	10	140
Pentachlorophenol	87-86-5	0.3	6	0.1	6
Phenanthrene	85-01-8	NA	NA	0.3	NA
Phenol	108-95-2	2,000	40,000	10	40,000
Polychlorinated biphenyls (PCBs)	1336-36-3	0.02	0.4	0.5	0.5
Pyrene	129-00-0	200	4,000	0.1	140*
Selenium	7782-49-2	40	800	4	800
Silver	7440-22-4	40	800	1	800
Styrene**	100-42-5	100	2,000	2	2,000
Tertiary butyl alcohol (TBA)	75-65-0	100	2,000	2	2,000
1,1,2,2-Tetrachloroethane**	79-34-5	1	20	1	20
Tetrachloroethene (PCE) (Tetrachloroethylene)**	127-18-4	0.4	8	1	8
Thallium	7440-28-0	0.5	10	2	10
Toluene**	108-88-3	600	12,000	1	12,000
Toxaphene	8001-35-2	0.03	0.6	2	2

Contaminant	CAS Number	Health-based Ground Water Quality Criterion	Impact to GW Health Based Leachate Criterion	Aqueous PQL	Higher of the Health-based Leachate Criterion or PQL (Rounded)
1,2,4-Trichlorobenzene	120-82-1	9	180	1	180
1,1,1-Trichloroethane**	71-55-6	30	600	1	600
1,1,2- Trichloroethane **	79-00-5	3	60	2	60
Trichloroethene (TCE) Trichloroethylene**	79-01-6	1	20	1	20
Trichlorofluoromethane**	79-65-4	2,000	40,000	1	40,000
2,4,5-Trichlorophenol	95-95-4	700	14,000	10	14,000
2,4,6-Trichlorophenol	88-06-2	1	20	20	20
Vanadium	7440-62-2	NA	NA	NA	NA
Vinyl chloride**	75-01-4	0.08	1.6	1	2
Xylenes**	1330-20-7	1,000	20,000	2	20,000
Zinc	7440-66-6	2,000	40,000	10	40,000

*Adjusted so as not to exceed water solubility

** Volatile organic compound

Water solubility below reporting limit; criterion set at reporting limit

NA- Not available

APPENDIX C

Calculation of Leachate Concentrations under Field Conditions Using the Results of the Synthetic Precipitation Leaching Procedure

The Synthetic Precipitation Leaching Procedure (SPLP) is a batch equilibrium procedure which measures desorption of contaminant from soil after shaking overnight with an extracting solution. It is assumed that equilibrium is achieved between the sorbed and aqueous (leachate) phases at the end of the experiment. Specifically, the ratio of the sorbed and aqueous phase concentrations (known as the K_d parameter) is constant over a range of contaminant concentrations and soil-to-water ratios. The SPLP test may conveniently be used to measure the K_d value for a particular contaminant and soil type. The K_d parameter also provides the foundation of the USEPA soil-water partition equation, which additionally includes a vapor phase. As will be demonstrated below, leachate concentrations measured under the conditions of the SPLP test do not necessarily represent leachate concentrations that would be observed in the field because the water to soil ratio affects the resulting leachate concentration. For chemicals that are not strongly adsorbed, a large percentage of the initial contaminant mass desorbs from soil during the SPLP extraction because of the large volume of extracting solution relative to soil. This results in the final soil sorbed concentration being much lower than the initial total concentration, which is balanced by a low leachate concentration in the large volume of extracting solution order to maintain the correct equilibrium concentration ratio. Under field conditions, the much lower volume of water results in a much lower decrease in the final soil sorbed concentration, which is balanced by a higher leachate concentration in the small leachate volume. Leachate concentrations under field conditions are the relevant data needed to compare against the leachate criteria or to calculate site-specific impact to ground water remediation standards. These can be determined using the SPLP results, the known initial total soil concentration, and the assumptions underlying the basis of the USEPA soil water partition equation.

There are two fundamental relationships governing the equilibrium behavior of contaminants in soil. The first is that for the soil-water adsorption-desorption coefficient:

$$K_d = \frac{C_s}{C_w} \quad (1)$$

where, at equilibrium, C_s is the concentration of the chemical in the soil sorbed phase, C_w is the concentration of the chemical in the aqueous phase, and K_d is the soil-water partition coefficient. For a particular soil, K_d is assumed to be constant over a range of total concentrations. Note that the relationship requires the ratio of the two concentrations to be constant, not the absolute concentration in each phase. Therefore, as the relative amounts of soil and water change, the absolute concentrations in each phase must vary in order to keep the ratio constant. Since the K_d is a constant, it remains the same under both field and SPLP leaching conditions.

The above equation may be expanded:

$$K_d = \frac{m_s/M_s}{C_L} \quad (2)$$

where C_s is now expressed as the mass of contaminant, m_s , in a given mass of soil, M_s . C_w has now been relabeled C_L , the leachate concentration at equilibrium.

The second relationship describes equilibrium partitioning between the air phase and the water (aqueous) phase:

$$H' = \frac{C_a}{C_w} \quad (3)$$

where, at equilibrium, C_a is the concentration of the chemical in the air phase, C_w is the concentration of the chemical in the water (aqueous) phase, and H' is the dimensionless Henry's law constant, also assumed to be constant over a range of concentrations. This equation may also be expanded:

$$H' = \frac{m_a/V_a}{C_L} \quad (4)$$

where C_a is now expressed as the mass of contaminant, m_a in a given volume of air, V_a , and C_L is again relabeled the leachate concentration. This equation may be rearranged:

$$m_a = C_L V_a H' \quad (5)$$

The total contaminant concentration in soil before leaching may be defined as C_T , and the volume of the extracting leaching solution as V_L . The mass of contaminant sorbed to soil at equilibrium after leaching may be calculated as the total mass of contaminant in the soil prior to the leaching experiment, $C_T M_s$, minus the mass of contaminant that ends up in the leachate at equilibrium, $C_L V_L$, minus the mass of contaminant in the air phase, $C_L V_a H'$. Substituting these terms into Equation (2) yields

$$K_d = \frac{(C_T M_s - C_L V_L - C_L V_a H')}{C_L} \quad (6)$$

Rearranging, the equation transforms to:

$$C_L K_d M_s = C_T M_s - C_L V_L - C_L V_a H' \quad (7)$$

$$C_T M_s = C_L K_d M_s + C_L V_L + C_L V_a H' \quad (8)$$

$$C_T M_s = C_L (K_d M_s + V_L + V_a H') \quad (9)$$

$$C_T = C_L \frac{K_d M_S + V_L + V_a H'}{M_S} \quad (10)$$

$$C_T = C_L \left(K_d + \frac{V_L + V_a H'}{M_S} \right) \quad (11)$$

Under soil conditions in the field, V_L is the fractional volumetric water content, θ_w , V_a is the fractional air content, θ_a , and M_S is the mass of soil per unit volume (dry soil bulk density), ρ_b . Equation 11 thus transforms to the USEPA soil-water partition equation:

$$C_T = C_L \left(K_d + \frac{\theta_w + \theta_a H'}{\rho_b} \right) \quad (12)$$

where

- $\theta_w = 0.23$ mL of water per mL of soil volume (NJ default field conditions)
= 2 L of water in 2.038 L volume in SPLP test (0.5 L water/0.51 L volume for volatiles)
- $\theta_a = 0.18$ mL of water per mL of soil volume (NJ default field conditions)
= 0 in SPLP test
- $\rho_b = 1.5$ g of soil per mL of soil volume (NJ default field conditions)
= 100 g of soil per 2.038 L volume in SPLP test (25 g soil/0.51 L volume for volatiles)

The total volume of the SPLP test is approximately 2.038 L, due to the soil solids volume of approximately 0.039 L per 100 grams soil, assuming a soil particle density of 2.65 g/mL, added to the 2 L of extracting solution. For volatiles, these amounts are divided by four, due to the smaller sample size and extraction vessel.

Rearrangement of Equation (12) yields the equation to predict field leachate concentrations from the total contaminant concentration in a soil sample:

$$C_L = \frac{C_T}{K_d + \frac{\theta_w + \theta_a H'}{\rho_b}} \quad (13)$$

Since this equation is derived from the soil-water partition coefficient and the Henry's law constant, the assumptions governing those parameters apply to the use of this equation. Note that as K_d becomes large relative to the other term in the denominator, C_L becomes independent of the relative amounts of water, soil, and air, and C_L becomes constant. Therefore, for chemicals with a high K_d values, leachate concentrations measured under SPLP and field conditions will be similar. In contrast, chemicals with low K_d values will exhibit leachate concentrations that are dependent on the amounts of water, soil and air. Table 1 illustrates the behavior of this equation for selected contaminants with widely varying K_d values, with the mass of soil normalized to 1 gram, and the total mass of contaminant held constant at 13.33 μg . For

trichloroethene, a contaminant with a very low K_d value, the difference between the leachate concentration under SPLP and field conditions is quite large, and under SPLP conditions, the leachate concentration does not reflect the much higher concentration that would be observed in the field. This is because the soil-sorbed concentration after equilibrium under SPLP conditions is only a small fraction of the initial total soil concentration, which requires a lower leachate concentration to maintain the proper equilibrium ratio. In contrast, DDT exhibits virtually the same leachate concentration under both conditions because of its very high K_d constant. The soil-sorbed concentration essentially remains at the initial total soil concentration, because very little desorbs. In this case, the SPLP leachate concentration could be used directly to approximate field conditions.

Figure 1 illustrates that when the K_d becomes less than about 25-50 mL/g, the SPLP leachate concentration cannot be used directly to estimate the field leachate concentration. In this case, the K_d value, along with the total soil concentration, C_T , and the field values for soil moisture and soil vapor volume, should be used in Equation 13 to estimate the leachate concentration for the sample under field conditions. Since Equation 13 is the technically complete calculation, it is used for all chemicals when evaluating SPLP test results.

To do this, first a sample-specific K_d value is determined, using the SPLP test results. Since the K_d is a constant, it can be measured using the SPLP test and then used to predict leachate concentrations under field conditions. The SPLP leachate (C_{SPLP}) concentration and a modified version of Equation (6) is used, since the SPLP test does not contain an air phase:

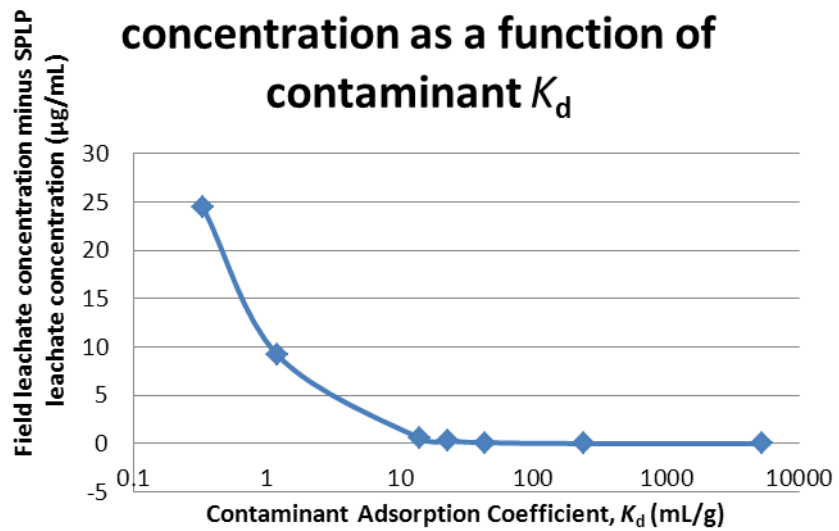
$$K_d = \frac{(C_T M_S - C_{SPLP} V_L) / M_S}{C_{SPLP}} \quad (14)$$

The volume of the extracting solution and the mass of soil in the SPLP test, the total soil concentration, and the SPLP leachate concentration are used in Equation (14) to determine the sample-specific K_d . This K_d is then used in Equation (13) along with C_T , H' , and the field values of θ_w , θ_a and ρ_b to calculate the leachate concentration under field conditions.

Table 1
Leachate concentrations under SPLP and field conditions for various contaminants

Representative contaminant	K_d Soil adsorption coefficient with default fraction organic carbon content of 0.002 (mL/g)	H' Henry's law constant, dimensionless, 25°C	Conditions	Liquid to air to solid ratio (mL water-mL air/g soil)	θ_w Volume of water (mL)	ρ_b Mass of soil (g)	θ_a Volume of air (mL)	Total mass in sample (μg)	C_T Total (initial) soil concentration ($\mu\text{g/g}$)	Equilibrium soil sorbed concentration ($\mu\text{g/g}$)	C_L Equilibrium leachate concentration ($\mu\text{g/mL}$)	% of total mass in leachate at equilibrium	Difference between SPLP and field leachate concentration ($\mu\text{g/mL}$)
TCE	0.33	0.422	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	8.29 0.22	25.12 0.66	28 98	24.46
1,4 Dichlorobenzene	1.2	0.0996	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	11.74 0.75	9.79 0.63	11 94	9.16
2-Methylnaphthalene	14	0.0213	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	13.19 5.49	0.94 0.39	1.1 58.8	0.55
Cadmium	23	0	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	13.24 7.13	0.58 0.31	0.6 46.5	0.27
Dieldrin	43	6.19E-04	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	13.28 9.10	0.31 0.21	0.3 31.7	0.10
Chlordane	240	1.99E-03	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	13.32 12.30	0.056 0.051	0.06 7.69	0.004
DDT	5260	3.32E-04	Field SPLP	0.23/0.18/1.5 2000/0/100	0.15 20	1 1	0.12 0	13.33 13.33	13.33 13.33	13.33 13.28	0.00253 0.00252	0.003 0.379	0.00001

Figure 1
Difference between SPLP leachate concentration and field leachate concentration as a function of contaminant K_d



References

- Brown, S.H., Alleman, D.W., Stewart, A., Andrew, L. and Hyde, B.G. (1996). The SPLP as an Alternative to TCLP Analysis for Metals: Connecticut Example Using Lead. In: Contaminated Soils, Vol. I, Calabrese, E.J., Kostecki, P.T. and Bonazountas, M., (eds.), Amherst Scientific Publishers, Amherst, MA, pp. 353-362.
- Fendorf, S., La Force, M.J. and Guangchao, L. (2004). Temporal Changes in Soil Partitioning and Bioaccessibility of Arsenic, Chromium, and Lead. *J. Environ. Qual.* 33:2049-2055.
- Lackovic, J.A., Nikolaidis, N.P., Chheda, P., Carley, R.J. and Patton, E. (1997). Evaluation of Batch Leaching Procedures for Estimating Metal Mobility in Glaciated Soils. *Ground Water Monitoring Review*. Summer, 1997. 231-240.
- Lock, K. and Janssen, C.R. (2003). Influence of Aging on Metal Availability in Soils. *Rev. Environ. Contam. Toxicol.* 178:1-21.
- Loehr, R.C. and Webster, M.T. (1996). Behavior of Fresh vs. Aged Chemicals in Soil. *J. Soil Contamination*. 5(4):361-383.
- NJDEP (2013). Vapor Intrusion Technical Guidance, Version 3. New Jersey Department of Environmental Protection, Trenton, NJ
(http://www.nj.gov/dep/srp/guidance/vaporintrusion/vig_main.pdf).
- Riley, R.G., Szecsody, J.E., Sklarew, D.S., Mitroshkov, A.V., Gent, P.M., Brown, C.F. and Thompson, C.J. (2010). Desorption Behavior of Carbon Tetrachloride and Chloroform in Contaminated Low Organic Carbon Aquifer Sediments. *Chemosphere* 79:807-813.
- Roy, W.R. and Griffin, R.A. (1985). Mobility of Organic Solvents in Water-Saturated Soil Materials. *Environ. Geol. Water Sci.* 7(4):241-247.
- Sander, M., Lu, Y. and Pignatello, J.J. (2006). Conditioning-Annealing Studies of Natural Organic Matter Solids Linking Irreversible Sorption to Irreversible Structural Expansion. *Environ. Sci. Technol.* 40:170-178.
- USEPA (1996). Soil Screening Guidance: Technical Background Document, May 1996. U.S. Environmental Protection Agency, Office of Emergency Response: Washington, DC, EPA/540/R-95/128 PB96-963502.