GUIDANCE DOCUMENT

DEVELOPMENT OF IMPACT TO GROUND WATER SOIL REMEDIATION STANDARDS USING THE SOIL-WATER PARTITION EQUATION

Version 2.0 – November 2013

New Jersey Department of Environmental Protection
Trenton, New Jersey

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I. Introduction

This guidance describes the use of the Soil-Water Partition Equation to develop Impact to Ground Water Soil Remediation Standards.

Modified versions of the USEPA Soil Screening Level (SSL) Soil-Water Partition Equations (USEPA, 1996b, Equations 22 and 24) may be used to calculate default Impact to Ground Water Soil Screening Levels (IGWSSL) or site-specific (alternative) Impact to Ground Water Soil Remediation Standards (IGWSRS). The Department expanded these equations to separate the target leachate concentration discussed in the USEPA SSL guidance document into its component parts. The target leachate concentration is the product of the health-based ground water criterion (C_{gw}) and the dilution-attenuation factor (*DAF*). This modification allows the Department's health-based Ground Water Quality Criterion to be directly entered as an input parameter**.**

The equations for calculating IGWSSL and site-specific IGWSRS are provided in Equations 1a and 1b below. The Soil-Water Partition Equation back-calculates a concentration in soil from an acceptable ground water concentration.

The Department has provided a table of default Impact to Ground Water (IGW) soil screening levels (Table 1) considering the health based Class II-A ground water quality criteria using default site conditions and assumptions. The screening levels provided in Table 1 are appropriate for use at sites where no site-specific data are available.

When site-specific information is available, it may be used to calculate alternative impact to ground water soil remediation standards as described in Section VI below. This option will be most useful in the following situations:

1) When a site-specific *DAF* is higher than the default value,
2) For organic contaminants, when the site-specific soil organic content is higher than the default value,
3) When the Synthetic Precipitation Leaching Procedure (SPLP) is used to determine a site-specific soil-water partition coefficient (K_{d}) for organic or inorganic contaminants. In this case, the partition equation is implemented using the Synthetic Precipitation Leaching Procedure guidance and spreadsheet.

For metals and inorganic contaminants, the use of the SPLP procedure to determine a site-specific K_{d} value is a primary mechanism for site-specifically adjusting the soil-water partition equation remediation standard. Since site-specific organic carbon contents are only used in conjunction with K_{oc} values for organic contaminants, this leaves only the *DAF* and K_{d} parameters that may be adjusted. Since adjustment of the *DAF* parameter requires information from a ground water investigation, the K_{d} value from the SPLP test is often the easiest information to obtain. The particular species of these contaminants, as well as the soil pH, greatly influence their adsorptive capacity, or K_{d} value. The default screening criteria assume mobile species of these contaminants are present since the actual species are unknown. The SPLP test determines the K_{d} value for the actual species on site and frequently results in higher remediation standards than the default soil screening levels.

The SPLP procedure is also useful for organic contaminants (particularly semivolatile organic contaminants) because the resulting K_d value may reflect the effect of age of the discharge and the effect of soil parameters other than organic carbon. This will often increase the remediation standard relative to the default value.

For Class I and III ground water, ground water quality criteria must be developed by the Department on a site-specific basis. IGW soil remediation standards are then back calculated from ground water criteria using the Soil-Water Partition Equation.

In 2012, the Department established a Committee to review and update the guidance 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. Equations for Calculating the Soil Remediation Standards

For organic contaminants:

$$IGWSRS = C_{gw}\left\{(K_{oc}\,f_{oc}) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF$$

Equation 1a

For inorganic contaminants (and organic contaminants with SPLP-determined K_d value):

$$IGWSRS = C_{gw}\left\{(K_d) + \frac{\theta_w + \theta_a H'}{\rho_b}\right\}DAF$$

Equation 1b

$IGWSRS$ = Impact-to-ground water soil remediation standard (mg/kg)
C_{gw} = Ground Water Quality Criterion (mg/L)
f_{oc} = organic carbon content of soil (kg/kg)
K_{oc}=soil organic carbon-water partition coefficient (L/kg)
K_d = soil-water partition coefficient (L/kg)
θ_w = water-filled soil porosity (L_{water}/L_{soil})
θ_a = air-filled soil porosity (L_{air}/L_{soil})
H' = Henry’s law constant (dimensionless)
ρ_b = dry soil bulk density (kg/L)
DAF = dilution-attenuation factor

The sensitivity of these equations to their input parameters is presented in Appendix A.

III. Soil-Water Partition Equation Assumptions

The USEPA SSL Soil-Water Partition Equation assumes that contaminants in soil exist in equilibrium between the sorbed phase (on soil solids), aqueous phase (in soil moisture) and vapor phase (in the soil airspace). The equation calculates the total amount of the contaminant that may be left behind in the soil so that the aqueous phase concentration of a contaminant will not exceed a specified criterion (the health-based Ground Water Quality Criteria).

Because soil water will be diluted once it enters the ground water, a dilution-attenuation factor (*DAF*) is included in the equation to account for this process. The model does not account for dilution of the contaminant during transport through the unsaturated soil zone or chemical degradation. The model assumes that the soil contamination is immediately adjacent to the water table, and that the health-based Ground Water Quality Criteria must be achieved directly under the area of concern immediately after remediation.

IV. Practical Quantitation Levels (PQLs)

When developing the remediation standard, the value determined using Equation 1a or 1b above is compared to the soil practical quantitation level (PQL) for the contaminant (listed in the Remediation Standards, N.J.A.C. 7:26D Tables 1A and 1B). The IGW soil remediation standards will be the higher of the health-based standard or the PQL.

V. Soil Saturation Limit (C_{sat})

The Department requires, pursuant to the Technical Requirements for Site Remediation N.J.A.C. 7:26E-1.10 and 5.1(e), that non-aqueous phase liquid (NAPL), or free and residual product, must be treated or removed whenever practicable. The concentration at which non-aqueous phase liquid (NAPL) begins to form is referred to, in the USEPA SSL guidance document, as the Soil Saturation Limit.

The USEPA SSL guidance document contains an equation for calculating the Soil Saturation Concentration (USEPA 1996b):

Soil Saturation Concentration Equation:

$$C_{sat} = \frac{S}{\rho_b}(K_{oc} f_{oc} \rho_b + \theta_w + H'\theta_a) \qquad \textbf{Equation 2}$$

Where C_{sat} is the soil saturation concentration (mg/kg), S is the contaminant's water solubility (mg/L), and the remaining parameters are as defined earlier. Values for the input parameters are the same as those for Equations 1a and 1b above. Soil saturation concentrations are listed in the chemical properties table:

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

In order to avoid the occurrence of NAPL, a soil remediation standard calculated for the impact to ground water pathway for a particular contaminant may not exceed its soil saturation concentration.

VI. Developing an Impact to Ground Water Soil Remediation Standard

A. Sites with No Site-Specific Information

Default impact to ground water soil remediation screening levels were calculated using Equation 1a for organic contaminants and Equation 1b for inorganic contaminants using the following default parameters:

Soil-Water Partition Equation
Default Input Parameters

Parameter	DEP Default Value
Health-based ground water criteria, C_{gw}	chemical specific
Fraction organic carbon, f_{oc}	0.002
Soil-water partition coefficient, K_d *or* K_{oc}	chemical specific
Water content, θ_w	0.23
Air content, θ_a (L_{air}/L_{soil})	0.18
Henry's law constant at 25°C, H' (dimensionless)	chemical specific
Dry soil bulk density, ρ_b (kg/L)	1.5
Dilution-attenuation factor, *DAF*	20

Values for soil properties are set in the Remediation Standards rule (See N.J.A.C. 7:26D Appendix 3). They are appropriate for New Jersey as explained in the basis and background document for the inhalation soil standards.

Chemical properties required for Equations 1a and 1b are those used for calculation of the inhalation soil standards. They are listed in the basis and background document for that exposure pathway and may also be accessed online:

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

The value of 20 for the DAF is explained in the *DAF* guidance document:

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

A table of default Impact to Ground Water Soil Screening Levels is provided below (Table 1). These screening levels were calculated considering the health based Class II-A ground water quality criteria and the soil water partition equation. They may be used as impact to ground water soil remediation standards at sites when no site specific information is available.

Table 1
Default Impact to Ground Water Soil Screening Levels for Contaminants (mg/kg)

Contaminant	CAS Number	Health based Ground Water Quality Criteria (µg/L)	Default Impact to GW Health-Based Soil Screening Level (mg/kg)	Soil PQL (mg/kg)	Impact to GW Soil Screening Level (mg/kg)
Acenaphthene	83-32-9	400	110	0.2	110
Acenaphthylene	208-96-8	NA	NA	0.2	NA
Acetone (2-propanone)	67-64-1	6000	19	0.01	19
Acetophenone	98-86-2	700	3	0.2	3
Acrolein	107-02-8	4	0.01	0.5	0.5[†]
Acrylonitrile	107-13-1	0.06	0.0002	0.5	0.5[†]
Aldrin	309-00-2	0.002	0.2	0.002	0.2
Aluminum	7429-90-5	200	6000	20	6000
Anthracene	120-12-7	2000	2400	0.2	2400
Antimony	7440-36-0	6	5	6	6[†]
Arsenic	7440-38-2	0.02	0.01	1	19*
Atrazine	1912-24-9	3	0.05	0.2	0.2[†]
Barium	7440-39-3	6000	2100	20	2100
Benzaldehyde	100-52-7	NA	NA	0.2	NA
Benzene	71-43-2	0.2	0.001	0.005	0.005[†]
Benzidine	92-87-5	0.0002	0.000001	0.7	0.7[†]
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.05	0.8	0.2	0.8
Benzo(a)pyrene	50-32-8	0.005	0.2	0.2	0.2
Benzo(b)fluoranthene (3,4-benzofluoranthene)	205-99-2	0.05	2	0.2	2
Benzo(ghi)perylene	191-24-2	NA	NA	0.2	NA
Benzo(k)fluoranthene	207-08-9	0.5	25	0.2	25
Beryllium	7440-41-7	1	0.7	0.5	0.7
1,1'-Biphenyl	92-52-4	400	140	0.2	140
Bis(2-chloroethyl)ether	111-44-4	0.03	0.0001	0.2	0.2[†]
Bis(2-chloroisopropyl)ether	108-60-1	300	5	0.2	5
Bis(2-ethylhexyl)phthalate	117-81-7	2	1200	0.2	1200
Bromodichloromethane (Dichlorobromomethane)	75-27-4	0.6	0.003	0.005	0.005[†]
Bromoform	75-25-2	4	0.03	0.005	0.03
Bromomethane (Methyl bromide)	74-83-9	10	0.04	0.005	0.04
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	300	0.9	0.01	0.9
Butyl benzyl phthalate	85-68-7	100	230	0.2	230
Cadmium	7440-43-9	4	2	0.5	2
Caprolactam	105-60-2	3500	12	0.2	12
Carbazole	86-74-8	NA	NA	0.2	NA
Carbon disulfide	75-15-0	700	6	0.5	6
Carbon tetrachloride	56-23-5	0.4	0.005	0.005	0.005
Chlordane (alpha and gamma)	57-74-9	0.01	0.05	0.002	0.05
Chlorobenzene	108-90-7	50	0.6	0.005	0.6
Chloroethane (Ethyl chloride)	75-00-3	NA	NA	0.005	NA
Chloroform	67-66-3	70	0.4	0.005	0.4
Chloromethane (Methyl chloride)	74-87-3	NA	NA	0.005	NA
2-Chlorophenol (o-Chlorophenol)	95-57-8	40	0.8	0.2	0.8
Chrysene	218-01-9	5	80	0.2	80
Cobalt	7440-48-4	100	90	5	90
Copper	7440-50-8	1300	11000	3	11000
Cyanide	57-12-5	100	20	3	20

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Contaminant	CAS Number	Health based Ground Water Quality Criteria (µg/L)	Default Impact to GW Health-Based Soil Screening Level (mg/kg)	Soil PQL (mg/kg)	Impact to GW Soil Screening Level (mg/kg)
4,4’-DDD	72-54-8	0.1	4	0.003	4
4,4’-DDE	72-55-9	0.1	18	0.003	18
4,4’-DDT	50-29-3	0.1	11	0.003	11
Dibenz(a,h)anthracene	53-70-3	0.005	0.8	0.2	0.8
Dibromochloromethane (Chlorodibromomethane)	124-48-1	0.4	0.002	0.005	0.005[†]
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.0001	0.005	0.005[†]
1,2-Dibromoethane (ethylene dibromide)	106-93-4	0.0004	0.000002	0.005	0.005[†]
1,2-Dichlorobenzene (o-Dichlorobenzene)	95-50-1	600	17	0.005	17
1,3-Dichlorobenzene (m-Dichlorobenzene)	541-73-1	600	19	0.005	19
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	75	2	0.005	2
3,3'-Dichlorobenzidine	91-94-1	0.08	0.003	0.2	0.2[†]
Dichlorodifluoromethane	75-71-8	1000	39	0.005	39
1,1-Dichloroethane	75-34-3	50	0.2	0.005	0.2
1,2-Dichloroethane	107-06-2	0.3	0.001	0.005	0.005[†]
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	1	0.008	0.005	0.008
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	70	0.3	0.005	0.3
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	100	0.6	0.005	0.6
2,4-Dichlorophenol	120-83-2	20	0.2	0.2	0.2
1,2-Dichloropropane	78-87-5	0.5	0.003	0.005	0.005[†]
1,3-Dichloropropene (cis and trans) (summed)	542-75-6	0.4	0.003	0.005	0.005[†]
Dieldrin	60-57-1	0.002	0.002	0.003	0.003[†]
Diethyl phthalate	84-66-2	6000	88	0.2	88
2,4-Dimethylphenol	105-67-9	100	1	0.2	1
Di-n-butyl phthalate	84-74-2	700	950	0.2	760**
4,6-Dinitro-2-methylphenol (4,6-Dinitro-o-cresol)	534-52-1	0.7	0.005	0.3	0.3[†]
2,4-Dinitrophenol	51-28-5	10	0.03	0.3	0.3[†]
2,4-Dinitrotoluene	121-14-2	NA	NA	0.2	NA
2,6-Dinitrotoluene	606-20-2	NA	NA	0.2	NA
2,4-Dinitrotoluene/2,6-Dinitrotoluene (mixture)	25321-14-6	0.05	0.0003	0.2	0.2[†]
Di-n-octyl phthalate	117-84-0	100	330000	0.2	3300**
1,2-Diphenylhydrazine	122-66-7	0.04	0.001	0.7	0.7[†]
Endosulfan I and Endosulfan II (alpha and beta)	115-29-7	40	4	0.003	4
Endosulfan sulfate	1031-07-8	40	2	0.003	2
Endrin	72-20-8	2	1	0.003	1
Ethyl benzene	100-41-4	700	13	0.005	13
Fluoranthene	206-44-0	300	1300	0.2	1300
Fluorene	86-73-7	300	170	0.2	170
Alpha-HCH (alpha-BHC)	319-84-6	0.006	0.0003	0.002	0.002[†]
Beta-HCH (beta-BHC)	319-85-7	0.02	0.001	0.002	0.002[†]
Heptachlor	76-44-8	0.008	0.5	0.002	0.5
Heptachlor epoxide	1024-57-3	0.004	0.01	0.002	0.01
Hexachlorobenzene	118-74-1	0.02	0.04	0.2	0.2[†]
Hexachloro-1,3-butadiene	87-68-3	0.4	0.9	0.2	0.9
Hexachlorocyclopentadiene	77-47-4	40	320	0.2	320
Hexachloroethane	67-72-1	2	0.1	0.2	0.2[†]
Indeno(1,2,3-cd)pyrene	193-39-5	0.05	7	0.2	7
Isophorone	78-59-1	40	0.2	0.2	0.2

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Contaminant	CAS Number	Health based Ground Water Quality Criteria (µg/L)	Default Impact to GW Health-Based Soil Screening Level (mg/kg)	Soil PQL (mg/kg)	Impact to GW Soil Screening Level (mg/kg)
Lead	7439-92-1	5	90	1	90
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	0.03	0.001	0.002	0.002[†]
Manganese	7439-96-5	50	65	2	65
Mercury	7439-97-6	2	0.01	0.1	0.1[†]
Methoxychlor	72-43-5	40	160	0.02	160
Methyl acetate	79-20-9	7000	22	0.005	22
Methylene chloride (Dichloromethane)	75-09-2	3	0.01	0.005	0.01
2-Methylnaphthalene	91-57-6	30	8	0.17	8
2-Methylphenol (o-cresol)	95-48-7	NA	NA	0.2	NA
4-Methylphenol (p-cresol)	106-44-5	NA	NA	0.2	NA
Methyl tert-butyl ether (MTBE)	1634-04-4	70	0.2	0.005	0.2
Naphthalene	91-20-3	300	25	0.2	25
Nickel (Soluble salts)	7440-02-0	100	48	4	48
2-Nitroaniline	88-74-4	NA	NA	0.3	NA
Nitrobenzene	98-95-3	4	0.02	0.2	0.2[†]
N-Nitrosodimethylamine	62-75-9	0.0007	0.000002	0.7	0.7[†]
N-Nitrosodi-n-propylamine	621-64-7	0.005	0.00002	0.2	0.2[†]
N-Nitrosodiphenylamine	86-30-6	7	0.4	0.2	0.4
Pentachlorophenol	87-86-5	0.3	0.06	0.3	0.3[†]
Phenanthrene	85-01-8	NA	NA	0.2	NA
Phenol	108-95-2	2000	8	0.2	8
Polychlorinated biphenyls (PCBs)	1336-36-3	0.02	0.2	0.03	0.2
Pyrene	129-00-0	200	840	0.2	840
Selenium	7782-49-2	40	11	4	11
Silver	7440-22-4	40	0.3	1	1[†]
Styrene	100-42-5	100	3	0.005	3
Tertiary butyl alcohol (TBA)	75-65-0	100	0.3	0.1	0.3
1,1,2,2-Tetrachloroethane	79-34-5	1	0.007	0.005	0.007
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	0.4	0.004	0.005	0.005[†]
Thallium	7440-28-0	0.5	0.5	3	3[†]
Toluene	108-88-3	600	7	0.005	7
Toxaphene	8001-35-2	0.03	0.3	0.2	0.3
1,2,4-Trichlorobenzene	120-82-1	9	0.7	0.005	0.7
1,1,1-Trichloroethane	71-55-6	30	0.3	0.005	0.3
1,1,2-Trichloroethane	79-00-5	3	0.02	0.005	0.02
Trichloroethene (TCE) (Trichloroethylene)	79-01-6	1	0.01	0.005	0.01
Trichlorofluoromethane	75-69-4	2000	34	0.005	34
2,4,5-Trichlorophenol	95-95-4	700	68	0.2	68
2,4,6-Trichlorophenol	88-06-2	1	0.04	0.2	0.2[†]
Vanadium	7440-62-2	NA	NA	5	NA
Vinyl chloride	75-01-4	0.08	0.0005	0.005	0.005[†]
Xylenes	1330-20-7	1000	19	0.005	19
Zinc	7440-66-6	2000	930	6	930

NA = Standard not available   *Health based standard defaults to background   **Health based standard defaults to soil saturation limit   [†]standard set at PQL

B. Sites with Site-Specific Information

The Department has provided partition equation spreadsheets that will enable the person conducting the remediation to quickly and easily generate site-specific (alternative) soil remediation standards that will be protective of ground water. The spreadsheets have built-in databases that include the necessary chemical properties and ground water criteria. The spreadsheet will also factor in C_{sat} values, soil PQLs and the arsenic statewide background value when calculating a remediation standard. In addition, they allow for modification of default values of certain input parameters used in the partition equation, when site-specific information is available, and enable calculation of standards for unlisted contaminants, as well as listed contaminants where alternate ground water quality criteria may apply.

When only the *DAF* is being modified in the partition equation (either Equation 1a or 1b), the partition equation spreadsheet provided at the following link should be used:

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

This spreadsheet incorporates both the partition equation and the capability of calculating a site-specific *DAF*, so that use of the separate Department-provided *DAF* spreadsheet is not necessary. However, documentation of the site-specific *DAF* should be provided as per the *DAF* guidance document.

When using the Soil-Water Partition Equation and a site-specific organic carbon content for organic contaminants (with or without *DAF* adjustment), Equation 1a and the following spreadsheet (same link as above) should be used:

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

The use of a site-specific organic carbon content is generally most useful when it is significantly higher than the default value of 0.002, unless only a modest increase in the default screening level is needed.

When using the Soil-Water Partition Equation and a site-specific value for the soil adsorption coefficient (K_d) that was determined using the SPLP test, Equation 1b and the Department's SPLP guidance and spreadsheet should be used, rather than this guidance. The SPLP guidance and spreadsheet includes Equation 1b and conducts all necessary calculations on sample results. The SPLP spreadsheet does not include the calculation of a site-specific *DAF*, so the separate *DAF* spreadsheet should be used if this parameter is also being adjusted. The SPLP and *DAF* spreadsheets can be found at the following links:

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

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

Calculate a site-specific IGW soil remediation standard using site-specific input parameters in Equation 1a or 1b as follows:

1. Site-specific values may be developed for 4 different input parameters using the procedures described in Section VII below. Use the default values provided above for other parameters when no site-specific values are available.

2. For Class II ground water, use the health-based ground water quality criteria, N.J.A.C. 7:9C.

3. Use the chemical properties that are provided in the Chemical Properties Table:

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

4. The site-specific IGW soil remediation standard will be based on the calculated health-based standard or the soil practical quantitation levels PQL, whichever is higher. The standard may not exceed the soil saturation concentration for the contaminant.

5. For Class I or III ground water, the Department will develop site-specific health-based ground water quality criterion appropriate for the ground water classification on which a site-specific IGW soil remediation standard can be based.

VII. Determination of Site-Specific Parameters

The following parameters may be based on site-specific information and used in Equation 1a or 1b to develop a site-specific IGW soil remediation standard.

A. Fraction Organic Carbon - f_{oc}

Soil organic carbon content is used with a contaminant's K_{oc} value to determine the extent that an organic contaminant will be adsorbed to the soil. In general, the soil remediation standard is linearly related to the organic carbon content. For example, doubling the organic carbon content of the soil will double the calculated remediation standard, unless it is limited by the soil PQL. To determine organic carbon content, a method that uses high temperature dry combustion of the soil followed by measurement of the evolved CO_2 should be used. The Lloyd Kahn method is recommended (USEPA, 1988), but other equivalent methods may be used. See Appendix B for further information. Determine a site-specific fraction organic carbon as follows:

1. Collect a minimum of 3 soil samples from locations at the site that are representative of the area of concern including soil type and contaminant depth. Samples should not be collected from areas with high levels of organic contamination (greater than 1,000 ppm) because high levels of organic contaminants will contribute to artificially high carbon content.

2. Analyze the samples for soil organic carbon content using the Lloyd Kahn or equivalent method.

3. Use the average soil organic carbon content as f_{oc} in the Equation 1a to develop a site-specific standard. This calculation is incorporated in the partition spreadsheet. If the f_{oc} values vary by more than an order of magnitude, they may not be averaged to develop a site-

specific standard. In this case, the lowest f_{oc} value must be used to develop a site-specific standard.

Additional soil samples should be collected when soil types vary across the area of concern or for larger areas of concern.

B. Soil-Water Partition Coefficient - K_d

A site-specific K_d value from the SPLP test may be determined for both inorganic and organic contaminants. In this case, the partition equation should be used as discussed in the NJDEP SPLP guidance document, and the SPLP spreadsheet should be used to calculate a site-specific K_d value using SPLP results. The SPLP spreadsheet includes the partition equation calculations. The document and spreadsheet may be found at the following links:

http://www.nj.gov/dep/srp/guidance/rs/splp_guidance.pdf

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

1. Use the SPLP Guidance Document and spreadsheet to derive a site-specific soil-water partition coefficient, K_d .

2. Substitute the derived K_d value into Equation 1b. The K_d calculation is incorporated in the SPLP spreadsheet.

C. Dilution-Attenuation Factor - *DAF*

1. Develop a site-specific dilution-attenuation factor following the DAF guidance document. The actual calculation of the *DAF* may be accomplished with either the partition spreadsheet or the *DAF* spreadsheet. The *DAF* guidance document may be found at the following link:

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

2. Substitute the site-specific DAF into Equation 1a or Equation 1b. This calculation is incorporated in the partition spreadsheet and the SPLP spreadsheet.

D. Ionizable Phenol K_{oc} Values for Soil pH

For ionizable phenols, the adsorption constant (K_{oc}) is dependent on soil pH (USEPA, 1996b). A site-specific soil remediation standard may be developed for ionizable phenols for which pH-dependent K_{oc} values (USEPA, 1996a). Determine a site-specific K_{oc} as follows:

1. Collect a minimum of 3 soil samples from locations at the site that are representative of the area of concern including soil type and contaminant depth.

2. Measure the soil pH in each sample using standard methods.

3. Use the soil pH value for each sample to select a soil organic carbon-water partition coefficient (K_{oc}) for the contaminant from Table 2 below. If the measured soil pH is less than 4.9, use the K_{oc} for pH 4.9. If the measured pH is higher than 8.0, use the K_{oc} value for pH 8.0.

4. Use the resulting K_{oc} value in Equation 1a to calculate the site-specific IGW soil remediation standard for each sample. This calculation may be accomplished in the partition spreadsheet, but the spreadsheet for unlisted chemicals must be selected in order to allow entry of an alternate K_{oc} value, and several of the other parameters must be entered manually. If the calculated standards vary by less than an order of magnitude, they may be averaged to determine the site-specific IGW soil remediation standard. If calculated standards vary by more than an order of magnitude, the lowest calculated standard must be selected as the site-specific IGW soil remediation standard.

Table 2

K_{oc} Values (L/kg) for Ionizing Organics as a Function of pH

pH	Benzoic Acid	2-Chloro-Phenol	2,4-Dichloro-phenol	2,4- Dinitro-phenol	Pentachloro-phenol	2,3,4,5-Tetrachloro-Phenol	2,3,4,6-Tetrachloro-phenol	2,4,5-Trichloro-Phenol	2,4,6 Trichloro-phenol
4.9	5.54E+00	3.98E+02	1.59E+02	2.94E-02	9.05E+03	1.73E+04	4.45E+03	2.37E+03	1.04E+03
5.0	4.64E+00	3.98E+02	1.59E+02	2.55E-02	7.96E+03	1.72E+04	4.15E+03	2.36E+03	1.03E+03
5.1	3.88E+00	3.98E+02	1.59E+02	2.23E-02	6.93E+03	1.70E+04	3.83E+03	2.36E+03	1.02E+03
5.2	3.25E+00	3.98E+02	1.59E+02	1.98E-02	5.97E+03	1.67E+04	3.49E+03	2.35E+03	1.01E+03
5.3	2.72E+00	3.98E+02	1.59E+02	1.78E-02	5.10E+03	1.65E+04	3.14E+03	2.34E+03	9.99E+02
5.4	2.29E+00	3.98E+02	1.58E+02	1.62E-02	4.32E+03	1.61E+04	2.79E+03	2.33E+03	9.82E+02
5.5	1.94E+00	3.97E+02	1.58E+02	1.50E-02	3.65E+03	1.57E+04	2.45E+03	2.32E+03	9.62E+02
5.6	1.65E+00	3.97E+02	1.58E+02	1.40E-02	3.07E+03	1.52E+04	2.13E+03	2.31E+03	9.38E+02
5.7	1.42E+00	3.97E+02	1.58E+02	1.32E-02	2.58E+03	1.47E+04	1.83E+03	2.29E+03	9.10E+02
5.8	1.24E+00	3.97E+02	1.58E+02	1.25E-02	2.18E+03	1.40E+04	1.56E+03	2.27E+03	8.77E+02
5.9	1.09E+00	3.97E+02	1.57E+02	1.20E-02	1.84E+03	1.32E+04	1.32E+03	2.24E+03	8.39E+02
6.0	9.69E-01	3.96E+02	1.57E+02	1.16E-02	1.56E+03	1.24E+04	1.11E+03	2.21E+03	7.96E+02
6.1	8.75E-01	3.96E+02	1.57E+02	1.13E-02	1.33E+03	1.15E+04	9.27E+02	2.17E+03	7.48E+02
6.2	7.99E-01	3.96E+02	1.56E+02	1.10E-02	1.15E+03	1.05E+04	7.75E+02	2.12E+03	6.97E+02
6.3	7.36E-01	3.95E+02	1.55E+02	1.08E-02	9.98E+02	9.51E+03	6.47E+02	2.06E+03	6.44E+02
6.4	6.89E-01	3.94E+02	1,54E+02	1.06E-02	8.77E+02	8.48E+03	5.42E+02	1.99E+03	5.89E+02
6.5	6.51E-01	3.93E+02	1.53E+02	1.05E-02	7.81E+02	7.47E+03	4.55E+02	1.91E+03	5.33E+02
6.6	6.20E-01	3.92E+02	1.52E+02	1.04E-02	7.03E+02	6.49E+03	3.84E+02	1.82E+03	4.80E+02
6.7	5.95E-01	3.90E+02	1.50E+02	1.03E-02	6.40E+02	5.58E+03	3.27E+02	1.71E+03	4.29E+02
6.8	5.76E-01	3.88E+02	1.47E+02	1.02E-02	5.92E+02	4.74E+03	2.80E+02	1.60E+03	3.81E+02
6.9	5.60E-01	3.86E+02	1.45E+02	1.02E-02	5.52E+02	3.99E+03	2.42E+02	1.47E+03	3.38E+02
7.0	5.47E-01	3.83E+02	1.41E+02	1.02E-02	5.21E+02	3.33E+03	2.13E+02	1.34E+03	3.00E+02
7.1	5.38E-01	3.79E+02	1.38E+02	1.02E-02	4.96E+02	2.76E+03	1.88E+02	1.21E+03	2.67E+02
7.2	5.32E-01	3.75E+02	1.33E+02	1.01 E-02	4.76E+02	2.28E+03	1.69E+02	1.07E+03	2.39E+02
7.3	5.25E-01	3.69E+02	1.28E+02	1.01E-02	4.61E+02	1.87E+03	1.53E+02	9.43E+02	2.15E+02
7.4	5.19E-01	3.62E+02	1.21E+02	1.01E-02	4.47E+02	1.53E+03	1.41E+02	8.19E+02	1.95E+02
7.5	5.16E-01	3.54E+02	1.14E+02	1.01E-02	4.37E+02	1.25E+03	1.31E+02	7.03E+02	1.78E+02
7.6	5.13E-01	3.44E+02	1.07E+02	1.01E-02	4.29E+02	1.02E+03	1.23E+02	5.99E+02	1.64E+02
7.7	5.09E-01	3.33E+02	9.84E+01	1.00E-02	4.23E+02	8.31E+02	1.17E+02	5.07E+02	1.53E+02
7.8	5.06E-01	3.19E+02	8.97E+01	1.00E-02	4.18E+02	6.79E+02	1.13E+02	4.26E+02	1.44E+02
7.9	5.06E-01	3.04E+02	8.07E+01	1.00E-02	4.14E+02	5.56E+02	1.08E+02	3.57E+02	1.37E+02
8.0	5.06E-01	2.86E+02	7.17E+01	1.00E-02	4.10E+02	4.58E+02	1.05E+02	2.98E+02	1.31E+02

VIII. 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 spreadsheets provided by the Department as discussed above.

The spreadsheets do all necessary calculations, including comparison of the health-based standard with soil reporting limits and soil saturation concentrations. To use a site-specific K_d value determined using the SPLP test, use the SPLP guidance and spreadsheet instead of this guidance.

Submit a copy of the appropriate spreadsheet(s) to the Department. Also submit supporting documentation for site-specific parameters that were used in calculation of the standard.

APPENDIX A

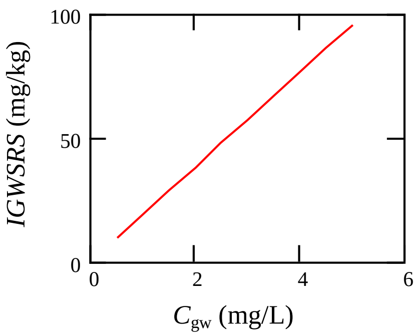
Sensitivity of the Soil-Water Partition Equation to Modification of Component Parameters

The Department conducted a sensitivity analysis of the USEPA partition equation to determine the effects of modifying different equation parameters on the development of soil remediation standard. For this analysis, one variable was modified at a time, while the other chemical and environmental parameter values were set at default New Jersey values. Soil properties were varied within their normal ranges (USEPA, 1996b). The analysis was conducted in two phases. First, the sensitivity of Equation 1 was evaluated with respect to the organic carbon content, K_{oc}, K_d, Henry's law constant, ground water standard, the dilution-attenuation factor (*DAF*), soil moisture, soil air content, and soil bulk density. Second, the sensitivity of the *DAF* calculations (Equations 2 and 3) to the various parameters incorporated was evaluated. The examples below are for specific contaminants, but the observed sensitivities are the same for all contaminants.

1. Sensitivity of the remediation standard (*IGWSRS*) to changes to the ground water standard (C_{gw}).
   Results shown for xylene

C_{gw} (mg/L)	*IGWSRS* (mg/kg)
0.5	9.6
1	19.2
1.5	28.7
2	38.3
2.5	47.9
3	57.5
3.5	67.1
4	76.7
4.5	86.2
5	95.8

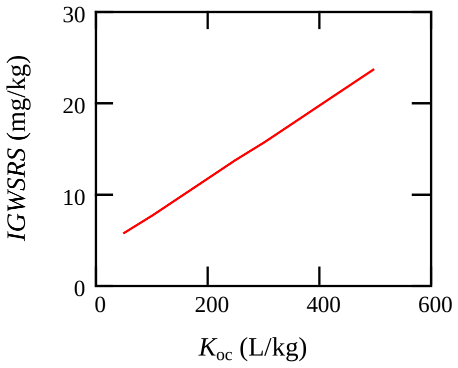
Sensitivity to groundwater criteria is line



2. Sensitivity of remediation standard (*IGWSRS*) to changes to the (K_{oc}) soil organic carbon-water partition coefficient value.
   Results shown for xylene

K_{oc} (L/kg)	*IGWSRS* (mg/kg)
50	5.7
100	7.7
150	9.7
200	11.7
250	13.7
300	15.7
350	17.7
400	19.7
450	21.7
500	23.7

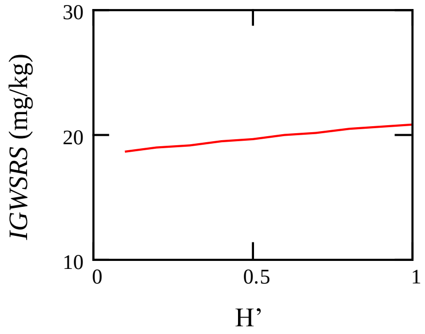
Sensitivity to K_{oc} is linear.



3. Sensitivity of remediation standard (*IGWSRS*) to the Henry's law constant (*H'*). Results shown for xylene

H'	*IGWSRS* (mg/kg)
0.1	18.7
0.2	19
0.3	19.2
0.4	19.5
0.5	17.9
0.6	20
0.7	20.2
0.8	20.4
0.9	20.7
1	20.9

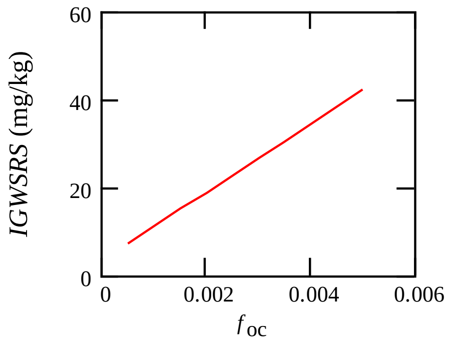
Sensitivity to *H* is small.



4. Sensitivity of remediation standard (*IGWSRS*) to fraction organic carbon (f_{oc}). Results shown for xylene.

f_{oc}	*IGWSRS* (mg/kg)
0.0005	7.6
0.001	11.4
0.0015	15.3
0.002	19.2
0.0025	23
0.003	26.9
0.0035	30.7
0.004	34.6
0.0045	38.5
0.005	42.3

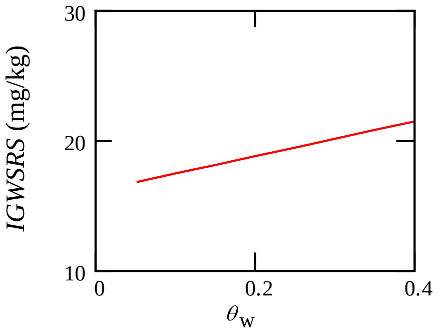
Sensitivity to f_{oc} is linear.



5. Sensitivity of remediation standard (*IGWSRS*) to soil moisture (θ_w) Results shown for xylene.

Sensitivity to θ_w is small.

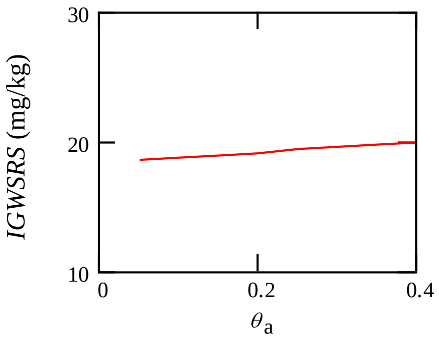
θ_w	*IGWSRS* (mg/kg)
0.05	16.7
0.1	17.4
0.15	18.1
0.2	18.8
0.25	19.4
0.3	20.1
0.35	20.8
0.4	21.4



6. Sensitivity of remediation standard (*IGWSRS*) to soil air content (θ_a). Results shown for xylene.

θ_a	*IGWSRS* (mg/kg)
0.05	18.7
0.1	18.9
0.15	19
0.2	19.2
0.25	19.4
0.3	19.6
0.35	19.8
0.4	20

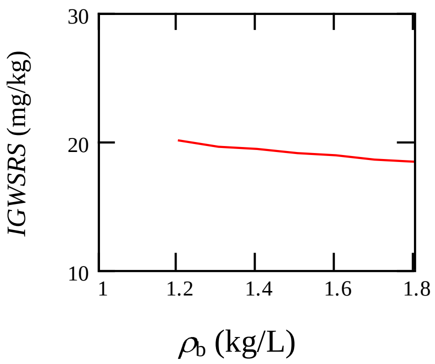
Sensitivity to θ_a is small



7. Sensitivity of remediation (*IGWSRS*) to soil bulk density (ρ_b) Results shown for xylene.

ρ_b (kg/L)	*IGWSRS* (mg/kg)
1.2	20.1
1.3	19.7
1.4	19.4
1.5	19.2
1.6	18.9
1.7	18.7
1.8	18.5

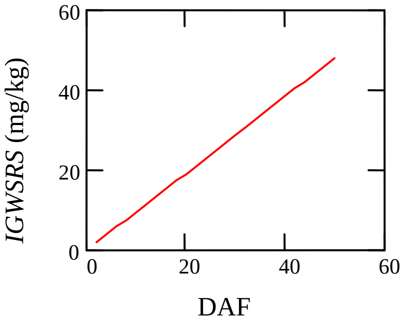
Sensitivity to ρ_b is small.



8. Sensitivity of remediation standard (*IGWSRS*) to dilution-attenuation Factor (*DAF*). Results shown for xylene.

DAF	*IGWSRS* (mg/kg)
2	1.9
4	3.8
6	5.8
8	7.7
10	9.6
12	11.5
14	13.4
16	15.3
18	17.2
20	19.2
22	21.1
24	23
26	24.9
28	26.8
30	28.8
32	30.7
34	32.6
36	34.5
38	36.4
40	38.3
42	40.2
44	42.2
46	44
48	46
50	47.9

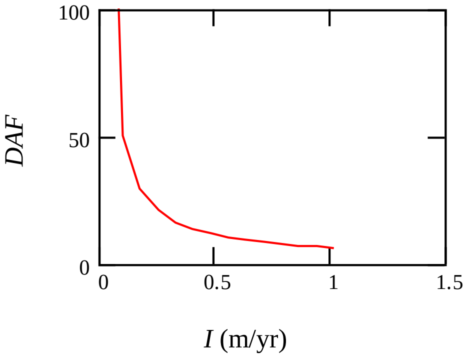
Sensitivity is linear with respect to *DAF*



9. Sensitivity of dilution-attenuation Factor (*DAF*) (and remediation standard (*IGWSRS*)) to infiltration rate (*I*).

I (m/yr)	*DAF*
0.025	198
0.102	51
0.178	30
0.254	22
0.33	17
0.406	14
0.483	12
0.559	11
0.635	9.8
0.711	8.9
0.787	8.3
0.864	7.7
0.94	7.2
1.016	6.8

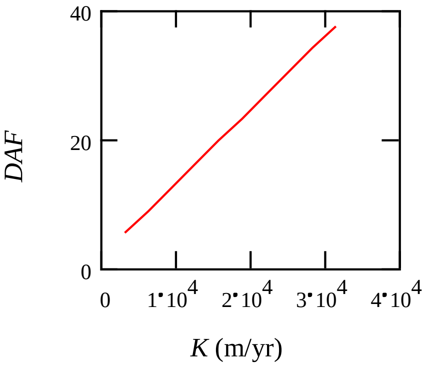
DAF (and cleanup) sensitivity is inversely proportional to infiltration rate, I. Mixing zone depth not constrained by aquifer thickness (3.8 m maximum).



10. Sensitivity of dilution-attenuation factor (*DAF*) (and remediation standard (*IGWSRS*) to hydraulic conductivity (*K*).

DAF (and cleanup) sensitivity is slightly less than linear with respect to conductivity, K. Mixing zone depth not constrained by aquifer thickness in this calculation.

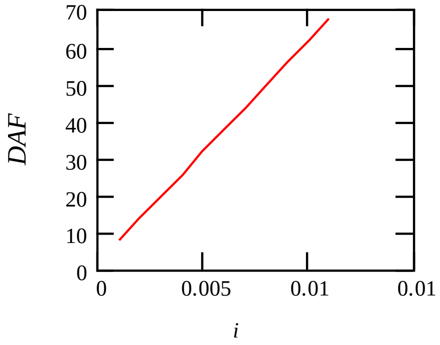
K (m/yr)	*DAF*
3155	6
6311	9
9467	13
12622	16
15778	20
18934	23
22089	27
25245	30
28401	34
31556	38



11. Sensitivity of dilution-attenuation factor (*DAF*) and remediation standard (*IGWSRS*) to gradient (*i*).

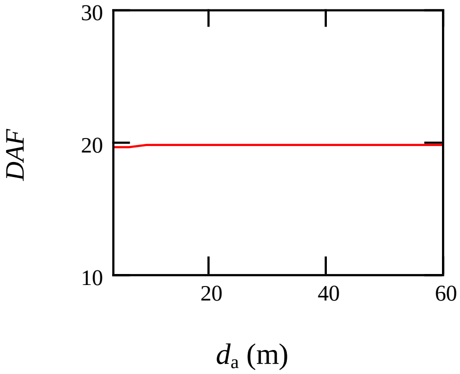
DAF (and cleanup standard) sensitivity is slightly less than linear with respect to gradient, *i*. Mixing zone depth not constrained by aquifer thickness in this calculation.

i	*DAF*
0.001	8
0.002	14
0.003	20
0.004	26
0.005	32
0.006	38
0.007	44
0.008	50
0.009	56
0.01	62
0.011	68



12. Sensitivity of dilution-attenuation factor (*DAF*) (and remediation standard (*IGWSRS*)) to aquifer thickness (d_a).

When aquifer thickness is 3.4 m or greater, the aquifer thickness has no effect on *DAF* or the remediation standard.



13. Effect of size of area of concern on the remediation standard.
    Results shown for xylene.

Remediation standard for xylene as a function of the size of the area of concern (mg/kg)			
	Length of Site		
	Parallel to GW flow (m)		
	15.2	*30.5*	*152*
Aquifer thickness = 3.5 m	19	19	5
Aquifer thickness = 15.2 m	19	19	17

Under default conditions, a lower remediation standard results when the site length becomes large. However, this effect is reduced when the aquifer thickness increases.

APPENDIX B

Determining Organic Carbon Content of Soil

The preferred method to be used for determining fraction organic carbon is the "Lloyd Kahn method" (USEPA, 1988) or equivalent. The Lloyd Kahn method was developed by USEPA Region 2 and can be found at the following link:

http://www.nj.gov/dep/srp/guidance/rs/lloydkahn.pdf

A similar method is documented on the USEPA Great Lakes website:

http://www.epa.gov/greatlakes/monitoring/sop/chapter_6/LG601.pdf.

The method first removes inorganic carbon via acid treatment. Then, high temperature dry combustion of the sample in the presence of oxygen is conducted using a carbon analyzer, followed by measurement of the evolved CO_2. The primary difference between the Great Lakes method and the Lloyd Kahn method is that the Great Lakes method is more specific in the type of carbon analyzer used.

Schumacher (2002) has compared dry combustion, wet oxidation, furnace (loss on ignition) and hydrogen peroxide treatment techniques for determination of total organic carbon in soils and sediments. The furnace and hydrogen peroxide treatments are best considered to be semiquantitative techniques since they exhibit problems such as incomplete oxidation of organic matter and loss of soil components other than soil organic matter. The wet oxidation technique is more quantitative but also suffers from potential incomplete oxidation of the sample, is subject to interference problems, and requires careful laboratory technique. The author recommends the dry combustion technique because minimal sample preparation is required, complete combustion of the organic carbon is assured, sample analysis time is short, and the method gives more reproducible results. Therefore, the NJDEP has decided that the Lloyd Kahn method (dry combustion) is the method of choice.

USEPA Methods 9060 and 5310 are frequently cited as a method for determination of total organic carbon. However, these method are designed for water and liquid wastes, and do not discuss the analysis of soil samples.

References

Schumacher, B.A. (2002). Methods for the Determination of Total Organic Carbon (TOC) in Soil and Sediments. U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Las Vegas, NV. NCEA-C-1282, EMASC-001, April 2002.

USEPA (1996a). Soil Screening Guidance: User's Guide, April 1996. Office of Solid Waste and Emergency Response: Washington, DC, EPA/540/R-96/018.

USEPA (1996b). 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.

USEPA (1988). Determination of Total Organic Carbon in Sediment (Lloyd Khan Method). U.S. Environmental Protection Agency, Region II, Edison, New Jersey. Available at http://www.nj.gov/dep/srp/guidance/rs/lloydkahn.pdf