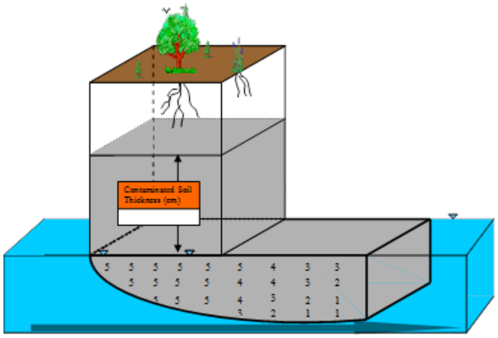
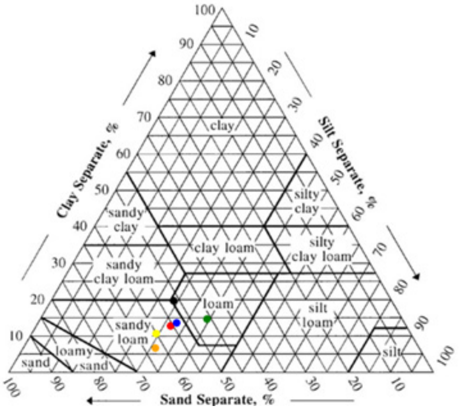
New Jersey
Department of Environmental Protection

Site Remediation and
Waste Management Program

Alternative Remediation Standards Technical Guidance

for Soil and Soil Leachate for the Migration to Ground Water Exposure Pathway





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1.0 INTENDED USE OF GUIDANCE DOCUMENT

This guidance is designed to assist the person responsible for conducting the remediation in complying with the New Jersey Department of Environmental Protection's (Department) requirements established by the Remediation Standards, N.J.A.C. 7:26D. This guidance will be used by many different people involved in the remediation of a contaminated site, such as Licensed Site Remediation Professionals (LSRPs), Non-LSRP environmental consultants, and other environmental professionals. Therefore, the generic term "investigator" is used to refer to any person that uses this guidance to remediate a contaminated site on behalf of a remediating party, including the remediating party itself.

The procedures for an investigator to develop and obtain an Alternative Remediation Standard (ARS) are outlined in the Remediation Standards at N.J.A.C. 7:26D-8 and Appendix 8. Both the development of an ARS or departure from the process provided in this guidance must be documented and adequately supported with site-specific data or other information. In applying technical guidance, the Department recognizes that professional judgment (with adequate justification) may result in a range of interpretations on the application of the guidance, depending on site conditions and other factors.

This guidance supersedes previous Department guidance issued on this topic. Technical guidance may be used immediately upon issuance. However, the Department recognizes the challenge of using newly issued technical guidance when a remediation affected by the guidance may have already been conducted or is currently in progress. To provide for the reasonable implementation of new technical guidance, the Department will allow a six-month "phase-in" period between the date the technical guidance is issued final (or the revision date) and the time it should be used. This guidance was prepared with stakeholder input. The following people were on the committee that prepared this document:

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2.0 INTRODUCTION

This section discusses the purpose of the document, document overview, background for the Soil Remediation Standards (SRS) for the Migration to Ground Water (MGW) exposure pathway (SRS-MGW), the Soil Leachate Remediation Standards (SLRS) for the MGW exposure pathway (MGW), and when development of alternative remediation standards (ARS) for soil and soil leachate for the MGW exposure pathway may be useful.

This pathway was formerly known as the Impact to Ground Water pathway. Previously, several guidance documents and spreadsheets for the Impact to Ground Water pathway were present on the Department website. These documents and spreadsheets were:

- Introduction to Site-Specific Impact to Ground Water Soil Remediation Standards Guidance Documents – Revised December 2008
- Frequently Asked Questions for the Impact to Ground Water Pathway in Soil Remediation Standards, Version 2.0 - March 2014
- Development of Impact to Ground Water Soil Remediation Standards Using the Soil-Water Partition Equation, Version 2.0 – November 2013
- Partition Spreadsheet - Version 2.1 Issued November 2013 - [Updated version posted December 2013]
- Development of Site-Specific Impact to Ground Water Soil Remediation Standards Using the Synthetic Precipitation Leaching Procedure, Version 3.0 – November 2013
- SPLP Spreadsheet - Version 3.1 Issued November 2013 - [Updated version posted December 2013
- Development of a Dilution-Attenuation Factor for the Impact to Ground Water Pathway, Version 2.0 – November 2013
- DAF Calculator Spreadsheet - Version 2.1 Issued November 2013 - [Updated version posted December 2013]
- Guidance for the Evaluation of Immobile Chemicals for the Impact to Ground Water Pathway, June 2, 2008
- Site Soil and Ground Water Analytical Data Evaluation – Metals & Semi-Volatile Organic Compounds Contamination, Updated January 25, 2009
- Using the SESOIL Transport Model to Assess the Impact to Ground Water Pathway, Revised December 2008
- Using the Combined SESOIL/AT123D Models to Develop Site-Specific Impact to Ground Water Soil Remediation Standards for Mobile Contaminants, Version 2.1 – May 2014

This guidance document incorporates and replaces all the guidance documents listed above.

With prior approval by the Department, an ARS may also be developed using scientific methods other than those described above, including relevant guidance from the USEPA, other states, and other relevant, applicable, and appropriate methods and practices that ensure the protection of public health and safety and of the environment.

Major changes from the previous Impact to Ground Water guidance documents are listed in Appendix E.

Information on the application, documentation, and review process (when Department approval prior to use is required) of an ARS for soil or soil leachate for the MGW exposure pathway r is found in N.J.A.C. 7:26D-8.4, 8.5 and Appendix 8.

This document does not include guidance on when a cap may be used to address the migration to ground water exposure pathway. Capping is a compliance option, not an ARS option. Capping is allowed in some situations, with restrictions. Guidance documents regarding capping as a compliance option for the MGW pathway are available at https://www.nj.gov/dep/srp/guidance/rs/igw_capping.pdf and https://www.nj.gov/dep/srp/guidance/rs/igw_vo_capping.pdf.

Another compliance option, "Volatile Organic Contamination including methyl tertiary butyl ether (MTBE) and tertiary butyl alcohol (TBA) derived from discharges of Petroleum mixtures" is still in effect and is available at https://www.nj.gov/dep/srp/guidance/

The procedures to update standards or to develop interim SRS are not addressed in this guidance. These procedures are outlined in N.J.A.C. 7:26D-6 and 7. Pursuant to N.J.A.C.7:26D-6, the person responsible for conducting remediation may request the Department develop an interim SRS when a contaminant of concern is not listed in the Remediation Standards Appendix 1, Tables 5 and 6. The Department may establish an interim SRS for the contaminant. The LSRP may contact the Department for a technical consultation to determine if an interim SRS request is appropriate at a site or AOC. Contact information for technical consultations can be found at http://www.state.nj.us/dep/srp/srra/technical_consultation. The form requesting development of an interim or ARS may be found on the Department's website at http://www.nj.gov/dep/srp/srra/forms. The Department must approve an interim SRS prior to its use (N.J.A.C.7:26D-6). The Department will periodically update Remediation Standards as outlined in N.J.A.C. 7:26D-7.

2.1 Purpose

The purpose of this document is to provide detailed guidance to investigators on how to develop an ARS for the MGW exposure pathway as well as to determine if the MGW exposure pathway can be addressed via a narrative standard, as discussed below.

This document combines and updates the previous guidance documents for this pathway (as stated above with the exception of the guidance for petroleum mixtures as discussed above).

Area of Concern (AOC) or site-specific Alternative Remediation Standard for the Migration to

Ground Water Exposure Pathway (ARS-MGW) may be proposed by the investigator or the Department at any time during the remediation process, when there is sufficient data and/or site-specific information (as described in this document) on which to base an ARS. N.J.A.C. 7:26D-8.3, 8.4 and 8.5 establish the processes and procedures for the investigator to establish an ARS. The Brownfield and Contaminated Site Remediation Act (N.J.S.A. 58:10B-1 et seq., "Brownfield Act") requires that the person requesting an ARS must demonstrate that the proposed ARS will be protective of human health, safety and the environment. This guidance document assists investigators with developing MGWARS based on AOC- or site-specific conditions.

The Department will inspect and review all ARS-MGW submittals. Certain options require Department pre-approval (*see below*). ARS-MGW calculated in accordance with this guidance, both those that require Department approval prior to use and those that do not, are applicable only to the AOCs or sites for which they have been developed; they are not applicable at any other AOCs or sites (N.J.A.C. 7:26D-8.2).

2.2 Document Overview

This document provides technical guidance to support the investigator in developing ASRS-MGW for soil and soil leachate for the MGW pathway. It presents the options available for the development of an ARS-MGW and supplements Appendix 8 and Section 8.3 of the Remediation Standards, N.J.A.C. 7:26D.

In particular, this document provides:

- Background on the Soil and Soil Leachate Remediation Standards for the migration to ground water exposure pathway to help investigators identify when an ARS-MGW is appropriate to support site remedial decisions.

- ARS-MGW options that require approval by the Department prior to use, include determination of a site-specific Dilution-Attenuation Factor (*DAF*) and modeling with the Seasonal Soil Compartment (SESOIL) model or the combined Seasonal Soil Compartment Model/Analytical Transient 1-,2-, and 3-Dimensional Ground Water (SESOIL/AT123D) model.

- ARS options that do not require approval from the Department prior to use include those utilizing the Soil Water Partition Equation (SWPE), the Synthetic Precipitation Leaching Procedure (SPLP), the Immobile Chemicals Option and the Site Soil and Ground Water Data Evaluation option.

2.3 Background

All Soil and Soil Leachate Remediation Standards for the MGW exposure pathway were developed to protect the ground water from future exceedances of Ground Water Remediation Standards (GWRS) that may result from leaching of contaminants from the unsaturated soil zone to the underlying ground water. The MGW pathway and the corresponding SRS-MGW, $MGW_{LEACHATE}$ and ARS-MGW do not apply in the saturated zone.

The SRS-MGW, $MGW_{LEACHATE}$ and ARS-MGW do not address current ground water conditions. All standards pertinent to the MGW exposure pathway are designed to prevent future contamination of the ground water from current soil contamination or residual contamination remaining after remediation. In the past, the impact to groundwater standards were sometimes inappropriately used as a trigger for ground water investigation. The *Ground Water Technical Guidance: SI/RI/RAP* document details when a ground water investigation is needed, and when to install a well (see https://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw). If ground water on a site is not currently impacted by any contaminants above their respective GWRS, it may be because contamination in the soil has not yet made its way to the water table. Alternatively, it may be that contamination in the soil is at a low enough concentration that it will never impact the ground water in concentrations that exceed of the applicable GWRS. Whenever there is a known or suspected discharge, the MGW exposure pathway must be investigated and addressed along with the other exposure pathways in accordance with the Technical Requirements for Site Remediation, N.J.A.C 7:26E. Soil sampling and comparison to the SRS-MGW and/or $MGW_{LEACHATE}$ is the only way to begin an investigation as to whether the MGW exposure pathway is potentially an issue for the site or area of concern in question. If there are exceedances, the pathway may be either addressed using these standards (via either remediation or compliance options detailed in other guidances) or by using the options discussed in this guidance (*see* sections 3.1 and 3.2). Ground water must be protected even if it is not being used for potable purposes. In accordance with the Water Pollution Control Act, N.J.S.A. 58:10A-1 et seq. “It is the policy of this State to restore, enhance and maintain the chemical, physical, and biological integrity of its waters, to protect public health, to safeguard fish and aquatic life and scenic and ecological values, and to enhance the domestic, municipal, recreational, industrial and other uses of water.” In order to maintain the integrity of ground water, no addition of chemicals to the soils that would result in an exceedance of the GWRS is allowed.

The MGW pathway must be addressed even when an active ground water remedy is in place. Existing ground water remedial actions address current ground water contamination. The MGW pathway addresses the potential for future ground water contamination from the current soil contamination in the vadose zone. Therefore, the two are not connected. The MGW pathway must be addressed such that future contamination of the ground water does not occur in the absence of active remedial action of the ground water.

Aluminum, manganese, sodium and iron are not normally of concern for the MGW exposure pathway. Per N.J.S.A. 58:10B-12, soil and soil leachate remediation standards must be based on health considerations. The health-based GWRS are used as the endpoint from which to back-calculate the SRS-MGW and $MGW_{LEACHATE}$. The GWRS for aluminum and manganese are secondary; that is, they are not based on health considerations, but instead are based on aesthetic considerations such as taste, odor and appearance. Additionally, these elements may be found as background contaminants. Therefore, the Department has decided that for aluminum and/or manganese contamination in soil and/or soil leachate, the MGW pathway does not need to be addressed unless there is reason to believe that the presence of either contaminant is due to a site discharge. However, the ingestion-dermal and inhalation exposure pathways may still need to be addressed. Contaminants such as sodium and iron are also not health-based and are therefore not included on the soil or soil leachate remediation standard contaminant lists.

While the SRS-MGW, may be used on all sites, they have been specifically developed to be used on sites where there is little or no AOC- or site-specific information. The SRS-MGW are concentrations of contaminants in soil that are protective of ground water quality as defined by the GWRS and are protective of the majority of sites regardless of the location of the contamination in relation to the underlying aquifer being protected. These standards were developed using the Soil Water Partition Equation (SWPE) with parameter values typical of New Jersey sites and soils. The SRS-MGW may be compared directly with total contaminant concentrations in soil to determine if exceedances of these standards need to be addressed.

The $\text{MGW}_{\text{LEACHATE}}$ are remediation standards that are used when AOC- or site-specific leaching information is available from the SPLP test. They are also protective of ground water quality regardless of the location of the contamination in the unsaturated zone in relation to the underlying aquifer being protected. They are developed by multiplying the GWRS by the default *DAF* of 20. These standards are aqueous concentrations of contaminants that are compared to field leachate concentrations, the latter of which are derived by entering the SPLP leachate concentrations into the Department's SPLP calculator.

SRS-MGW and $\text{MGW}_{\text{LEACHATE}}$ are listed in Tables 1 and 2 of this document respectively.

Because both standards need to be protective of the majority of sites, assumptions are made about representative conditions on a site situated in New Jersey. The conditions at any given AOC or site may vary and it may be beneficial to use AOC- or site-specific data to generate an ARS-MGW.

The development of an ARS-MGW or the demonstration that the MGW pathway has been adequately addressed does not exempt the investigator from addressing other policies or exposure pathways that impact the allowable concentrations of contaminants in the soil. The other pathways are the ingestion-dermal, inhalation, and vapor intrusion pathways. Guidance documents for these pathways are at https://www.nj.gov/dep/srp/guidance/rs/. The ingestion-dermal pathway regulates Extractable Petroleum Hydrocarbons (EPH), but there is a separate guidance document for EPH (*see* https://www.nj.gov/dep/srp/guidance/#eph_soil). Ecological concerns at a site, if any, must also be addressed in accordance with separate technical guidance at https://www.nj.gov/dep/srp/guidance/#eco_eval.

2.4 Determining whether to develop an ARS-MGW

The SRS-MGW and $\text{MGW}_{\text{LEACHATE}}$ standards were developed to be protective of the majority of sites when no site-specific information is available. They were calculated assuming standard conditions and parameter values for soil and aquifer properties. No assumptions were made regarding the amount of contaminant or its location in the unsaturated zone relative to the ground water. The standards are protective even when contamination is in contact with the water table or extends through the entire unsaturated soil zone. When AOC- or site-specific information is available, calculation of an ARS-MGW may be appropriate. Development of an ARS-MGW may be beneficial in the following situations:

- When soil properties differ from assumptions used for SRS-MGW;
- When contaminant leachability is likely to vary from the soil leachate standards;
- When it is desired to take into account the location of the contaminant relative to the water table or the amount of contaminant present;
- When aquifer properties differ from default assumptions;
- When the aquifer is not classified Class II-A and therefore is not subject to Class II-A GWRS;
- When contaminant transport modeling is likely to show no ground water impact;
- When ground water is already contaminated with mobile contaminants and a CEA is in place;
- When the location of less mobile contaminants are such that ground water is not likely to be impacted; or
- When maximum concentrations of contaminants are located at the water table and GWRS are not exceeded in ground water.

Subsequent sections of this document detail the options that are pertinent to these scenarios.

3.0 OVERVIEW OF ALTERNATIVE REMEDIATION STANDARDS FOR THE MGW EXPOSURE PATHWAY (ARS-MGW)

The purpose of the Alternative Remediation Standards for the Migration to Ground Water Exposure Pathway (ARS-MGW) is the same as the Soil Remediation Standards for the Migration to Ground Water Exposure Pathway (SRS-MGW) or Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$), which is to prevent unacceptable risk to human health from the ingestion of contaminated ground water caused by the migration of contaminants from the unsaturated soil zone to the ground water. They vary only in terms of the degree to which site-specific information is incorporated into the calculations from which the standards are derived. They are developed to protect against future contamination of ground water and use the applicable Ground Water Remediation Standards (GWRS) where the site is located. The procedures that are incorporated into this guidance document are mainly designed to be protective of Class II-A ground water. For Class I or III ground water, the Department will develop Area of Concern (AOC)- or site-specific GWRS appropriate for the ground water classification from which an ARS-MGW can be derived as needed. For arsenic, the health-based ARS-MGW defaults to the state-wide natural background of 19 mg/kg unless the alternative health-based standard is higher.

The Brownfield Act (N.J.S.A. 58:10B-1 et seq.) requires the Department to consider site-specific factors in determining an ARS. This document presents several methods that may be used to develop ARS-MGW. The procedures and site-specific factors may vary from those used by the Department in the development of the proposed SRS-MGW pursuant to N.J.A.C. 7:26D. The methods developed by the Department and presented in this guidance document are:

1. Modification of the Soil Water Partition Equation (SWPE) on an AOC- or site-specific basis;

2. AOC- or site-specific determination of contaminant leachability [Synthetic Precipitation Leaching Procedure (SPLP)];

3. AOC or site-specific adjustment of contaminant dilution into ground water [adjustment of the Dilution-Attenuation Factor (*DAF*)];

4. Assessment of contaminant transport through the soil column (SESOIL modeling);,

5. Assessment of contaminant transport through both the soil column and ground water (SESOIL/AT-123D modeling);

6. Immobile Chemical evaluation, and

7. Assessment of conditions when maximum contaminant concentrations in soil are at the water table but the GWRS are not exceeded (Site Soil and Ground Water Data Evaluation).

The Department recommends that the investigator review all options prior to selection of a method for determining an ARS-MGW.

The person responsible for conducting remediation may use any of these methods to develop an ARS-MGW. The methods may be used at any time during the remediation provided that adequate AOC or site data, as described in this document and N.J.A.C. 7:26D, Appendix 8, is available on which to base the ARS-MGW. If it is suspected that conditions on a site vary by AOC, a site-wide ARS-MGW may not be appropriate; rather, the ARS would only be applicable to an AOC. Additionally, two or more ARS options may be combined if appropriate. For example, an AOC- or site-specific soil adsorption coefficient (K_d values) developed using the SPLP procedure may be used in another ARS procedure. However, the ARS-MGW calculated using an SPLP-derived K_d may not exceed the highest contaminant concentration tested.

The MGW pathway is sensitive to variations in contaminant types and soil properties. The amount of information and data that are needed to develop an ARS-MGW varies based on the procedure that is used. Each of the ARS-MGW development options have their own site information and data requirements that are described in the pertinent section of this document.

In most instances, a minimum of three samples is required from each AOC to characterize its soil properties. If soil properties are variable across an AOC, additional sampling may be required. All sampling must be conducted in accordance with the Technical Requirements for Site Remediation, N.J.A.C. 7:26E, and the Soil PA/SI/RI guidance document (http://www.nj.gov/dep/srp/guidance/#si_ri_ra_soils) should also be followed. A minimum of three samples is also required when conducting SPLP analysis, except under limited circumstances as discussed in Section 6. Contaminant concentrations on-site must be compared to the ARS-MGW developed for the AOC or the site in accordance with the Technical Guidance for the Attainment of Remediation Standards and Site-Specific Criteria (https://www.nj.gov/dep/srp/guidance/#attainment_comp). Note that while point-by-point compliance may be applied to all ARS-MGW, compliance via averaging or other attainment methods is not permitted when using the SESOIL or SESOIL/AT123D models. Compliance averaging methods may be applied to the remaining numerical site-specific remediation standard options in this document.

If soil and contaminant conditions are similar throughout a site and/or across multiple AOCs, multiple AOCs may be combined into a site-wide AOC for purposes of developing ARS-MGW. However, for larger combined AOCs, the number of samples required to assess site-specific soil properties and to conduct procedures such as SPLP testing should be increased from the minimum of 3 samples to a more appropriate number in accordance with the Technical Requirements and other guidance. Where the LSRP uses professional judgment in this respect, adequate supporting documentation should be provided in appropriate Remedial Phase Reports and in the ARS submissions.

An overview of each of the methods available to develop an ARS-MGW is presented below, along with the type of contaminants and site conditions where each method is most useful. There are two types of ARS-MGW, numerical standards (Section 3.1) and narrative standards (Section 3.2). Prior to implementing any of these methods, a thorough review of the method, as detailed in the appropriate section of this guidance document and N.J.A.C. 7:26D,

Appendix 8, should be undertaken.

For the user's convenience, SRS-MGW and $\mathrm{MGW}_{\mathrm{LEACHATE}}$ are provided in Tables 1 and 2 of this document, respectively. The derivation of these standards with equations and input parameters is contained in Appendices 4, 8 and 10 of N.J.A.C 7:26D as well as in the "Soil and Soil Leachate Remediation Standards for the Migration To Ground Water Exposure Pathway, Basis And Background" document, located at http://www.nj.gov/dep/srp/guidance/rs .

3.1 Summary of Methods to Develop Numerical ARS-MGW

3.1.1 Modification of the Soil-Water Partition Equation

In this method, ARS-MGW are back calculated from the GWRS (N.J.A.C. 7:26D), using AOC-specific or site-specific values for one or more parameters in the United States Environmental Protection Agency (USEPA) SWPE (USEPA 1996a). The Department does not allow all parameters to be varied. The parameters that may be varied on an AOC- or site-specific basis are the Dilution-Attenuation Factor (*DAF*), the organic carbon content of soil (f_{oc}), the soil organic carbon-water partition coefficient (K_{oc}, for ionizable phenols), the K_d value (via the SPLP test), and the GWRS (if applicable). For example, if values for f_{oc} are suspected to be higher than the default value of 0.002, the SWPE may calculate an ARS-MGW higher than the SRS-MGW. A substantial percentage of sites may have organic carbon contents somewhat higher than the default value. Therefore, in cases where there are only marginal exceedances of the SRS-MGW, a small increase in f_{oc} may be sufficient to result in an acceptable ARS-MGW. Additional guidance for this method is provided in Section 4 below. The use of this procedure is not restricted by the location of the contaminant relative to the ground water and may be used for contaminants anywhere in the unsaturated zone, including cases where contamination is in contact with the water table.

3.1.2 Modification of the Dilution-Attenuation Factor

As infiltrating precipitation containing leached contaminant recharges an aquifer at the water table, it mixes with ground water, reducing the concentration of the contaminant in the leachate. The amount of dilution and the resulting ground water contaminant concentration can be calculated with the *DAF*. The *DAF* is dependent on the rate of ground water recharge and the ground water flow rate. The default value for this parameter is twenty (20), based on an assessment of New Jersey aquifers and ground water recharge rates. When AOC-specific or site-specific information is available regarding the ground water flow rate, it may be used to calculate a different *DAF* value. If the AOC-or site-specific *DAF* is greater than the default value of 20, this will result in an ARS-MGW greater than the SRS-MGW. Sites with higher-than-average aquifer flow rates would be the most likely candidates for consideration of this option. Additional guidance for this method is provided in Section 5 below. The use of this procedure is not restricted by the location of the contaminant relative to the ground water and may be used for contaminants anywhere in the unsaturated zone, including cases where contamination is in contact with the water table.

3.1.3 Synthetic Precipitation Leaching Procedure

The Synthetic Precipitation Leaching Procedure (SPLP) determines the AOC- or site-specific leachability of the contaminant. For inorganic and semi-volatile organic contaminants, the SPLP methodology will often be the most useful and practical procedure by which to develop an AOC- or site-specific ARS-MGW. These contaminants may be highly adsorbed to soil and exhibit low mobility, which limits their potential to migrate to ground water. The SPLP procedure provides an accurate measure of this mobility for these types of contaminants and may be used to develop an ARS-MGW. While the SPLP option may also be used for volatile organic contaminants, the lower sorption and higher mobility of these contaminants (especially in the case of more recent discharges) limits its practical application for these contaminants.

The use of this option is not restricted by the location of the contaminant relative to the ground water and may be used for contaminants anywhere in the unsaturated zone, including cases where contamination is in contact with the water table. The data required are total soil concentrations and the SPLP leachate results (including pH for certain contaminants). The $MGW_{LEACHATE}$ ($DAF = 20$) are provided as Table 2 in this document. Additional guidance for this method is provided in Section 6 below.

3.1.4 SESOIL Model

The Seasonal Soil Compartment Model (SESOIL) may be used to demonstrate that a specified existing or proposed concentration distribution of contaminant in soil will not result in future contamination of ground water above the GWRS. This contaminant concentration distribution may then be used to define an ARS-MGW. The ARS-MGW developed under this option will typically be a depth-dependent vertical concentration distribution, rather than a single number. This option will be most useful when:

1. there are contaminants with lower mobility that are located a significant distance above the water table and will not reach the water table in 100 years;

2. there are degradable volatile hydrocarbons at concentrations that do not greatly exceed the ARS-MGW; or

3. there are volatile contaminants that do not greatly exceed the SRS-MGW and the soil texture at the site has been characterized.

For all three of these conditions, the likelihood of the SESOIL model providing an ARS-MGW greater than the SRS-MGW increases as the distance between the contamination and the water table increases. Determination of the soil texture at the site is most important in the case of volatile organic contaminants as this site–specific determination enables the SESOIL model to simulate volatilization of the contaminant from the soil. This contaminant loss through volatilization often results in a significant reduction in contaminant transport downward to the ground water. Sites with impermeable caps must be modeled as if no cap is present. Because of this requirement, the ARS-MGW determined using the SESOIL model allows for unrestricted land use (capped or uncapped). Additional guidance for this method is provided in Section 7 below.

3.1.5 SESOIL/AT123D Model

When ground water is already impacted and a ground water Classification Exception Area (CEA) is established, the combined Seasonal Soil Compartment Model/Analytical Transient 1-, 2- and 3-Dimensional Ground Water (SESOIL/AT123D) model may be used to demonstrate that a specific vertical contaminant concentration distribution in the unsaturated zone will not result in an increasing ground water plume size or unacceptable ground water impacts beyond the time frame specified in the CEA. First, SESOIL is used to model vertical transport of contaminants of concern through the vadose zone to the water table. Then, the AT123D model evaluates contaminant transport in the ground water. The model-predicted contaminant ground water concentration as a function of time is evaluated at two locations in the ground water plume to determine whether the modeled soil concentration profile in the unsaturated zone is acceptable as an ARS-MGW. The SESOIL/AT123D option will mainly be useful for volatile organic contaminants, since contaminants must be relatively mobile to naturally attenuate within the timespan of the CEA. The likelihood that application of SESOIL/AT123D will provide an ARS-MGW greater than the SRS-MGW will increase when contaminant concentrations are relatively low, such as when simulating residual contaminant concentrations following source removal. Additional guidance for this method is provided in Section 8 below.

3.1.6 Comparison of SESOIL and SESOIL/AT123D

SESOIL and the combination SESOIL/AT123D model are both used to estimate the transport of contaminants to ground water resulting from the infiltration of precipitation. Both SESOIL and AT123D are contained within the commercially available SEVIEW software package. The circumstances under which these modeling methods may be employed varies and certain constraints apply to their use. These are summarized below to help the investigator differentiate the application of these two options to obtain an ARS-MGW. Additional guidance for this method is provided in Sections 7 and 8 below.

SESOIL is used to calculate the concentration of a contaminant in soil that will ensure that no additional contamination of ground water occurs beyond that already present, if any. This is accomplished through estimation of the dissolved contaminant (“leachate”) concentration at the bottom of the soil column, and comparison of this leachate concentration to the $\mathrm{MGW}_{\mathrm{LEACHATE}}$ standard concentration (Table 2 of this document). SESOIL can be used regardless of whether or not the ground water is currently contaminated.

AT123D incorporates the leachate concentration calculated by SESOIL and estimates the distribution and persistence of contamination in ground water. The combined SESOIL/AT123D model is used to calculate the concentration of a contaminant in soil that will ensure that existing ground water contamination will decrease to concentrations below the GWRS through natural attenuation within the CEA timeframe. SESOIL/AT123D is used only where ground water contamination already exists, and a CEA has been established; it is understood that the GWRS will be exceeded during the CEA timeframe. This option works best with mobile contaminants that are quickly transported to and through the ground water.

The chart below provides a summary of the uses and constraints associated with the SESOIL and

SESOIL/AT123D models.

	SESOIL	SESOIL/AT123D
Media	Unsaturated soil	Unsaturated soil and ground water
Objective	Calculated leachate < $MGW_{LEACHATE}$	GWRS achieved within CEA timeframe
CEA Required?	No	Yes
Impermeable Cap?	May be present (but modeled as if not present)	Cannot be present (for duration of CEA)
Contaminants	All	All, but typically used only for mobile contaminants (VOCs)
Site-specific testing of soil/aquifer parameters	Not required	Some required

3.2 Methods to Develop Narrative Standards

The Department has identified methods to determine whether, under certain specified conditions, contaminants in the vadose zone soil do not pose a risk of contaminating ground water. In these cases, an ARS-MGW is not determined. The nature and extent of the contamination and other AOC- or site-specific conditions will dictate whether there is a potential for future ground water contamination and whether further remediation is required. When specified AOC- or site-specific conditions are met, the Department will not require further remediation for the migration to ground water exposure pathway. These two options are summarized below.

3.2.1 Immobile Chemicals

The Department has modeled the transport of contaminants that exhibit very low mobility in soil and has determined that, under certain conditions, the contamination is not likely to migrate to ground water. For these contaminants, if the investigator can demonstrate that a minimum two-foot clean zone is present between the contamination and the water table, no remediation may be required for the MGW pathway. Additional information on this method, as well as a list of the contaminants for which this narrative standard may be applied, are provided in Section 9 below.

3.2.2 Site Soil and Ground Water Data Evaluation Method

In situations where the highest concentrations of a contaminant are located at the water table, and where ground water monitoring demonstrates that the GWRS are not exceeded, the Department considers the MGW pathway satisfactorily addressed. Additional guidance for this method is provided in Section 10 below.

3.3 Site Information and Data Needs

3.3.1 General Submittal Information

The “Alternative or New Remediation Standard and/or Screening Level Application” as well as the “Remediation Standards Notification Spreadsheet” forms must be prepared and certified by the person responsible for conducting remediation and LSRP when applying an ARS-MGW to a site or AOC. This form and its instructions are found in the Forms Library (under General Forms) located on the SRP website at http://www.state.nj.us/dep/srp/srra/forms/. Forms are periodically updated, and it is important to check the website to ensure that the latest versions of the form and instructions are being used. All the necessary information for completing the form and submitting the documentation are provided in the instructions and are further detailed in this guidance. Questions regarding the completion of the form or a request for an AOC- or site-specific technical consultation may be directed to contacts listed at http://www.nj.gov/dep/srp/srra/srra_contacts.htm.

For all ARS-MGW submittals, the following information must be entered on the form noted above and submitted along with the appropriate remedial phase report (*see* specific sections of this guidance for requirements):

1. A description and justification for modified parameters;

2. A description of how the standards will be used in the remediation of the site or area of concern, including institutional controls and remedial action permits (where appropriate); and

3. A comparison of the ARS-MGW with the appropriate standard from the other soil remediation standard exposure pathways (e.g., ingestion-dermal and inhalation exposure pathways). If the ARS-MGW applies only to a particular AOC this should be clearly stated in the Remediation Standards Notification Spreadsheet.

The ARS-MGW information provided in this guidance may be developed and submitted on an AOC- or site-specific basis but may not be applied at any other site or AOC in accordance with N.J.A.C. 7:26D-8.2. An ARS-MGW may incorporate elements from both the prior approval and no prior approval methods; however, an ARS using this combination requires prior approval by the Department.

The development and use of an ARS-MGW, is not justification for the extension of any regulatory or mandatory timeframes (ARRCS, N.J.A.C. 7:26C-3 and N.J.A.C. 7:26D-8.2).

As noted previously, guidance concerning attainment of and compliance with the Remediation Standards is provided in a separate guidance document (https://www.nj.gov/dep/srp/guidance/#attainment_comp)

3.3.2 Option-Specific Submittal Information

The Migration to Ground Water exposure pathway is sensitive to variations in contaminant type, contaminant location (within the soil column), and soil properties. The amount of information and data that are needed to develop an ARS-MGW varies based on the method that is used. Each of the ARS-MGW development methods have their own AOC or site information and data requirements, which are described in the pertinent subsequent sections of this document.

4.0 ARS-MGW DEVELOPMENT USING SITE-SPECIFIC PARAMETERS IN THE SOIL-WATER PARTITION EQUATION (SWPE)

4.1 Overview

This section describes the use of the SWPE to develop a Migration to Ground Water Alternative Remediation Standard (ARS-MGW). This section replaces the earlier guidance document titled "Development of Impact to Ground Water Soil Remediation Standards Using the Soil-Water Partition Equation, Version 2.0 – November 2013".

The Soil Remediation Standards for the Migration to Ground Water Exposure Pathway (SRS-MGW) are calculated using the SWPE, Class II-A Ground Water Remediation Standards (GWRS), and default site conditions and assumptions listed in N.J.A.C.7:26D, Appendix 4. These standards are provided in Table 1 of this document and are also cited in N.J.A.C 7:26D Appendix 1 Table 5. They are appropriate for use at all sites, including those where no site-specific data are available. The standards are calculated using Equations (1) and (2) below.

The SWPE assumes that contaminants in soil exist in equilibrium among the sorbed phase, aqueous phase, and vapor phase in the unsaturated zone. It makes no assumptions about the location of the contaminant relative to the ground water, the mass of the contaminant, or its persistence in the soil. It is protective of ground water quality even if the contaminant is located immediately above the water table or extends through the entire unsaturated soil zone. A Dilution-Attenuation Factor (*DAF*) accounts for dilution of contaminant when contaminant contained in the soil aqueous phase (soil leachate) enters the ground water.

Certain parameters may be varied on an Area of Concern (AOC)- or site-specific basis in the SWPE to develop an ARS-MGW as follows:

1. The organic carbon content of soil (f_{oc}) when it is greater than the default value;

2. The soil organic carbon-water partition coefficient (K_{oc}) for ionizable phenols, when the site-specific soil pH leads to a greater value;

3. The GWRS, when potentially impacted aquifer is classified as either a Class I or Class III aquifer pursuant to the Ground Water Quality Standards (N.J.A.C. 7:9C), or when a contaminant does not have a GWRS listed in Table 1 of this document;

4. The Dilution-Attenuation Factor (*DAF)*, when the AOC- or site-specific value is greater than the default value of 20; and

5. The soil-water partition coefficient (K_d) when a site-specific value has been developed. This parameter is adjusted using the Synthetic Precipitation Leaching Procedure (SPLP). However, the ARS-MGW calculated using an SPLP-derived K_d may not exceed the greatest contaminant concentration tested, for reasons discussed in Section 6.

In some cases, the ARS-MGW may require Department approval prior to use, as discussed below and in Section 2.2.

Other soil parameters in Equations (1) and (2) - soil bulk density, water- and air-filled soil porosity - are fixed and may not be changed because these parameters have only a small effect on the calculated standards and are difficult to measure. Chemical properties are constants for particular contaminants and may not be changed (except K_{oc} for ionizable phenols, as discussed below); refer to Table 3 and the "Soil and Soil Leachate Remediation Standards for the Migration To Ground Water Exposure Pathway, Basis And Background" document located at https://www.nj.gov/dep/srp/guidance/rs/).

An ARS-MGW may be developed under this option prior to completion of contaminant delineation and may be used as a new target concentration for delineation when evaluating the migration to ground water pathway. The alternative standards developed under this option may be used for soil in the unsaturated zone regardless of the location of the contamination relative to the water table.

4.2 Development of Migration to Ground Water Alternative Remediation Standard

To calculate an ARS-MGW, a Migration to Ground Water Soil Criterion (MGW_c) is calculated using Equations (1) or (2) below, using available site-specific values for one or more of the parameters listed in the situations above, and default values for the remaining parameters. Equation (1) is used for inorganic contaminants (and organic contaminants when the SPLP procedure is used), and Equation (2) is used for organic contaminants. The MGW_c is then compared to the soil reporting limit (RL) and soil saturation limit (C_{sat}) for the contaminant, listed in Table 1[1]. If the criterion is greater than its soil saturation limit, an SRS-MGW does not apply; however, free and residual product must be treated, removed or contained in accordance with the Technical Requirements for Site Remediation [N.J.A.C. 7:26E-5.1(e)]. If the criterion is less than the soil reporting limit for the contaminant, the ARS-MGW defaults to the SRS-MGW. Otherwise, the criterion calculated using Equation (1) or (2) becomes the ARS-MGW.

4.2.1 Equations for Calculating the ARS-MGW

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

$$MGW_c = GWRS * \frac{mg}{1000\mu g} * \left\{ K_d + \frac{\theta_w + (\theta_a * H')}{\rho_b} \right\} * DAF \qquad \text{Equation (1)}$$

For organic contaminants:

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[1] When the soil organic carbon content (f_{oc}) parameter is modified, a site-specific soil saturation limit must be determined as discussed in Section 4.2.2.1.

$$MGW_c = GWRS * \frac{mg}{1000\mu g} * \left\{ (K_{oc} * f_{oc}) + \frac{\theta_w + (\theta_a * H')}{\rho_b} \right\} * DAF$$ Equation (2)

Parameter	Definition	Units	Default
MGW_c	Migration to ground water soil criterion	mg/kg	Contaminant-specific
$GWRS$	Ground water remediation standard	µg/L	Contaminant-specific
K_d	Soil-water partition coefficient	L/kg	Contaminant-specific or site-specific*
K_{oc}	Soil organic carbon-water partition coefficient	L/kg	Contaminant-specific
f_{oc}	Organic carbon content of soil	kg/kg	0.002 or site-specific
θ_w	Water-filled soil porosity	L_{water}/L_{soil}	0.23
θ_a	Air-filled soil porosity	L_{air}/L_{soil}	0.18
H'	Henry's law constant	unitless	Contaminant-specific
ρ_b	Dry soil bulk density	kg/L	1.5
DAF	Dilution-attenuation factor	unitless	20 or site-specific

*ARS-MGW determined using a SPLP-derived K_d may not exceed the highest concentration tested

Contaminant-specific properties are listed in Table 3.

4.2.2 Development of Site-Specific Parameter Values

As stated in 4.1, parameters whose values may be determined on an AOC- or site-specific basis are the organic carbon content of soil (f_{oc}), the DAF, the soil organic carbon-water partition coefficient (K_{oc}) for ionizable phenols, a contaminant or aquifer-specific GWRS and, when the SPLP procedure is used, the soil-water partition coefficient (K_d). These parameters are used with the SWPE to determine the ARS-MGW. The ARS-MGW calculated using an SPLP-derived K_d may not exceed the highest contaminant concentration tested, for reasons discussed in Section 6.

The Department has provided spreadsheets that perform the necessary calculations for Equation

(1) or (2) and generate the ARS-MGW. These spreadsheets include the necessary chemical properties and the GWRS. They allow for site-specific adjustment of the f_{oc}, DAF, and K_{oc} value for ionizable phenols. The spreadsheets also factor in C_{sat} values, soil Reporting Limits and the arsenic statewide background value when calculating an ARS-MGW. Finally, they enable calculation of standards for unlisted contaminants, as well as for listed contaminants where the GWRS differs from the Class IIA standard. These spreadsheets are contained in the MGW calculator available at https://www.nj.gov/dep/srp/guidance/rs/.

Two parameters that may be adjusted on an AOC- or site-specific basis in the SWPE are covered in separate sections:

1. AOC- or site-specific determination of the DAF is described in Section 5. The ARS-MGW developed using this procedure require Department approval prior to use and

2. AOC- or site-specific determination of K_d values and the ARS-MGW from SPLP analysis is described in Section 6. The ARS-MGW developed using this procedure do not require Department approval prior to use.

Modification of the soil organic content of soil (f_{oc}), the soil organic-carbon water partition coefficient (K_{oc}) for ionizable phenols, the GWRS, the DAF, and the soil-water partition (K_d) are described in the following sections.

4.2.2.1 Organic Carbon Content of Soil - f_{oc}

Soil organic carbon content (also known as fraction organic carbon content of soil) is used with a contaminant's K_{oc} value to determine the extent to which an organic contaminant will be adsorbed to the soil. In general, the soil remediation standard is linearly related to the organic carbon content. For many contaminants, doubling the organic carbon content of the soil will approximately double the calculated SRS-MGW[2]. The use of an AOC - or 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. An ARS-MGW developed using this procedure does not require Department approval prior to use.

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.

Since the organic carbon content also affects the soil saturation limit (C_{sat}) for a contaminant, this value must also be adjusted for an AOC- or site-specific soil organic carbon content. The following equation is used:

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[2] Unless constrained by the soil reporting limit or soil saturation limit

$$C_{sat} = \frac{S}{\rho_b}[(K_{oc} * f_{oc} * \rho_b) + \theta_w + (H' * \theta_a)] \qquad \text{Equation (3)}$$

where C_{sat} is the soil saturation limit (mg/kg), S is the contaminant's water solubility (mg/L), and the other parameters are as defined in Equations (1) and (2).

This adjustment is incorporated into the Department's soil-water partition spreadsheet in the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/.

An AOC- or site-specific-soil organic carbon content value is determined as follows:

1. Collect a minimum of 3 soil samples from locations at the site that are representative of the AOC, 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 an artificially high organic carbon content.

2. Analyze the samples for soil organic carbon content using the Lloyd Kahn or equivalent method. The sample results are entered into the Department fraction organic carbon spreadsheet in the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/, which determines the appropriate organic carbon content value to be used to calculate an ARS-MGW.

3. Enter the f_{oc} value into the soil-water partition spreadsheet in the MGW calculator, located at https://www.nj.gov/dep/srp/guidance/rs/.

4. If the f_{oc} values vary by less than an order of magnitude, the average soil organic carbon content (but not less than the default value of 0.002) is used as the f_{oc} in Equation (2) to develop the ARS-MGW.

5. If f_{oc} values vary by more than an order of magnitude, they may not be averaged to develop an AOC- or site-specific standard. In this case, either the minimum f_{oc} value shall be used (but not less than the default value of 0.002), or the investigator shall evaluate whether the AOC or site should be separated into multiple AOCs (horizontal or vertical) with more uniform organic carbon contents that may be averaged (less than an order of magnitude variation). High variability in f_{oc} values may be due to a number of factors, including, but not necessarily limited to: natural variability in the same soil type laterally and/or vertically, occurrence of different soil types laterally and/or vertically, sampling methodology (e.g., incomplete homogenization), and/or poor laboratory precision (e.g., due to matrix interferences or heterogeneous soil/fill). If the investigator determines that variability is due to natural variations in the soil conditions in the investigation area (laterally and/or vertically), separate contiguous areas (AOCs) may be designated and separate ARS-MGW may be developed for each area. A minimum of three organic carbon samples would be needed for each AOC.

Additional soil samples should be collected when soil types vary across the AOC, horizontally and/or vertically (as discussed in item five above), or for larger AOCs.

4.2.2.2 Ionizable Phenol K_{oc} Values for Soil pH

For ionizable phenols, the adsorption constant (K_{oc}) is dependent on soil pH (USEPA, 1996a). A site-specific soil remediation standard may be developed for ionizable phenols using pH-dependent K_{oc} values (USEPA, 1996b). When an AOC- or site-specific K_{oc} value is higher than the default, a higher soil remediation standard will result. An ARS-MGW developed using this procedure does not require Department approval prior to use. 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 AOC including soil type and contaminant depth.

2. Measure the soil pH in each sample using standard methods. If the pH values vary by more than 1 pH unit, use the maximum pH measured (but not higher than pH 5.3). Otherwise, the average pH should be used (but not higher than pH 5.3). If desired, the AOC or site may be separated into multiple areas (horizontal or vertical) with more uniform soil pH characteristics, and separate ARS-MGW may be calculated. A minimum of three soil samples should be used to determine the pH of each area.

3. Use the appropriate soil pH value to select a soil organic carbon-water partition coefficient (K_{oc}) for the contaminant from Table 4. 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 the default value of 5.3, the K_{oc} value will be lower than its default value, which could result in a calculated ARS-MGW lower than the standard, if no other AOC- or site-specific parameters are being adjusted. The default K_{oc} should be used in this case.

4. Use the resulting K_{oc} in Equation (2) to calculate the AOC- or site-specific ARS-MGW for each sample. Use the soil-water partition spreadsheet in the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/. The spreadsheet for unlisted contaminants must be selected in order to allow entry of an alternate K_{oc} and the other parameters must be entered manually.

4.2.2.3 Aquifer- or Contaminant-Specific Ground Water Remediation Standard

The ARS-MGW developed using these procedures require Department approval prior to use.

1. For Class I and III ground water, obtain approval for the use of site-specific GWRS from the Department. The investigator shall propose a numeric GWRS based on the narrative standards outlined in the Ground Water Quality Standards (GWQS) pursuant to N.J.A.C. 7:26D-. This standard is then entered into the SWPE spreadsheet in the MGW calculator located at http://www.nj.gov/dep/srp/guidance/rs/ to develop the appropriate ARS-MGW. The spreadsheet for unlisted contaminants must be selected and the other parameters must be entered manually.

2. For a contaminant not found in Table 1 of this document, the GWRS should be used, if available. If a GWRS does not exist for the contaminant of concern, the investigator must request an Interim GWRS from the Department as set forth in N.J.A.C. 7:9C-1.7(c). Contact the Department (Bureau of Environmental Evaluation and Risk Assessment) for the procedures for developing and requesting the establishment of an interim SRS-MGW (N.J.A.C. 7:26D-6.2(c)iii. This interim GWRS is then entered into the SWPE spreadsheet in the MGW calculator located at http://www.nj.gov/dep/srp/guidance/rs/ to calculate an ARS-MGW if there are site-specific parameter values. The spreadsheet for unlisted contaminants must be selected, and the other parameters must be entered manually.

4.2.2.4 Dilution-Attenuation Factor *(DAF)*

DAF values vary widely depending on the ground water flow rate under the site. In cases where Darcy ground water flow rates are higher than the default value of 0.43 ft/day, the AOC- or site-specific *DAF* may be significantly higher than the default value of 20, which will result in a higher remediation standard than the promulgated standard. See Section 5 for additional guidance for determining a site-specific *DAF* value. Utilizing a site-specific *DAF* value requires Department pre-approval prior to implementation.

4.2.2.5 AOC- or Site-Specific Soil-Water Partition Coefficient (K_d)

Frequently, a direct assessment of contaminant adsorption/desorption to soil is preferred to using default soil-water partition coefficients (K_d values for inorganics, equivalent to $K_{oc}*f_{oc}$ for organics). This is particularly true for metal contaminants since their adsorption/desorption behavior is highly sensitive to pH and the species of the metal. Additionally, for both inorganic and organic contaminants, contaminant adsorption to soil may increase with the age of a discharge, which is reflected in a contaminant's K_d value being elevated relative to default values. In these cases, an ARS-MGW higher than the SRS-MGW may be determined. The SPLP procedure (Section 6 of this document) provides a direct measure of a contaminant's K_d value for both inorganic and organic contaminants, which may be used in the SWPE. (K_d is used instead of $K_{oc}*f_{oc}$ for organic contaminants). The SPLP guidance and the accompanying MGW calculator include the soil-water partition equation calculations in the SPLP spreadsheet. ARS-MGW developed using this procedure do not require Department approval prior to use. The ARS-MGW calculated using an SPLP-derived K_d may not exceed the highest contaminant concentration tested, for reasons discussed in Section 6.

4.2.3 Submission Requirements

For the Department to efficiently review proposed ARS-MGW, the investigator must submit the following documentation in accordance with N.J.A.C. 7:26D Appendix 8 III. (d) 4:

1. A printout of the Department's fraction organic carbon spreadsheet and the soil-water partition spreadsheet showing the input parameters and the resultant remediation standards. SPLP and *DAF* spreadsheet printouts should also be submitted, if used. The

MGW calculator is located at https://www.nj.gov/dep/srp/guidance/rs/ and

2. A discussion and supporting documentation for AOC- or site-specific parameters that were used in calculation of the standard. This includes appropriate summary tables and figures for the AOC- or site-specific parameter, as well as laboratory analytical data (and supporting data packages). This also includes documentation for parameters detailed elsewhere in this document, such as the *DAF* guidance (Section 5) and SPLP guidance (Section 6).

5.0 ARS-MGW DEVELOPMENT USING A SITE-SPECIFIC DILUTION-ATTENUATION FACTOR

5.1 Overview

This section describes the determination of an Area of Concern (AOC)- or site-specific Dilution-Attenuation factor (*DAF*) that may be used in the Soil Water Partition Equation (SWPE) to develop a Alternative Remediation Standard for the Migration to Ground Water exposure pathway (ARS-MGW). This section replaces the earlier guidance titled "Development of a Site-Specific Dilution-Attenuation Factor for the Migration to Ground Water Pathway, Version 3.0, November 2013."

As infiltrating precipitation containing leached contaminant recharges an aquifer at the water table, it mixes with ground water, reducing the leachate contaminant concentration. The amount of dilution and the resulting ground water contaminant concentration can be calculated with a *DAF*.

The *DAF* is described in the USEPA Soil Screening Level (USEPA SSL) document (USEPA 1996a). The *DAF* is used in the various options for calculating ARS-MGW, including calculation of the Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway ($\mathrm{MGW}_{\mathrm{LEACHATE}}$). See Table 2 of this document.

The default value of the *DAF* assumes an aquifer hydraulic gradient of 0.003 and an aquifer hydraulic conductivity of 142 ft/day (51865 ft/yr). If site-specific values for either of these parameters are higher than these default values, a *DAF* higher than the default value of 20 may be calculated. This will result in an ARS-MGW or $\mathrm{MGW}_{\mathrm{LEACHATE}}$ that is higher than the promulgated standard. A *DAF* or $\mathrm{MGW}_{\mathrm{LEACHATE}}$ that is higher than the $\mathrm{MGW}_{\mathrm{LEACHATE}}$ may be used in the soil-water partition equation, the SPLP method and the SESOIL model in order to obtain an ARS-MGW higher than the SRS-MGW.

ARS-MGW developed using an AOC- or site-specific *DAF* require approval from the Department prior to use.

5.2 Equations for Calculation of the *DAF*

The *DAF* is calculated using Equation (4) below. In addition to physical parameters for the aquifer and site, this equation requires a value for the mixing zone depth in the aquifer, which is calculated using Equation (5). These two equations are taken from the USEPA SSL guidance document (USEPA, 1996a).

Equation for calculating the dilution-attenuation factor (*DAF*):

$$DAF = 1 + \frac{K * i * d}{I * L} \qquad \text{Equation (4)}$$

where

DAF = dilution-attenuation factor (unitless)
K = aquifer hydraulic conductivity (m/yr)
i = aquifer hydraulic gradient (unitless)
d = mixing zone depth (m), calculated below (Equation (5))
I = infiltration rate (m/yr)
L = length of area of concern parallel to ground water flow (m)

Equation for calculating the aquifer mixing zone depth, d:

$$d = (0.0112 * L^2)^{0.5} + d_a * \{1 - \exp[(-L * I)/(K * i * d_a)]\} \qquad \text{Equation (5)}$$

where

d_a = aquifer thickness (m), and the rest of the parameters are as defined for Equation (4).

Dilution of the contaminant due to transport through the unsaturated soil zone is ignored because soil contamination is allowed to be immediately adjacent to the water table. Volatilization and contaminant degradation are also not considered because contaminant contact with the ground water may occur immediately.

A default *DAF* of 20 has been determined to be appropriate for New Jersey based on a default aquifer gradient of 0.003 and default aquifer hydraulic conductivity of 142 ft/day. (See the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/, for information pertaining to the development of the default *DAF*.)

5.3 AOC- or Site-Specific Modification of the Default Dilution-Attenuation Factor (*DAF*)

Several parameters that are used in the calculation of the *DAF* may be adjusted on an AOC- or site-specific basis. An AOC- or site-specific *DAF* may then be calculated and used to determine an ARS-MGW and/or an AOC- or site-specific MGWLEACHATE. In particular, higher ground water flow rates than those assumed for calculation of the default *DAF* will result in a higher *DAF* and may significantly increase the SRS-MGW or MGWLEACHATE.

When calculating an AOC- or site-specific *DAF,* the SWPE or *DAF* spreadsheets in the MGW calculator which are located at https://www.nj.gov/dep/srp/guidance/rs/ must be used.

In accordance with N.J.A.C. 7:26D, Appendix 8 III.(a)1, when determining a AOC- or site-specific *DAF* value, the length of the AOC parallel to ground water flow, *L*, must be adjusted in all cases to reflect actual conditions. In addition, the calculated mixing zone depth cannot be greater than the aquifer thickness (see below). The following parameters may be modified in the *DAF* equation:

5.3.1 Length, *L*

The *DAF* is only affected by the length of the area of concern (*L*) when it becomes large enough to cause the calculated mixing zone depth to become greater than the actual thickness of the aquifer (See the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/). Use the procedure below to calculate an AOC or site-specific *DAF* when adjusting the value of *L*:

1. Measure the length of the AOC parallel to ground water flow.
2. Use the length to develop an AOC- or site-specific mixing zone depth using Equation (5). If the calculated mixing zone depth is greater than the aquifer thickness (see below), set the mixing zone depth equal to the aquifer thickness.
3. Substitute the AOC- or site-specific values for the mixing zone depth and *L* into the equation for the *DAF* (Equation (4)).

These calculations must ((N.J.A.C. 7:26D Appendix 8 III. (a) 2) be conducted using the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/.

5.3.2 Infiltration Rate, *I*

The default infiltration rate is 11 inches/year, calculated for sandy loam soil, as described in the See the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/. However, if AOC- or site-specific infiltration rate data (i.e., ground water recharge data) are available or determined by site investigation, this information may be used. At this time, AOC- or site-specific adjustment of infiltration rates is allowed only after consultation with the Department. The Department will not allow low or impermeable covers to be considered in the development of the infiltration rate; for example, paving, which may result in a reduced infiltration rate, would not be allowed to modify the infiltration rate.

5.3.3 Ground Water Velocity Parameters (Hydraulic Conductivity, *K*, and Gradient, *i*)

Because *K* and *i* are closely linked parameters affecting ground water velocity, they must be adjusted together. The *DAF* is approximately linear with respect to these two parameters. Use the following procedure:

1. Determine *K* and *i* from field measurements pursuant to the Department's Ground Water

SI/RI/RA Technical Guidance at https://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw .

2. Measure the length (*L*) of the AOC parallel to the ground water flow.

3. Substitute *K*, *i*, and *L* into the mixing zone equation (Equation (5)) to determine a site-specific mixing zone depth. If the calculated aquifer mixing zone depth is greater than the aquifer thickness (see below), set the mixing zone depth equal to the aquifer thickness.

4. Substitute the site-specific values for *K*, *i, L* and the mixing zone depth into the equation for the dilution-attenuation factor (Equation (4)) to calculate a site-specific *DAF*.

These calculations must be conducted using the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/.

5.3.4 Aquifer Thickness, d_a

This parameter only affects the *DAF* if the calculated mixing zone depth is greater than the aquifer thickness. Use the following procedure to adjust the aquifer thickness and calculate a site-specific *DAF*:

1. Aquifer thickness shall be measured in the field using appropriate methods or shall be determined using available data from the New Jersey Geological Survey (NJGS) or the United States Geological Survey (USGS), assuming aquifer thickness determinations by the NJGS or USGS are in close proximity to the subject site. In cases where the aquifer thickness is large, it is only necessary to demonstrate that the aquifer thickness is greater than the calculated mixing zone depth.

2. Measure the length (*L*) of the AOC parallel to ground water flow.

3. Use the site-specific aquifer thickness and the actual length of the area of concern in the mixing zone depth equation (Equation (5)) to calculate a site-specific mixing zone depth. If the calculated aquifer mixing zone depth is greater than the aquifer thickness, set the mixing zone depth equal to the aquifer thickness.

4. Use the calculated site-specific mixing zone depth and the site-specific value for *L* in the *DAF* equation to calculate an AOC- or site-specific *DAF* (Equation (4)).

These calculations must be conducted using the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/.

5.4 Submission Requirements

In order for the Department to review the proposed site-specific *DAF*, it is required that the investigator use the SWPE or *DAF* spreadsheet in the MGW calculator provided by the Department at https://www.nj.gov/dep/srp/guidance/rs/.

In addition to submittal of the *DAF* calculation spreadsheet, documentation for all site-specific input parameters used to determine the site-specific *DAF* value (i.e., hydraulic conductivity, *K*, and aquifer gradient, *i*) must be submitted to the Department in accordance with N.J.A.C. 7:26D, Appendix 8 III.(a)3.

6.0 ARS-MGW DEVELOPMENT USING THE SYNTHETIC PRECIPITATION LEACHING PROCEDURE (SPLP)

6.1 Overview

This section describes the use of the Synthetic Precipitation Leaching Procedure (SPLP) that can be used in conjunction with additional calculations to derive an Alternative Remediation Standard for the Migration to Ground Water Exposure Pathway (ARS-MGW). This section replaces the earlier guidance titled "Development of Site-Specific Impact to Ground Water Soil Remediation Standards Using the Synthetic Precipitation Leaching Procedure, Version 3.0 – November 2013".

The Soil Remediation Standards for the Migration to Ground Water Exposure Pathway (SRS-MGW) were calculated using default values for a contaminant's soil-water partition coefficient (K_d value, equivalent to $K_{oc}*f_{oc}$ for organic contaminants). For metal contaminants, the default K_d value assumes the most mobile species of the metal (see the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/), which may not reflect the form of the metal or its mobility at a particular site. In addition, for both inorganic and organic contaminants, contaminant adsorption to soil may increase with the age of a discharge, which may result in a contaminant's K_d value being elevated relative its default value. This would result in an ARS-MGW higher than the SRS-MGW. For this reason, a direct assessment of contaminant adsorption/desorption to soil may be preferred to using a default soil-water partition coefficient. The SPLP procedure provides a direct measure of a contaminant's K_d value for both inorganic and organic contaminants and may be used in the soil-water partition equation to determine an ARS-MGW. The ARS-MGW calculated may not exceed the highest contaminant concentration tested, for reasons explained in Section 6.6, item 8 below.

ARS-MGW derived using the SPLP method do not require approval by the Department prior to use. The sequential steps involved are as follows:

1. Selection of either the Soil Leachate Remediation Standard for the Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) or derivation of an alternate $MGW_{LEACHATE}$ standard (Section 6.2);

2. Soil sample collection and execution of the SPLP procedure (Section 6.3); and

3. The processed results are used to develop a site-specific ARS-MGW (Section 6.4).

The Synthetic Precipitation Leaching Procedure (SPLP) is a United States Environmental Protection Agency (USEPA) SW-846 test method (Method 1312) that measures leaching of contaminants from soil. The method may be found at http://www3.epa.gov/epawaste/hazard/testmethods/sw846/pdfs/1312.pdf.

The Department has adapted and expanded this test as discussed in this document in order to determine the AOC- or site-specific adsorption-desorption coefficient of the contaminant of concern, and thus its site-specific potential to migrate to ground water. Using this adsorption-desorption coefficient, an AOC- or site-specific ARS-MGW can be developed.

The SPLP procedure itself consists of a batch equilibrium experiment in which the contaminant is partitioned between soil solids and an extracting solution using a 20:1 ratio of solution to solid. Further background on the SPLP test is found in the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/. The resulting solution is known as the SPLP 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. To determine an ARS-MGW, the results from this test are first used to calculate the leachate concentration of a contaminant in soil solution under natural conditions in the field. This adjustment is necessary for reasons explained in the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/. Then, the calculated field leachate concentration is compared to the appropriate leachate standard, the $\mathrm{MGW_{LEACHATE}}$, to determine whether the contaminated soil represents a potential threat to ground water quality. When the estimated field leachate concentration exceeds the $\mathrm{MGW_{LEACHATE}}$, the Department has developed procedures to determine a site-specific ARS-MGW using results from the SPLP test. In cases where all field leachate concentrations are below $\mathrm{MGW_{LEACHATE}}$, the highest soil concentration tested becomes the ARS-MGW.

The SPLP method may often be the method of choice for determining ARS-MGW for inorganic and low mobility organic contaminants for reasons discussed in Section 6.1 above. Low mobility organic contaminants may be conveniently defined as those with K_{oc} values greater than 20,000 L/kg (Roy and Griffin, 1985). K_{oc} values are provided in Table 3.

Volatile Organic Contaminants (VOCs) may also be tested using the SPLP procedure. The benefit of the SPLP procedure may be more limited for these contaminants, since VOCs are quite mobile, and the effect of the age of the discharge on their adsorption to soil may be limited. When testing VOCs, soil samples collected for SPLP must be obtained using an En Core® sampler (or equivalent) as discussed below[3]. For purposes of this document, VOCs are defined as contaminants with vapor pressures greater than 1 mm Hg at 25°C. These are identified in Table 2.

The SPLP option may be used at any time during site investigation or remedial investigation, provided that sufficient site data and information are available on which to base a standard. If determined during the Site Investigation, the ARS-MGW may be used to delineate the extent of the contamination during a remedial investigation. The Department has provided a spreadsheet in the MGW calculator to be located at https://www.nj.gov/dep/srp/guidance/rs/ that will enable the investigator to quickly and easily generate soil remediation standards that will be protective of ground water for any given site.

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[3] Methanol (or any other preservation method) cannot be used with any soil samples collected for SPLP extraction of VOCs because it affects contaminant desorption.

This spreadsheet performs all the necessary calculations using the SPLP test results and calculates the ARS-MGW. The Department requires that the investigator use this spreadsheet and include printouts of the spreadsheet in the appropriate submitted report.

Prior to implementing this procedure, the user should review the additional considerations discussed in Section 6.6 of this document.

It should be noted that the AOC- or site-specific soil-water partition coefficient (K_d) developed using the SPLP test may also be used in association with other ARS-MGW options, such as in the modified SWPE (Section 4) or the SESOIL model (Section 7). However, the ARS-MGW calculated using an SPLP-derived K_d may not exceed the highest contaminant concentration tested.

6.2 Determination of the Soil Leachate Remediation Standard for the Migration to Ground Water exposure Pathway ($MGW_{LEACHATE}$)

$MGW_{LEACHATE}$ standards have been developed by the Department for regulated contaminants. These are provided in Table 2. The $MGW_{LEACHATE}$ standards are appropriate when all the following conditions apply: (1) the contaminant is listed in Table 1, (2) the ground water is classified as Class II-A and (3) the default Dilution-Attenuation Factor (*DAF*) of 20 is used, rather than an AOC- or site-specific *DAF*.

Alternatively, site-specific $MGW_{LEACHATE}$ standards may be developed as discussed below.

6.2.1 Development of an AOC- or Site-Specific $MGW_{LEACHATE}$ Standard

There are three conditions for which calculation of AOC- or site-specific $MGW_{LEACHATE}$ standards may be appropriate, as described below. The MGW calculator contains an SPLP spreadsheet for unlisted contaminants which is used when a new or alternative GWRS standard is used. The $MGW_{LEACHATE}$ is calculated after the required parameters are entered. If a new or alternative GWRS is not being used, the SPLP spreadsheet for listed contaminants is used.

6.2.1.1 Contaminants with no Class IIA Ground Water Remediation Standard (GWRS)

The following procedure should be used:

1. If a GWRS does not exist for the contaminant of concern, the person responsible for conducting remediation must obtain an interim GWRS from the Department N.J.A.C 7:26D-6.2 (c). Contact the Bureau of Ground Water Pollution Abatement for the procedures for developing and requesting the establishment of an Interim GWRS.

2. Multiply the Interim GWRS by the *DAF* to obtain the $MGW_{LEACHATE}$.

6.2.1.2 Sites Associated with Class I or III Ground Water

The following procedure should be used:

1. For Class I and Class III ground water, obtain approval for the use of a site-specific GWRS from the Department. The person responsible for conducting remediation shall propose a numeric GWRS based on the narrative standards outlined in the Ground Water Quality Standards pursuant to N.J.A.C. 7:26D-2.2 (a).

2. Multiply the site-specific GWRS by the *DAF* to obtain the $MGW_{LEACHATE}$.

6.2.1.3 Site with an AOC- or Site-Specific *DAF*

The following procedure should be used:

1. Determine the appropriate GWRS in accordance with N.J.A.C. 7:26D. (For Class IIA ground water, GWRS are provided in Table 1 for most listed contaminants and are incorporated into the SPLP spreadsheet).

2. Develop an AOC- or site-specific *DAF* in accordance with the guidance contained in Section 5 of this document, using the spreadsheet in the MGW calculator at https://www.nj.gov/dep/srp/guidance/rs/.

3. Multiply the GWRS by the site-specific *DAF* to obtain the AOC- or site-specific $MGW_{LEACHATE}$.

6.3 Instructions for Soil Sampling and Conducting the SPLP Test

6.3.1 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), the total contaminant analysis (5 or 25g of soil required) and the soil moisture test can be conducted. Leachate concentrations and total contaminant concentrations are interrelated, and the correlation of these data can be used when developing AOC- or 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. Sample Collection. The number of samples collected shall be determined by the size of the area being investigated pursuant to the Technical Guidance for SI/RI/RA Verification Sampling for Soil. The guidance may be found at https://www.nj.gov/dep/srp/guidance/#si_ri_ra_soils.

   Other pertinent guidance documents should also be followed; for example, the Department's Field Sampling Procedures Manual (FSPM), which may be found at: http://www.nj.gov/dep/srp/guidance/fspm/.

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; in this case, refer to the Department's Extractable Petroleum Hydrocarbon guidance at https://www.nj.gov/dep/srp/guidance/#eph_soil. 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 exceed the $\mathrm{MGW}_{\mathrm{LEACHATE}}$ concentration. The samples should be representative of the variation in soil conditions over the AOC, including variation with soil depth.

After thoroughly mixing, three sub-samples are taken and analyzed as described below.

2. One sub-sample must be analyzed for total contaminant concentrations using appropriate methods referenced in appropriate NJDEP rules and guidance.
3. One sub-sample must undergo 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 end of the SPLP extraction procedure.
6. Analyze the leachate for the contaminants of concern using appropriate methods as referenced in appropriate NJDEP rules and guidance.

6.3.2 Sampling, Extraction and Analysis – Volatile Organic Contaminants

When assessing soil contaminated with volatile organic contaminants (identified in Table 2), significant loss of these contaminants may occur during sample collection, preparation and analysis. It is recommended that soil samples be taken from in-situ soils or 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 for volatile loss. Samples must ((N.J.A.C. 7:26D Appendix 8 III. (e) 1) be obtained immediately to avoid volatile loss from the soil 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 Department's SPLP procedure requires samples for both total and SPLP analysis. Sample collection is more problematic for VOCs than for metals and semivolatile organic chemicals. Since a single soil sample cannot be collected, mixed and split into multiple subsamples 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. Three samples must be obtained: (1) a 5- or 25-gram sample for analysis of total VOCs in soil (depending on the method), (2) a 25-gram sample for use in the SPLP extraction test, and (3) a sample for soil moisture determination. The 25-gram sample taken for the SPLP test must be obtained using an En Core® sampler (or equivalent), since methanol preservation may not be used on this sample and volatile loss must be prevented. For consistency, it is recommended that the sample for analysis of total VOCs in soil also be taken using an En Core® sampler, but methanol preservation techniques may be used.

When using the En Core® 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, in accordance with the 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. Sample collection - The number of samples collected should be determined by the size of the area being investigated, pursuant to the Technical Guidance for Site Investigation of Soil, Remedial Investigation of Soil, and Remedial Action Verification Sampling for Soil. The guidance may be found at https://www.nj.gov/dep/srp/guidance/#si_ri_ra_soils.

   Other pertinent guidance documents should also be followed, such as the Department’s FSPM at http://www.nj.gov/dep/srp/guidance/fspm/.

   Collect a minimum of three sets of soil samples for each area of concern. A sample set consists of one sample for VOC analysis in soil (5 or 25 g), one En Core® sample for SPLP testing (25 g), and a sample for soil moisture determination. An exception to collecting three sets of soil samples is when small fuel oil or diesel cases are being investigated; in this case, refer to the Department’s Extractable Petroleum Hydrocarbon guidance at https://www.nj.gov/dep/srp/guidance/#eph_soil.

   The samples should include the highest suspected concentrations of the contaminants within the AOC or 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. For weakly adsorbed contaminants, such as volatile organic contaminants, it may be expected that samples with higher total volatile organic contaminant concentrations will have SPLP results that show exceedances of the $MGW_{LEACHATE}$. For these chemicals, it is especially important to select samples that are expected to exhibit a range of concentrations. The samples should also be representative of the variation in soil conditions over the AOC or site, including variation with soil depth. Additional information regarding required field sampling techniques may be found in the Department’s FSPM.

2. One sample (5 or 25-gram sample) must be analyzed for VOC contaminant concentrations in soil using appropriate methods as referenced in appropriate NJDEP rules and guidance.

3. One sample (25-gram En Core® sample) must be applied to the SPLP procedure described in USEPA SW-846, Analytical Method 1312. For volatile organic contaminants, 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 En Core® 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 referenced in appropriate Department rules and guidance.

6.4 Results Processing and Reporting

6.4.1 Overview

Once SPLP testing and total concentration sample analyses have been completed, sample-specific soil-water partition coefficient (K_d) values are calculated. These are used to calculate sample-specific field leachate concentrations. Both the K_d values and the field leachate concentrations may be used to derive the ARS-MGW. These steps are detailed below.

The Department requires the use of its SPLP spreadsheet to enter and report sample data and SPLP results. The SPLP spreadsheet uses the soil-water partition equation to calculate a potential ARS-MGW. (The final ARS-MGW may differ from the potential standard because it may not exceed the highest contaminant concentration tested.) In addition to it being a convenient method of reporting results, the spreadsheet performs all necessary calculations discussed below, including the determination of estimated field leachate concentrations, the ARS-MGW, and sample-specific and AOC- or site-specific soil-water partition coefficients. The Department's SPLP spreadsheet in the MGW calculator is located at https://www.nj.gov/dep/srp/guidance/rs/.

6.4.2 Using SPLP Results to Determine an AOC- or Site-Specific ARS-MGW

Step 1. Calculate sample-specific K_d values

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

$$K_d = \frac{(C_T * M_S - C_{SPLP} * V_L)/M_S}{C_{SPLP}} \qquad \text{Equation (6)}$$

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 contaminants 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 1: C_{SPLP} in Equation (6) must have units of mg/L when this equation is calculated manually. However, when using the Department SPLP spreadsheet, units of µg/L must be entered, and the spreadsheet converts the units.

NOTE 2: When C_T is below the soil reporting limit for the contaminant, the sample results should not be used.

NOTE 3: C_{SPLP} results between the aqueous reporting limit and the method detection limit may be used if desired, particularly if eliminating these samples results in less than the three required samples. If C_{SPLP} is less than the method detection limit, the method detection limit may be used if necessary, but this is not recommended because it will underestimate the K_d value.

NOTE 4: For weakly adsorbed contaminants, 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, it is recommended that the sample results not be used if results from at least three samples are available that do not yield negative K_d values. Otherwise, a K_d of 0.0001 should be used in Equation (7) below when negative K_d values are calculated. When using the SPLP spreadsheet, this adjustment is included if necessary.

Step 2. Calculate the estimated field leachate concentrations

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

$$C_L = \frac{C_T}{K_d + \frac{\theta_w + \theta_a * H'}{\rho_b}} \qquad \text{Equation (7)}$$

where

ρ_b = bulk density of the soil (1.5 kg/L)
θ_w = water-filled soil porosity under natural field conditions (0.23)
θ_a = air-filled soil porosity under natural field conditions (0.18)
H' = the dimensionless Henry’s law constant

C_L = field leachate concentration (mg/L).
C_T = the total concentration of the contaminant in the SPLP soil sample (mg/kg)

NOTE: The NJDEP SPLP spreadsheet converts the field leachate concentrations to units of µg/L for easier comparison with $MGW_{LEACHATE}$.

Step 3. Use the Field Leachate Concentrations and/or the sample-specific K_d values to Determine an ARS-MGW

The three options below allow for the determination of an AOC- or site-specific ARS-MGW using the estimated field leachate concentrations and/or the sample-specific K_d values. The Department has provided a spreadsheet in the MGW calculator that will calculate the site-specific ARS-MGW for each suitable option listed below, depending on the nature of the dataset. The spreadsheet may be found at https://www.nj.gov/dep/srp/guidance/rs/
When multiple results are obtained from the various options, the highest ARS-MGW result may be used as the AOC- or site-specific ARS-MGW.

Option 1. Determination of an AOC- or Site-Specific ARS-MGW 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 $MGW_{LEACHATE}$ as follows:

1. If all field leachate concentrations are at or below the $MGW_{LEACHATE}$, the highest total contaminant concentration tested can be used as the ARS-MGW (Option 1a). If this ARS-MGW is the highest concentration of the contaminant for the AOC or site, then no further investigation is required for the migration to ground water pathway.

2. If one or more of the field leachate concentrations exceed $MGW_{LEACHATE}$, an ARS-MGW is selected using the appropriate procedure shown in Example 1 or 2 below (Option 1b).

Example 1

Sample Number	Total Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L (mg/L)	Soil Leachate Remediation Standard for Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) (mg/L)
Sample 1	5	900	1950
Sample 2	10	1450	1950
Sample 3	30	1175	1950
Sample 4	50	1680	1950
Sample 5	75	2700	1950

In Example 1, the $MGW_{LEACHATE}$ for the contaminant of concern is 1950 mg/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 $MGW_{LEACHATE}$. Therefore, the alternative AOC- or site-specific ARS-MGW is 50 mg/kg.

Example 2

Sample Number	Total Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L (mg/L)	Soil Leachate Remediation Standard for Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) (mg/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, the $MGW_{LEACHATE}$ for the contaminant of concern is 1950 mg/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 $MGW_{LEACHATE}$, a sample with a lower total contaminant concentration (Sample 3) yielded a field leachate concentration above the $MGW_{LEACHATE}$. Therefore, the ARS-MGW is 10 mg/kg.

Option 2. Determination of an AOC- or Site-Specific ARS-MGW using an AOC- or Site-Specific K_d Value

Sample-specific K_d values are 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 are used to determine an AOC- or site-specific K_d value. This site-specific value is then used to determine an AOC- or site-specific ARS-MGW as follows:

1. Use the total contaminant concentration in a soil sample (C_T), and the corresponding SPLP leachate concentration (C_{SPLP}) in Equation (6) 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 (8) to calculate a site-specific soil cleanup criterion:

$$ARS - MGW = MGW_{LEACHATE} * \left\{K_d + \frac{\theta_w + \theta_a * H'}{\rho_b}\right\} \qquad \text{Equation (8)}$$

where

ARS-MGW = Alternative Remediation Standard for the Migration to Ground Water Exposure Pathway (mg/kg)
$MGW_{LEACHATE}$= Soil Leachate Remediation Standard for the Migration to Ground Water Exposure Pathway (mg/L)
K_d = is the average, or lowest, calculated sample specific soil-water partition coefficient (L/kg)
θ_w = the water-filled soil porosity under natural field conditions(0.23)
θ_a = the air-filled soil porosity under natural field conditions (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)

5. If the calculated ARS-MGW is greater than the highest contaminant concentration tested, set the ARS-MGW to the highest tested concentration.

Equation (8) is equivalent to the soil-water partition coefficient described in the USEPA Soil Screening Guidance document (USEPA, 1996a). The Soil Leachate Remediation Standard for the Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) is equivalent to EPA's target leachate concentration. Henry's law constants may be found in Table 3.

Option 3. Determination of an AOC- or Site-Specific ARS-MGW using SPLP Results and Linear Regression Analysis

A linear regression technique may be used to determine an AOC- or site-specific ARS-MGW 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. Plot the field leachate concentration data (in units of µg/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 Soil Leachate Remediation Standard for the Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) 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 in order to ensure this condition is met.

3. Calculate the ARS-MGW using Equation (9) below:

$$ARS - MGW = \frac{MGW_{LEACHATE} - b}{m} \qquad \text{Equation (9)}$$

where

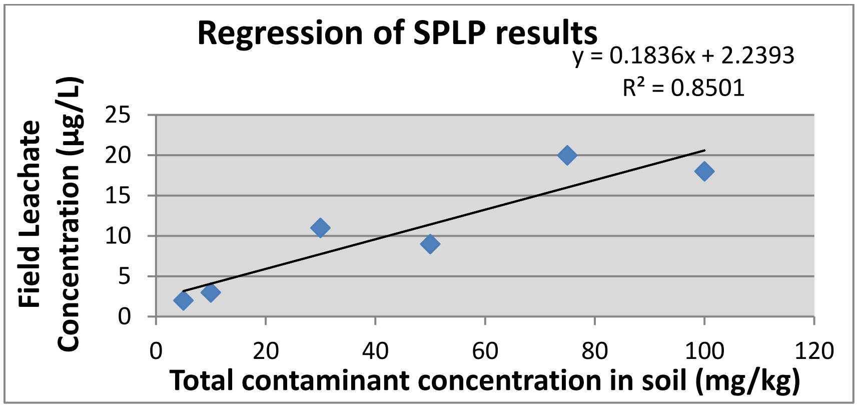
ARS-MGW = Alternative Remediation Standard for the Migration to Ground Water Exposure Pathway (mg/kg)
$MGW_{LEACHATE}$ = Soil Leachate Remediation Standard for the Migration to Ground

Water Exposure Pathway (µg/L)
m = the slope of the best fit line obtained via linear regression analysis ((µg/L)/(mg/kg))
b = the intercept of the best fit line obtained via linear regression (µg/L)

4. If the calculated ARS-MGW is greater than the highest contaminant concentration tested, set the ARS-MGW to that highest concentration.

Example 3

Sample Number	Contaminant Concentration in Soil C_T (mg/kg)	Contaminant Field Leachate Concentration C_L (µg/L)	Soil Leachate Remediation Standard for Migration to Ground Water Exposure Pathway ($MGW_{LEACHATE}$) (µg/L)
Sample 1	5	2	10
Sample 2	10	3	10
Sample 3	30	11	10
Sample 4	50	9	10
Sample 5	75	20	10
Sample 6	100	18	10



ARS-MGW = (10µg/L-2.240µg/L)/0.184 (µg/L)/(mg/kg) = 42 mg/kg

In Example 3, using the data and Equation (9), the ARS-MGW would be 42 mg/kg. In this case, Option 1 would have resulted in a standard of 10 mg/kg.

6.5 Submission Requirements

For the Department to review the proposed ARS-MGW, it is required that the SPLP calculation spreadsheet be used; the spreadsheet in the MGW calculator is located at https://www.nj.gov/dep/srp/guidance/rs/. The spreadsheet performs all necessary calculations, including the determination of the ARS-MGW using the three options discussed above. It also calculates the field leachate concentrations, displays calculated sample-specific K_d values, and determines an AOC- or site-specific K_d value that may be used in other methods for calculating an ARS-MGW.

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).

6.6 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 soil reporting limit.

   If the total contaminant concentration in a soil sample is below the soil reporting limit (RL), SPLP calculations are not able to be conducted on that sample. Furthermore, the sample is considered uncontaminated.

3. Samples with soil concentrations between the soil RL and the SRS-MGW

   On occasion, samples collected may exhibit total soil concentrations of the contaminant of concern that are below the SRS-MGW. This situation may occur when the SRS-MGW is above the soil RL. These sample results may still be used, as long as the concentration is above the soil RL. However, unless at least one soil sample has a total contaminant concentration above the standard, it will not be possible to calculate an alternative standard above the SRS-MGW.

4. Sites with minimal or scattered soil contamination

   In cases where the contamination is sporadic, it may be difficult to obtain 3 samples with total soil contaminant concentrations above the RL. If this is judged to be the case, results from one or two samples may be acceptable. This must be explained in the report submitted to the Department. The regression option may not be used with less than three sample results.

5. Concentrations in an SPLP leachate sample are below the aqueous RL, but above the aqueous method detection limit.

   The investigator may use professional judgement to decide if these samples should be used. They may be used if these samples are needed in order to obtain the minimum three required samples, or if it is judged that their inclusion helps improve the determination of the alternative remediation standard.

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

   If the total contaminant concentration in a soil sample is above the soil RL, but the corresponding SPLP leachate concentration is below the aqueous method detection limit, the results can still be used. However, it is recommended that these samples only be used if necessary to obtain the minimum three required samples. In this case, the aqueous method detection limit is used as the SPLP leachate concentration. The resulting standards calculated using Options 1 and 2 will be conservative since the SPLP leachate concentration for these samples would actually be less than the detection limit.

7. All field leachate concentrations are below $MGW_{LEACHATE}$, but contaminant concentrations in soil on site are higher than those tested.

   In situations where all SPLP samples give field leachate concentrations below the $MGW_{LEACHATE}$, the highest total concentration tested may be used as the ARS-MGW. The situation may arise where the ARS-MGW 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 $\mathrm{MGW}_{\mathrm{LEACHATE}}$, the newer sample results are used to set the maximum concentration observed on site and the ARS-MGW. This must be explained in the report sent to the Department.

8. Remediation standard limited to maximum concentration tested when using Option 2 and Option 3.

   Options 2 and 3 may initially calculate an ARS-MGW higher than the maximum contaminant concentration sample tested via SPLP. When this occurs, the standard is adjusted downward to the highest contaminant concentration actually tested. The reason for this is that at concentrations above those tested via SPLP, the adsorption capacity of the soil may be exceeded, and the linear relationship between sorbed concentration and leachate concentration that is assumed for Options 2 and 3 may no longer be valid. Therefore, the SPLP calculations should not be extrapolated beyond the concentrations actually tested, and the calculated remediation standard is limited to the maximum concentration actually tested. The SPLP spreadsheet automatically makes this adjustment if necessary.

7.0 ARS-MGW DEVELOPMENT USING THE SESOIL MODEL

7.1 Overview

This section describes the use of the Seasonal Soil Compartment Model (SESOIL) to develop Alternative Remediation Standards for the Migration to Ground Water Exposure Pathway (ARS-MGW). It replaces the earlier guidance titled "Using the SESOIL Transport Model to Assess the Impact to Ground Water Pathway, Revised December 2008".

Prior approval is needed from the Department before implementing the ARS-MGW that are developed using the SESOIL or SESOIL/AT123D models.

The Seasonal Soil Compartment Model (SESOIL) may be used to demonstrate that a specified existing or proposed concentration distribution of contaminant in soil will not result in future contamination of ground water above the Ground Water Remediation Standards (GWRS). This contaminant concentration distribution may then be used as an ARS-MGW. The ARS-MGW developed under this option will typically be a depth-dependent vertical concentration distribution, rather than a single number. The SEVIEW software package (ESCI, 2017) incorporates a convenient user interface for preparing and processing SESOIL model input and output.

The SESOIL model as used under this guidance may be used whether or not the ground water is currently contaminated. However, no additional ground water contamination from contaminants located in the unsaturated zone is permitted.

For low mobility contaminants (semivolatile and metal contaminants), the SESOIL model is most useful when a clean zone exists between the contaminated soil and the water table. Under this scenario, the SESOIL model may be used to show that the contaminant will not migrate to the water table even under long simulation times. Contaminants with higher mobility, such as Volatile Organic Contaminants (VOCs), will generally reach the water table during a SESOIL simulation. However, if these contaminants exhibit only minor exceedances of the SRS-MGW, they may volatilize, degrade or dilute sufficiently during contaminant transport such that ground water will not be impacted above the GWRS.

The SESOIL model predicts the contaminant leachate concentration at the bottom of the unsaturated soil zone as a function of time. Since this concentration will be diluted when the leachate mixes and combines with ground water at the water table, the SESOIL leachate concentrations are not compared directly to the GWRS. Rather, they are compared with the Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway ($\mathrm{MGW}_{\mathrm{LEACHATE}}$), which represent allowable leachate concentrations for contaminants in soil moisture at the bottom of the unsaturated zone prior to dilution into the ground water. The maximum leachate concentration predicted by the SESOIL model may not exceed the $\mathrm{MGW}_{\mathrm{LEACHATE}}$, for a given contaminant. The $\mathrm{MGW}_{\mathrm{LEACHATE}}$ standards are the GWRS multiplied by the Department's default Dilution-Attenuation Factor (*DAF*) of 20 (Table 2). An alternative $\mathrm{MGW}_{\mathrm{LEACHATE}}$ may be used if an AOC- or site-specific *DAF* is determined.

The SESOIL model assumes natural infiltration and ground water recharge occurs when simulating contaminant transport in the unsaturated zone. If the model indicates that the existing or proposed contamination concentration distribution in the unsaturated soil zone does not pose a threat to ground water, no further action for the Migration to Ground Water (MGW) pathway is required.

The following conditions apply to the use of the SESOIL model under this guidance:

- The use of this option requires that unsaturated soil contamination has been appropriately delineated.

- Capped sites may be modeled using this SESOIL model option, but the simulation must be conducted assuming no cap is present.[4] In this manner, the SESOIL model results represent a worst-case simulation scenario, and the ARS-MGW is unrestricted, whether or not a cap is present. The SESOIL model may not be used to simulate moisture infiltration through a cap, due to the difficulty in simulating moisture transport through this barrier, and because VOCs may exhibit a greater tendency to migrate downward to the water table in the vapor phase when a cap is present. The cap restricts upwards vapor movement and volatilization from the soil surface, and may result in concentration gradients that promote downward vapor movement of VOCs. SESOIL cannot simulate downward vapor movement.

- When considering capped sites, the Department's MGW capping guidance documents may be consulted as an alternative to running the SESOIL model with no cap present. These guidance documents are located at https://www.nj.gov/dep/srp/guidance/

7.2 General Guidelines for Running the SESOIL Model

- The SESOIL model simulates the transport of a specified soil concentration distribution in the unsaturated soil zone to assess whether this distribution is acceptable for the MGW exposure pathway. For this reason, the resulting ARS-MGW will typically be a depth-dependent concentration distribution, rather than a single number.

- The SESOIL model can be used in one of three ways: 1) to model an existing contaminant concentration distribution, in order to determine if existing soil contamination will result in an exceedance of the $\text{MGW}_{\text{LEACHATE}}$ concentration, 2) to model proposed contaminant concentrations that will be left behind following remediation, to determine if the proposed remediation plan is acceptable, or 3) to model a theoretical concentration distribution, such as a proposed maximum allowed concentration at each depth interval. If the theoretical concentration distribution is shown to be acceptable as a migration-to-ground water standard, then soil concentrations at a

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[4] IMPORTANT NOTE: When determining alternative remediation standards under the other guidance document that uses the SESOIL model (the SESOIL/AT123D guidance), the site may not be capped over the contaminated soil zone. See the SESOIL/AT123D guidance (Section 8) for further discussion.

particular depth interval may not exceed the modeled concentration for that particular depth. In all cases, upon determining an acceptable concentration distribution, the soil concentration on site at a particular depth interval may not exceed the modeled concentration for that particular depth.

- Contaminants need to be delineated (vertically and horizontally) to the SRS-MGW or ARS-MGW for the contaminant and AOC of interest. Examples of ARS-MGW would be those obtained from the site-specific adjustments to the Soil-Water Partition Equation (SWPE) or Synthetic Precipitation Leaching Procedure (SPLP) (for details see Sections 4 and 6 of this document). Documentation necessary for submittal of the SESOIL ARS-MGW option to the Department includes preparation of a table illustrating the concentrations measured (including non-detects and concentrations below the MGW-SRS or ARS-MGW) at the various depths (see Section 7.3(10)).

- The Department has assigned default input values for most of the parameters used in the SESOIL model. Several of these may be adjusted on an AOC- or site-specific basis, as described below. Two parameters, the contaminant concentration distribution in the unsaturated zone, and the depth to ground water, must be determined using AOC- or site-specific information.

- The SESOIL model cannot simulate contaminant transport in bedrock. When the water table is located in bedrock, SESOIL may be run assuming the water table is located at the surface of the bedrock.

- The SESOIL model is to be used only to model the uppermost unconfined aquifer beneath the zone of soil contamination. This is the aquifer of concern for the MGW pathway.

7.3 Setting up the SESOIL Model

(1) *Climate data* - Use the climate databases that are included with model software to select climate data from the weather station nearest to the site. A list of climate stations by county and municipality is presented in Table 5. The table includes latitude and longitude for the stations. These values may be entered into appropriate mapping applications such as Google® maps in order to check nearby climate station locations relative to the site location. The climate station locations are also available via a Keyhole Markup Language (KML) file on the department's remediation standards website at https://www.nj.gov/dep/srp/guidance/rs. This file may be used with any Geographic Information System software (such as Google Earth) in order to visualize climate station locations on a map.

(2) *Chemical properties* - Table 3 lists chemical properties approved by the Department for use in the model, which are taken from the NJDEP Soil Remediation Standards N.J.A.C. 7:26 D, Appendix 10. For metals and cyanide, the Henry's law constant and diffusion coefficients should be set to zero, and a high value for water solubility (e.g., 100,000 mg/L) should be entered unless the actual species and solubility of the metal are known. Degradation of contaminants may not be included except for volatile hydrocarbons. For these hydrocarbons

(which do <u>not</u> include polycyclic aromatic hydrocarbons, except for naphthalene and 2-methylnaphthalene), a one-month half-life (biodegradation rate constant of 0.023 days^{-1}) may be used in both the liquid and solid phases. Site-specific values for the soil organic carbon-water partition coefficient (K_{oc}) and the soil-water partition coefficient (K_d) may be determined and used as discussed below.

<u>Site-specific K_d values</u>: As an alternative to the standard K_{oc} and K_d lookup values, a site-specific K_d value may be developed for organic contaminants and metals using the SPLP test as described in Section 6 of this document. Refer to that section for further information on the usefulness of site-specific K_d values. A higher K_d value relative to the default value will lower the leachate concentrations in the SESOIL model and increase the time for the contaminant to reach the water table. As described in Section 6, the measured K_d values from the SPLP procedure can be averaged if they vary by less than an order of magnitude; otherwise, the lowest K_d value must be selected. The samples submitted for K_d determination using SPLP should include the highest contaminant concentration that will be modeled with SESOIL. A site-specific K_d value from the SPLP test cannot be used in SESOIL to model concentrations that are higher than those used in the SPLP test due to the potential for the adsorption capacity of the soil to be exceeded at higher concentrations than those tested. However, a K_d value from a sample that failed the SPLP test may be used when determining a site-specific K_d to use with the SESOIL model in accordance with Option 2 in Section 6.4.2 of this document. The test is being used in this case to obtain a K_d value for use in the SESOIL model, not to determine whether that sample yields an acceptable leachate concentration.

<u>Site-specific K_{oc} value for ionizable phenols:</u> A pH-dependent site-specific K_{oc} value may be developed for these contaminants using the following procedure:

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

b. Measure the soil pH for each sample using standard methods. If the pH values vary by less than one pH unit, the average pH is used (but not higher than pH 5.3). Otherwise, the highest pH measured is used (but not higher than pH 5.3).

c. Use the appropriate soil pH value to select a soil organic carbon-water partition coefficient (K_{oc}) for the contaminant from Table 4. If the soil pH is less than 4.9, use the K_{oc} for pH 4.9. If the soil pH is higher than the default value of 5.3, the K_{oc} value will be lower than its default value, which could result in a calculated ARS-MGW lower than the standard, if no other AOC- or site-specific parameters are being adjusted. The default K_{oc} should be used in this case.

Higher values for the K_{oc} than the default value will reduce contaminant leachate concentrations in the soil solution in the SESOIL model and increase the time for contaminant to reach the water table.

(3) *Soil Texture* – The SESOIL model uses the United States Department of Agriculture (USDA) soil texture classification system. Use sand as the soil texture unless an AOC- or site-specific USDA soil texture has been determined. The effect of soil texture on SESOIL model results is complex. Soil textures finer than sand may result in reduced contaminant transport rates to the ground water, thereby reducing ground water impacts. However, for VOCs, finer soil textures will also decrease the amount of contaminant that is lost to volatilization from the soil surface, which potentially <u>increases</u> ground water impacts. Therefore, in order to avoid potentially underestimating contaminant migration to ground water, use of a sand soil texture with the volatilization turned <u>off</u> is required unless an AOC- or site-specific soil texture has been determined. For VOCs, determining the soil texture allows the user to enable the volatilization process, which may substantially decrease the amount of contaminant that reaches the ground water.

To establish soil texture, collect soil cores that are representative of the variation in texture that occurs within the AOC. Cores should be collected using a direct push or split spoon sampler. The cores should be collected continuously (every two or four feet depending on the length of the sampling device) from the soil surface to the water table. Texture analysis should be conducted every two feet or for each distinct soil layer. Break points between the soil layers can be determined via visual inspection of core samples for changes in soil texture and/or appearance.

Gravel should be removed prior to determining soil texture by passing the sample through a 2 mm sieve. Soil aggregates should be crushed to pass through the sieve. The sand, silt and clay percentages should be calculated on the remaining material (the initial sample weight should be determined without the gravel). If the soil contains a large percentage of gravel (or other large particles or debris), water flow in the vadose zone may begin to exhibit characteristics similar to that of fractured bedrock material and ground water recharge may be underestimated. In this situation, use of the SESOIL model may not be appropriate. The investigator should use professional judgment to determine if the percentage of this material is too great for use of the model.

The soil texture used in the SESOIL model should be a median soil texture, such that half of the vertical soil column height should exhibit a texture coarser than or equal to the modeled soil texture, and the other half of the soil column should have a texture finer than or equal to the modeled soil texture. For example, a soil column with 10% sand, 30% loamy sand, 20% sandy loam, and 40% loam may be considered to have a sandy loam texture.

Although not commonly implemented, multiple soil texture layers may be modeled with the SESOIL model. If it is desired to use more than one soil texture layer, see Section (4), below for selection of appropriate SESOIL soil input parameters.

When running scenarios where a low permeability layer is present, an assessment should be made as to whether this layer is continuous and unfractured across the site. If field data suggest that this is the case, and an interval of saturated soil normally exists above this layer, this saturated zone may represent the water bearing zone for analysis of the Migration to Ground Water (MGW) pathway. In this case, the SESOIL model would be used to model transport down to and within this surficial aquifer, and the low permeability layer will not be part of the model. If a water bearing zone is not observed on top of the low permeability layer, the layer may be fractured or discontinuous, and preferential downward water infiltration pathways may exist around these low permeability areas. In this case, the SESOIL model should be used to simulate transport to the underlying surficial water bearing zone, and the low permeability layer should be assumed to be absent. If, however, the low permeability layer is continuous, and is also in the unsaturated zone above the water bearing zone of interest, it may be considered when determining the soil texture used in the model. It may be modeled either as a separate soil layer or factored in when determining a single median soil texture as discussed above.

For additional information on methods for determination of soil texture, see Appendix C.

(4) *SESOIL-specific soil parameters* - When using a single median soil texture (as discussed above), look up the soil parameter values for intrinsic permeability, soil pore disconnectedness index and effective porosity as recommended in the SEVIEW model documentation. These tables are reproduced below. The soil bulk density only has a minor effect on model results and should be set to 1.5 g/cm^3. The cation exchange capacity is not used in the model and should be set to zero. The Freundlich exponent should be set to one, since values for this parameter are not generally available. The soil pH is not used and therefore may be set to 7.0 for all layers. When using a single median soil texture, the same soil properties are to be used for all soil layers in the SESOIL model, with the exception of percent soil organic carbon content, which may be varied (see below).

When using more than one type of soil texture, enter the appropriate intrinsic permeability for each soil layer. SESOIL calculates a weighted mean intrinsic permeability for the entire soil column in order to calculate soil moisture movement, in effect determining a weighted mean soil texture. The following formula is used:

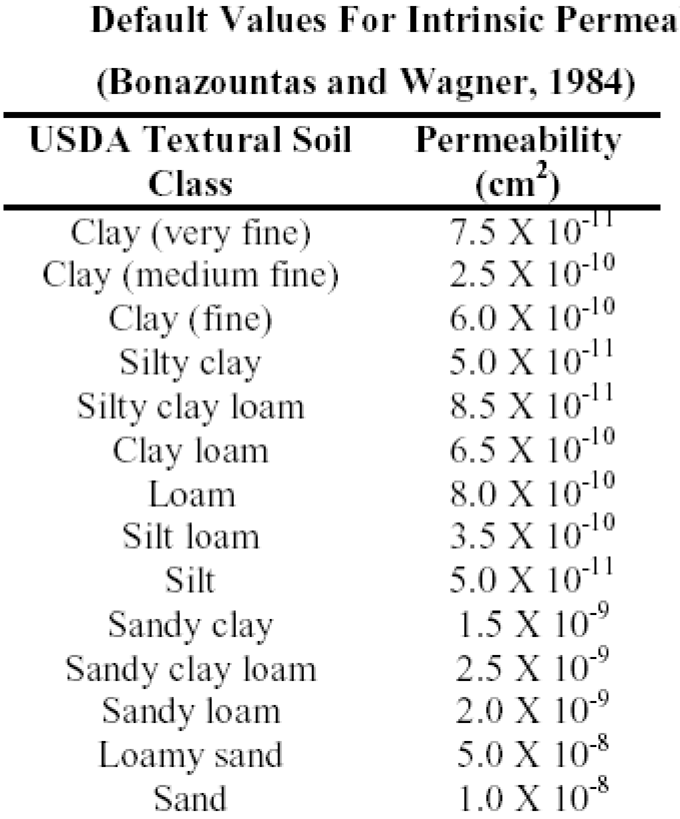
$$k_z = \frac{d}{\sum_{i=1}^{n} \frac{d_i}{k_i}} \qquad \text{Equation (10)}$$

where

k_z = depth-weighted average permeability (cm^2)
k_i = permeability for layer i (cm^2)
d = depth from soil surface to water table (cm)
d_i = thickness of layer i (cm)

The SESOIL model only accepts a single value for disconnectedness index and effective porosity. To determine these values, one of two approaches may be used. The first approach is to determine the depth-weighted intrinsic permeability that SESOIL will use in the simulation, and look up the "effective" soil texture corresponding to that permeability using the table below. That soil texture can then be used to look up the other two parameters using the other two tables.

In this manner, the three soil parameters will correspond to the same effective soil texture. The second approach is to calculate weighted mean values for the effective porosity and disconnectedness index using the formula above, substituting the disconnectedness index and effective porosity for k_i in Equation (10) above. Caution should be utilized when using these procedures, especially with widely disparate soil types. If the two approaches yield substantially different values for the soil parameters, they may be averaged, but professional judgment should be exercised as to the reasonableness of the modeled results, and to whether it is advisable to simulate multiple soil texture layers or to use the SESOIL model when this condition exists at the AOC or site.



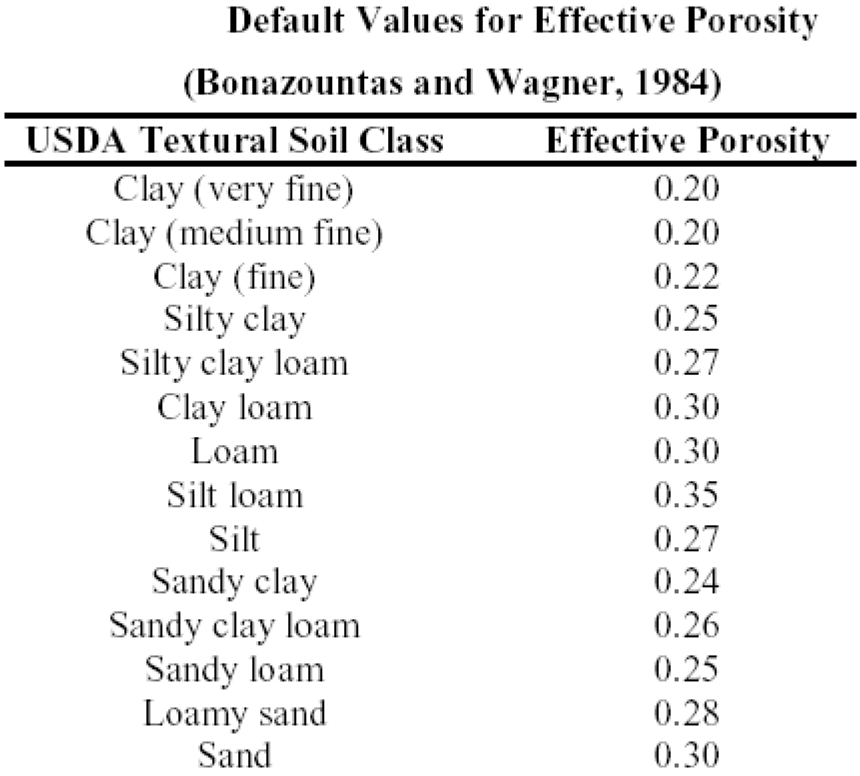
Default Values For Intrinsic Permeability

(Bonazountas and Wagner, 1984)

USDA Textural Soil Class	Permeability (cm^2)
Clay (very fine)	7.5×10^{-11}
Clay (medium fine)	2.5×10^{-10}
Clay (fine)	6.0×10^{-10}
Silty clay	5.0×10^{-11}
Silty clay loam	8.5×10^{-11}
Clay loam	6.5×10^{-10}
Loam	8.0×10^{-10}
Silt loam	3.5×10^{-10}
Silt	5.0×10^{-11}
Sandy clay	1.5×10^{-9}
Sandy clay loam	2.5×10^{-9}
Sandy loam	2.0×10^{-9}
Loamy sand	5.0×10^{-8}
Sand	1.0×10^{-8}

Default Values for Soil Pore Disconnectedness Index (Bonazountas and Wagner, 1984)

USDA Textural Soil Class	Soil Pore Disconnectedness Index
Clay (very fine)	12
Clay (medium fine)	12
Clay (fine)	12
Silty clay	12
Silty clay loam	10
Clay loam	7.5
Loam	6.5
Silt loam	5.5
Silt	12
Sandy clay	6
Sandy clay loam	4
Sandy loam	4
Loamy sand	3.9
Sand	3.7



Default Values for Effective Porosity

(Bonazountas and Wagner, 1984)

USDA Textural Soil Class	Effective Porosity
Clay (very fine)	0.20
Clay (medium fine)	0.20
Clay (fine)	0.22
Silty clay	0.25
Silty clay loam	0.27
Clay loam	0.30
Loam	0.30
Silt loam	0.35
Silt	0.27
Sandy clay	0.24
Sandy clay loam	0.26
Sandy loam	0.25
Loamy sand	0.28
Sand	0.30

In addition to the indirect determination of the SESOIL soil parameters from soil texture using the procedures described above, it is possible to determine the intrinsic permeability, disconnectedness index and the effective porosity directly through the use of appropriate laboratory tests (see Appendix D), although these analyses may be costly and time-consuming.

(5) *Percent soil organic carbon* - The default organic carbon content is 0.2 percent (fraction organic carbon of 0.002). Site-specific adjustment may be made to this parameter using soil samples from the AOC or site. Higher organic carbon contents result in lower leachate concentrations for organic contaminants in the SESOIL model, and longer transport times to ground water. 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. Either a representative percent organic carbon value may be assigned to the entire soil column, or up to four separate values may be used for different depth intervals in the soil column (maximum of four depth intervals). A separate soil layer (not sublayer) must be used in the SESOIL model for each organic carbon value. Since organic carbon content often decreases with depth, and since soil leachate concentrations for organic contaminants are affected by the organic carbon content of the soil, it may be advantageous in some cases to have separate values for surface and subsurface soil layers, depending on the location of the contaminant. If multiple vertical layers with different organic carbon values are to be used, organic carbon is determined separately for each layer. The following procedure is used to determine an AOC- or site-specific percent organic carbon value:

1. Collect a minimum of 3 soil samples from locations that are representative of the AOC or site and the vadose zone underlying the contamination. 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. The sample results are entered into the NJDEP fraction organic carbon spreadsheet in the MGW calculator located at https://www.nj.gov/dep/srp/guidance/ which determines the appropriate organic carbon content value to use in SESOIL.

3. Use the average percent soil organic carbon content (but not less than the default value of 0.2%) in the SESOIL model (percent organic carbon = fraction organic carbon x 100, or mg/kg organic carbon x 10,000). If the values vary by more than an order of magnitude, they may not be averaged. In this case, the lowest percent organic carbon content (but not less than the default value of 0.2%) is used in the model, in order to obtain a conservative estimate of the maximum concentration of contaminant in the leachate. (NOTE: This is in contrast to the SESOIL/AT123D guidance (Section 8), where the highest organic carbon value is used when the samples are not averaged, in order to obtain a conservative estimate of the time required for natural attenuation of contaminant.)

   The investigator may consider whether it is advantageous to run the SESOIL model with multiple vertical soil layers, if organic carbon contents vary by more than an order of magnitude due to substantial vertical variation in this parameter. This may result in each layer exhibiting a different and more uniform organic carbon content (less than an order of magnitude variation). A minimum of three soil samples should be used to determine the organic carbon content of each layer.

Additional soil samples should be collected when soil types vary across the AOC or for larger AOCs or across the site.

When entering variable organic carbon contents, the surface layer organic carbon content is entered directly (under the “Soil” tab in the SEVIEW model), and the values for subsequent layers are entered as ratios relative to the surface layer (under the “Application” tab, “Ratios” subtab) as described in the SEVIEW model documentation.

(6) *Sediment washload* - The sediment washload (surface runoff) option is not used unless adequate site-specific information is available for determination of the necessary input parameters.

(7) *Depth to water table* – When the SESOIL model is used, the vadose zone must be divided into layers and/or sublayers from the soil surface to the water table. For this reason, the depth to the water table must be known and documented. The average water table depth should be used if adequate data are available. If data are inadequate to determine the average water table depth, the depth determined during site investigation/delineation may be used.

(8) *Sublayer thickness* - When dividing the vadose zone into layers/sublayers, one foot soil sublayers are recommended to be used with the model, and should cover the entire soil column from the soil surface to the water table. Sublayer thicknesses greater than 1 foot will dilute calculated leachate concentrations in those sublayers and are generally not accepted. Sublayer thicknesses less than one foot may be used, but this will result in somewhat higher leachate concentrations reported by the model for the thinner sublayers in the vadose zone. The SESOIL model allows a maximum of 40 sublayers. If the depth to water table is greater than 40 feet, 40 sublayers are used, with the total depth evenly divided over the layers. When setting the number of sublayers, "instantaneous release" of contaminant should be selected on this screen, however this selection does not affect the applied contaminant loadings as explained in this technical guidance.

(9) *Source Size* – The Source Size in the model should be set equal to the size of the AOC. It is set on the SEVIEW project map and on the "Source Size" tab.

(10) *Soil contamination concentrations* - Prepare a table showing results from all soil borings for the AOC arranged in columns, with the SESOIL modeled concentrations in the final column, as illustrated below. The concentrations for the various borings should be the existing concentrations in the soil (if no remediation is proposed), or concentrations that are proposed to be left behind after remediation.

Soil Boring Table/SESOIL model table
Site-specific screening level = 30 mg/kg

Depth Interval (sublayer interval) (ft)	Boring #1	Boring #2	Boring #3	SESOIL model concentrations
0-1	-	-	-	74.1
1-2	-	74.1	-	74.1
2-3	-	-	-	487
3-4	487	-	-	487
4-5	-	-	-	487
5-6	-	nd	-	0
6-7	-	-	-	0
7-8	-	1.2	-	0
8-9	-	-	-	0
9-10	-	27	-	0
10-11	89.5	-	-	89.5
11-12	-	-	283	283
12-13	-	-	669	669
13-14	-	-	-	669
14-15	-	-	226	226
15-16	-	-	-	226
16-17	-	nd	183	183
17-18	342	-	-	342
18-19	-	-	-	342

- = not determined
nd = not detected

Since the SESOIL model is one-dimensional in the unsaturated zone (vertical only), the results from the various soil borings within the AOC must be compiled into one profile for modeling purposes. When entering contaminant concentrations into the SESOIL model (labeled a SESOIL source in SEVIEW 7), a value must be entered at each one-foot depth interval (i.e. for each sublayer) between the soil surface and the water table. To fill in the SESOIL modeling column, the highest concentration observed from the various soil borings for a particular depth interval should be entered in the SESOIL model column. If this concentration is below the SRS-MGW or the ARS-MGW (e.g. from SPLP results), zero may be entered in the SESOIL column for that depth interval. Note in the above table, that the 1.2 and 27 mg/kg results are below the screening level. Generally, there will be depth intervals for which no sample results are available from any boring (as illustrated in above table). To fill in these values, inspect the existing concentrations in the SESOIL model column for the vertically closest soil sample results above and below the depth range of interest. The higher of the two results should be used to fill in the missing depth interval. As an example from the above, notice that 487 mg/kg is determined to be the appropriate value for the 2-3 and 4-5 foot depth intervals. If contamination above the SRS-MGW or ARS-MGW does not extend to the soil surface or the water table, zeros may be entered above and below the delineated extent of contamination. Note that if delineation does not include samples above or below the boundaries of the contamination, this may result in modeled contamination extending to the water table or to the soil surface, as illustrated in the above example. One exception is for a subsurface discharge at a known depth, such as from an underground storage tank. In this case, contamination does not need to be delineated above the discharge point.

(11) *Ratios* - Except for the soil organic carbon ratio, all other soil property ratios between soil layers should be set to "1", since layer-specific values for these parameters are not generally available. The soil organic carbon ratios may be varied as discussed above if separate organic carbon contents are determined for some or all of the soil layers.

(12) *Layer Parameters* - The contaminant load parameters POLIN, TRANS, LIG, ISRM and ASL must be set to zero, since they are not used. The VOLF parameter is set to zero (no volatilization) unless site-specific soil texture is determined, in which case it is set to one (volatilization allowed). When setting the VOLF factor, check that the factor is set for each soil layer, for each month, and for years 1 and 2 (year 2 values are used for the remainder of the SESOIL model run). The reason volatilization is not allowed unless the site-specific soil texture is determined is that volatilization to the atmosphere may be overestimated when using the default soil texture (sand).

7.4 Using the SESOIL Model Results to Determine Compliance with the Migration to Ground Water Pathway

Print out all summary output pages provided by the model software.

Compare the time-dependent concentration of the contaminant in the soil moisture in the deepest soil layer (the leachate concentration) to the $\mathrm{MGW}_{\mathrm{LEACHATE}}$, to determine compliance with Department requirements. Leachate concentrations from the SESOIL model may be found in the "SESOIL POLLUTANT CYCLE REPORT" generated by the SEVIEW software. A time-dependent leachate concentration graph is shown, and the maximum leachate concentration for the model run is printed. The $\mathrm{MGW}_{\mathrm{LEACHATE}}$ values to compare with the model results are listed in Table 2. If the model predicts that the leachate concentration at the bottom of the soil column will not exceed the $\mathrm{MGW}_{\mathrm{LEACHATE}}$, then the soil contaminant concentration distribution used in the model (either existing concentration distribution or proposed concentration distribution after remediation) will not pose a threat to ground water and may be used as an ARS-MGW. Acceptable ground water conditions are illustrated in Figures (1), (2) and (3) below.

For mobile contaminants, the peak predicted concentration in the soil moisture at the bottom of the unsaturated zone (the leachate concentration) should not exceed the MGWLEACHATE, (Figure 1).

For contaminants that are immobile or exhibit low mobility, the SESOIL results should indicate a leachate concentration that does not exceed the MGWLEACHATE, for at least 100 years. This could result from a contaminant reaching the water table but not exceeding the MGWLEACHATE, (as shown in Figure 2), or from a contaminant not reaching the water table at all (as shown in Figure 3 on the contaminant depth plot from a SESOIL POLLUTANT CYCLE REPORT). The Department has decided that protection of ground water for a 100-year time period is acceptable policy, since low mobility contaminants would be expected to become irreversibly adsorbed or degraded during this time period.

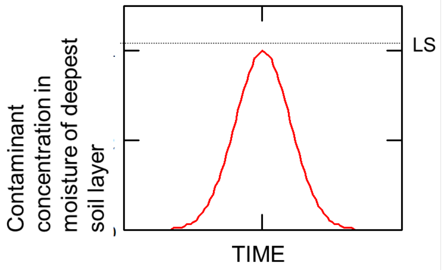


Figure 1

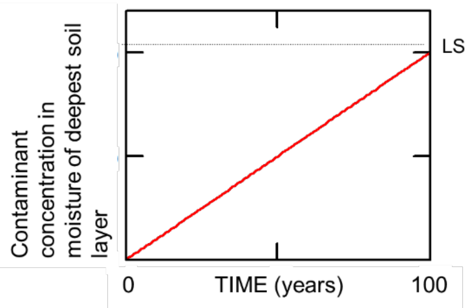


Figure 2

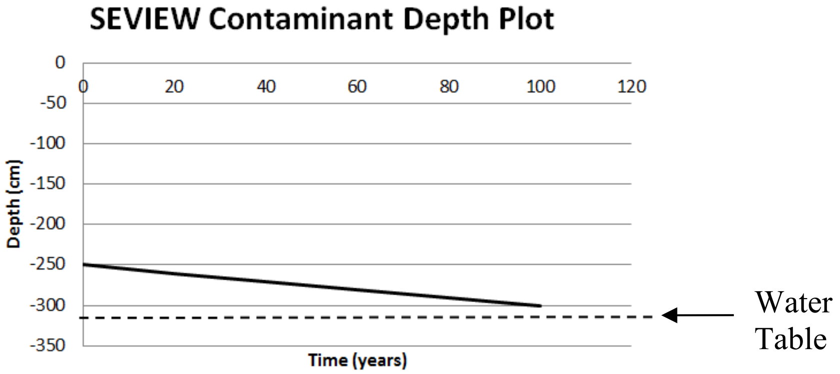


Figure 3

If SESOIL predicts that the leachate concentration will exceed the MGWLEACHATE, then the model may be rerun with a modified concentration distribution to identify an appropriate distribution of the contaminant in soil that will not result in an exceedance of the MGWLEACHATE. This identified soil concentration distribution will then be acceptable as the ARS-MGW.

Compliance with an approved ARS-MGW developed using the SESOIL model means that contaminant concentrations in the soil at the site as a function of depth may not exceed the modeled and approved depth-dependent concentration distribution. If necessary, the site must be remediated such that the final concentrations left at the site are in compliance with the approved depth-dependent concentration distribution.

7.5 SESOIL Model Reporting Requirements

The modeled SESOIL concentration distribution as a function of depth that yields acceptable results becomes the ARS-MGW. When completing the Remediation Standard Notification Spreadsheet for the Alternative Remediation Standard Form, “Alternative” is selected as the type of standard, “range” is entered as the proposed remediation standard, and the columns containing the depth ranges and the modeled concentrations from the SESOIL model table should be attached to the spreadsheet.

Submit the following information for the SESOIL runs to the Department:

1. A separate report (or separate section in a larger report such as RIR, RAR) should be prepared with a narrative of the model simulation. Items 2-6 below should also be included in this report.

2. The SESOIL model table (as described in Section 7.3. (10) above) should be submitted showing the measured contaminant concentrations as a function of depth and the modeled SESOIL concentrations. The modeled SESOIL concentration distribution as a function of depth that yields acceptable results becomes the ARS-MGW.

3. Supporting documentation for the depth to ground water should be submitted.

4. The values of all input parameters must be submitted and supporting information for any input parameters for which site-specific values are used must be supplied. Procedures for determining site-specific values for input parameters are described in Section 7.3 above.

5. All output summaries as provided by the model software for each contaminant. When using the SEVIEW modeling software, there are four reports: the CLIMATE report, the HYDROLOGIC CYCLE REPORT, the PROFILE AND LOAD REPORT, and the POLLUTANT CYCLE REPORT.

6. Graphical output of the leachate concentration as a function of time is preferred. The SEVIEW POLLUTANT CYCLE REPORT presents the output in this manner.

7.6 Additional Considerations

1. Compliance averaging of soil concentrations is not applicable to SESOIL modeling at this time.

2. The SESOIL model can be used in three ways. First, an existing concentration distribution may be modeled <u>before</u> remediation, to determine if the impact-to-ground water pathway is of concern. Second, the model can be used to model proposed

contaminant concentrations that will be left behind after remediation, to determine if the proposed remediation plan is acceptable. Third, the model can be used to model a theoretical concentration distribution, such as a proposed maximum allowed concentration at each depth interval. If a theoretical concentration distribution is shown to be acceptable as an impact-to-ground water standard, then soil concentrations at a particular depth interval may not exceed the modeled concentration for that particular depth.

3. The SESOIL option results in an allowed vertical contaminant distribution in soil, rather than a discrete number. When using the SESOIL option, a soil concentration is entered for each 1-foot interval between the soil surface and the water table. This concentration may be different for each depth interval. The entered concentration distribution may be either existing concentrations or proposed concentrations to be left behind after remediation. If this distribution yields acceptable SESOIL results (specifically, the leachate criterion is not exceeded), the distribution of chemical concentrations in the soil is acceptable as an ARS-MGW.

4. The SESOIL model alone can be used to determine unsaturated zone soil remediation standards even if the ground water is already contaminated. It is a simpler approach than using the combined SESOIL/AT-123D model. However, it must be used to show no additional ground water contamination will occur from vadose zone contamination. The modeling results are to only address the MGW pathway in soil. The contaminated ground water must be evaluated separately.

5. Contamination that extends to the water table:

    a. The SESOIL model is generally not useful when contamination extends all the way to the water table, since no transport is required to reach the ground water. When contamination above the SRS-MGW or ARS-MGW exists at the bottom of the water table, leachate concentrations in the SESOIL model will quickly exceed applicable $MGW_{LEACHATE}$ criteria. Therefore, this scenario will generally not pass the SESOIL model.

       Exceptions: 1) BTEX compounds and other volatile hydrocarbons, for which a one-month degradation half-life may be used, are often worthwhile modeling with this scenario. Since the SESOIL model begins contaminant transport in the middle of a soil sublayer, the contaminant must travel a minimum of 6 inches (in a 1-foot sublayer) in order to reach the water table. This may result in adequate degradation of contaminant before reaching the water table in order to pass the SESOIL model if the exceedances at the bottom of the vadose zone are not large, The NJDEP allows SESOIL modeling of this scenario. 2) Small exceedances of halogenated and other VOCs at the bottom of the water table may pass SESOIL if soil texture is determined and volatilization is turned on, since some volatilization of contaminant will occur while it is transporting through the bottom half of the sublayer at the water table. However, because degradation may not be used for these VOCs, anything greater than minor exceedances of these contaminants near the water table will usually result in leachate concentrations at the bottom of the vadose zone greater than $MGW_{LEACHATE}$.

When modeling these scenarios, the bottom sublayer thickness may not be increased to more than one foot in order to cause more degradation and volatilization to occur.

b. When modeling highly adsorbed contaminants that extend to the water table, it may appear that these contaminants do not reach the water table even though they are in direct contact with the ground water. This occurs because the SESOIL model begins contaminant transport in the middle of a soil sublayer, and the contaminant may not travel to the bottom of the sublayer during a 100-year model run (does not migrate 6 inches when using a 1-foot sublayer). This is an anomalous result, because contaminants at the water table are already in direct contact with the ground water. This can be illustrated by using a thinner bottom sublayer. If a thin enough sublayer is used, the contaminant will migrate through it during the model run and a leachate concentration above $MGW_{LEACHATE}$ will be demonstrated, when initial concentrations near the water table are above the SRS-MGW or ARS-MGW. Therefore, it is generally not advisable to use the SESOIL model with this scenario. If exceedances of contaminants in the vadose zone extend to the water table and no ground water exceedances are observed, then SPLP testing (section 6 of this document) will likely determine an alternative standard (ARS-MGW) that indicate that the soil zone immediately above the water table is actually not contaminated. Alternatively, if the highest concentrations of contaminant in the vadose zone are located at or just above the water table, and the ground water is uncontaminated, section 10 of this guidance document provides a mechanism for demonstrating that the impact to ground water pathway has been addressed.

8.0 ARS-MGW DEVELOPMENT USING THE COMBINED SESOIL/AT123D MODEL FOR MOBILE CONTAMINANTS

8.1 Overview

This section describes the use of the combined Seasonal Soil Compartment Model/Analytical Transient One-, Two-, and Three-Dimensional Model (SESOIL/AT123D) to develop Migration to Ground Water Alternative Remediation Standards (ARS-MGW). This section replaces the earlier 2014 guidance document (Version 2.1) entitled "Using the Combined SESOIL/AT123D Models to Develop Site-Specific Impact to Ground Water Soil Remediation Standards for Mobile Contaminants".

Prior approval is needed from the Department before implementing ARS-MGW that are developed using this option.

Contaminated sites with mobile contaminants frequently contain sources of contamination both in the unsaturated soil zone and the ground water. In these cases, a ground water Classification Exception Area (CEA) is often established to allow time for remediation or attenuation of the ground water contamination. Since the SRS-MGW are calculated to immediately protect the ground water against any degradation above the Ground Water Remediation Standards (GWRS), they are more protective than necessary when a ground water CEA is in effect. This section explains how ARS-MGW may be developed for mobile contaminants when both the vadose zone and ground water are contaminated with the contaminant of concern. The ARS-MGW developed under this option will typically be a depth-dependent concentration distribution, rather than a single number. Ground water concentrations are permitted to exceed the GWRS until the expiration of the CEA. The SEVIEW 7 software package (ESCI 2017) contains a combined SESOIL/AT123D model that may be used to simulate the fate of mobile contaminants that are present in both soil and ground water. The model may be used to show that existing contamination in the saturated and unsaturated zone will be attenuated prior to the expiration of the existing CEA at the site. The model must show that ground water concentrations are predicted to fall below the applicable standards at the end of the CEA time period, and that the predicted size of the ground water plume does not become larger than its currently estimated extent. The model prediction must be confirmed by ground water sampling before case closure.

This option will primarily be useful for mobile contaminants (e.g. chlorinated solvents), since low mobility contaminants will not be transported out of the soil/ground water system within a reasonable period of time. Sites with coarser-grained soils in the unsaturated zone, such as sand and sandy loam soils, will also provide for more rapid contaminant transport and attenuation. Finally, attenuation is more likely to be effective when contaminant concentrations in the unsaturated zone are relatively low.

The following conditions apply to the use of the SESOIL/AT123D model under this guidance:

- Ground water quality is currently degraded by contamination migrating from soil at the Area of Concern (AOC).

- A Ground Water Classification Exception Area (CEA) has been established for the ground water plume.

- The contaminant is present in both the ground water and vadose zone at concentrations above the applicable standards for the two media.

- When using the SESOIL/AT123D option, the AOC may not be capped, either currently or prior to the expiration of the CEA, with an impervious or low permeability cap. The SESOIL/AT123D model relies on infiltration, ground water recharge and volatilization within the AOC in order to attenuate contaminants. These processes are inhibited when a site is capped. Any cap used on site must allow natural infiltration of precipitation and volatilization of subsurface contaminant equivalent to what would occur if no cap was present. This is best accomplished by a soil cap that exhibits infiltration properties that are equal to or greater than the soil naturally present on site. Once the CEA is lifted, conventional caps may be used on the site.

- A receptor evaluation must be conducted. Impacts identified through performance of a Receptor Evaluation must have been addressed in accordance with N.J.A.C. 7:26E-1.12 through 1.16.

- At a minimum, remediation of highly contaminated soil should be performed pursuant to the Technical Requirements for Site Remediation; specifically (1) N.J.A.C. 7:26E-1.10(b), which specifies LNAPL reporting requirements and identifies regulatory timeframes for the initiation of LNAPL recovery, LNAPL delineation, and implementation of interim remedial actions (to the extent practicable), and (2) N.J.A.C. 7:26E-5.1(e), which states that free and residual product must be treated or removed to the extent practicable, or contained when treatment or removal is not practicable. In the vadose zone, NAPL may occur when contaminant concentrations are above the Soil Saturation Limit (C_{sat}); C_{sat} values for contaminants are found in Table 1. For contaminants that are denser than water, N.J.A.C. 7:26E-2.1(a)14i states that NAPL may be present in ground water when concentrations are greater than one percent of their water solubility.

- In accordance with N.J.A.C. 7:26C-7.9(f), ground water monitoring must demonstrate that contaminant concentrations are below the applicable standards in order to achieve site closure.

- Use of this option requires that soil and ground water contamination has been appropriately delineated, an adequate ground water monitoring network is installed, and long-term monitoring is performed in accordance with the requirements of the AOC- or site-specific remedial action permit for ground water.

8.2 General Guidelines for Running the SESOIL/AT123D Model

- The SESOIL/AT123D model simulates the transport of a specified soil concentration distribution in the unsaturated soil zone to assess whether this distribution is acceptable for the MGW pathway. For this reason, the resulting ARS-MGW will typically be a depth-dependent concentration distribution, rather than a single number.

- The SESOIL/AT123D model can be used in one of three ways: 1) to model an existing contaminant concentration distribution, to determine if the existing soil contamination is of concern for the MGW pathway, 2) to model proposed contaminant concentrations that will be left behind after proposed remediation, to determine if the proposed remediation plan is acceptable, or 3) to model a theoretical concentration distribution, such as a proposed maximum allowed concentration at each depth interval. If the theoretical concentration distribution is shown to be acceptable as a migration-to-ground water standard, then soil concentrations at a particular depth interval may not exceed the modeled concentration for that particular depth. In all cases, upon determining an acceptable concentration distribution, the soil concentration on site at a particular depth interval may not exceed the modeled concentration for that particular depth interval. Refer to section 8.3.11 for further details.

- Contaminants need to be delineated (vertically and horizontally) to the SRS-MGW or ARS-MGW for the contaminant and AOC of interest. Examples of ARS-MGW would be those derived from AOC- or site-specific adjustments to the Soil-Water Partition Equation or alternative soil standards derived from the Synthetic Precipitation Leaching Procedure (SPLP) (for details see Sections 4 and 6 respectively). A table should be prepared that shows the concentrations measured (including non-detects and concentrations below the standard) at the various depths (Sections 8.3, item (11), below).

- The ground water plume must be delineated as described in the Technical Regulations at 7:26E-4.3, the Department's Ground Water Technical Guidance Document for Site Investigation, Remedial Investigation and Remedial Action Performance Monitoring: (https://www.nj.gov/dep/srp/guidance/#pa_si_ri_gw), and the Monitored Natural Attenuation Technical Guidance (https://www.nj.gov/dep/srp/guidance/#mon_nat_atten).

- Since the SESOIL/AT123D model run time is to be matched with the estimated time for ground water remediation to be completed, the duration of the CEA for the site needs to be estimated and will form the basis for the maximum time frame for SESOIL/AT123D modeling. If the duration of the CEA is indefinite, a 30-year time frame shall be used for modeling. The model runtime is set in the SEVIEW 7 toolbar. The number of months for the model run is also entered in the SESOIL source AT123D "Load" tab (see instructions below).

- The percent soil organic carbon content of both the vadose zone and the contaminated aquifer must be determined when using this guidance, and the soil texture must be determined in the vadose zone. The default values for these parameters (used in calculating the SRS-MGW values, as explained in Section 4: Soil-Water Partition Equation), were designed to estimate predicted concentrations of a contaminant in ground water. In contrast, the purpose of the SESOIL/AT123D option is to estimate the time required for attenuation of a contaminant to occur via transport to and through the ground water plume. Therefore, the default values for soil texture and organic carbon content are not appropriate for this option. Instructions for the determination of these two parameters are provided in Section 8.3.

- The SESOIL/AT123D model cannot simulate contaminant transport in bedrock or in a confined aquifer. When multiple aquifers are contaminated from releases from the subject AOC or site, the SESOIL/AT123D model may be used only to model the uppermost unconfined aquifer beneath the zone of soil contamination.

8.3 Setting up the SESOIL Model

(1) *Adding a contamination source* - The soil contamination source (AOC) for the site should be set up on the SEVIEW 7 project map by adding a SESOIL source, dragging it to the proper location, and adjusting it to the appropriate size (x and y dimensions) in the "Source size" tab.

(2) *Climate data* - Use the climate databases that are included with model software to select climate data from the weather station nearest to the site. A list of climate stations by county and municipality is presented in Table 5. The table includes latitude and longitude for the stations. These values may be entered into appropriate mapping applications such as Google® maps in order to check nearby climate station locations relative to the site location. The climate station locations are also available via a Keyhole Markup Language (KML) file on the department's remediation standards website at https://www.nj.gov/dep/srp/guidance/rs/. This file may be used with any Geographic Information System software (such as Google Earth®) in order to visualize climate station locations on a map.

(3) *Chemical properties* - Table 3 lists chemical properties approved by the Department for use in the model. For metals and cyanide, the Henry's law constant and diffusion coefficients should be set to zero, and a high value for water solubility (e.g., 100,000 mg/L) should be entered unless the actual species and solubility of the metal are known. Degradation of contaminants may not be included except for volatile hydrocarbons. For these hydrocarbons (which do not include polycyclic aromatic hydrocarbons, except for naphthalene and 2-methylnaphthalene), a one-month half-life (biodegradation rate constant of 0.023 days^{-1}) may be used in both the liquid and solid phases. Site-specific values for the soil organic carbon – water partition coefficient (K_{oc}) and the soil-water partition coefficient (K_d) may be determined and used as discussed below.

Site-specific K_d values: As an alternative to the standard K_{oc} and K_d lookup values, a site-specific K_d value may be developed for organic contaminants and metals using the SPLP test (Section 6 of this document). As described in that section, the measured K_d values can be averaged if they vary by less than an order of magnitude; otherwise, the highest K_d value must be selected (as opposed to lowest K_d when using the SESOIL model alone). This will allow for maximum attenuation time. The samples submitted for K_d determination using SPLP should include the highest contaminant concentration that will be modeled with SESOIL/AT123D. A site-specific K_d value from the SPLP test cannot be used in SESOIL to model concentrations that are higher than those used in the SPLP test due to the potential for the adsorption capacity of the soil to be exceeded at higher concentrations than those tested. However, a K_d value from a sample that fails the SPLP test may be used when determining a site-specific K_d to use with the SESOIL model. The test is being used in this case to obtain a K_d for use in the SESOIL model, not to determine whether that sample yields an acceptable leachate concentration.

Site-specific K_{oc} value for ionizable phenols: A pH-dependent site-specific K_{oc} value may be developed for these contaminants using the following procedure:

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

b. Measure the soil pH for each sample using standard methods. If the pH values vary by less than 1 pH unit, the average pH is used (but not less than pH 5.3). Otherwise the lowest pH measured is used (but not less than pH 5.3).

c. Use the appropriate soil pH value to select a soil organic carbon-water partition coefficient (K_{oc}) for the contaminant from Table 4. If the soil pH is less than pH 5.3, use the K_{oc} for pH 5.3. If the pH is greater than 8.0, use the K_{oc} for pH 8.0.

NOTE: Steps b. and c. above are different than the corresponding steps for using the SESOIL model alone (Section 7). This is because of the different objectives of the two options (see Section 3). For application of the SESOIL/AT123D option, when there is a large variability in measured pH values, the *lowest* pH is used to obtain a conservative (high) K_{oc} for estimating *maximum attenuation time.* For application of the SESOIL-alone option (Section 7), when there is a large variability in measured pH values the, *highest* is used to obtain a conservative (low) K_{oc} for estimating *maximum leachate concentration*. However, in either case, site-specific K_{oc} values are not used if they are more conservative than the specified default values.

(4) *Soil Texture* - The SESOIL model uses the United States Department of Agriculture (USDA) soil texture classification system. Determine the appropriate USDA soil texture for the AOC. To establish soil texture, collect soil cores that are representative of the variation in texture that occurs within the AOC. Cores should be collected using a direct push sampler, or split spoon. The cores should be collected continuously (every two or four feet depending on the length of the sampling device) from the soil surface to the water table. Texture analysis should be conducted every two feet or for each distinct soil layer. Break points between the soil layers can be determined via visual inspection of core samples for changes in soil texture and/or appearance.

Gravel should be removed prior to determining soil texture by passing the sample through a 2 mm sieve. Soil aggregates should be crushed to pass through the sieve. The sand, silt and clay percentages should be calculated on the remaining material (the initial sample weight should be determined without the gravel). If the soil contains a large percentage of gravel (or other large particles or debris), water flow in the vadose zone may begin to exhibit characteristics similar to that of fractured bedrock material and ground water recharge may be underestimated. In this situation, use of the SESOIL/AT123D model may not be appropriate. The investigator should use professional judgment to determine if the percentage of this material is too great for use of the model.

The soil texture used in the SESOIL model should be a median soil texture, such that half of the vertical soil column height should exhibit a texture coarser than or equal to the modeled soil texture, and the other half of the soil column should have a texture finer than or equal to the modeled soil texture. For example, a soil column with 10% sand, 30% loamy sand, 20% sandy loam, and 40% loam may be considered to have a sandy loam texture**.**

Although not commonly implemented, multiple soil texture layers may be modeled with the SESOIL model. If it is desired to use more than one soil texture layer, see item (5) below for selection of appropriate SESOIL soil input parameters.

When running scenarios where a low permeability layer is present, an assessment should be made as to whether this layer is continuous and unfractured across the site. If field data suggest that this is the case, and an interval of saturated soil normally exists above this layer, this saturated zone may represent the water bearing zone for analysis of the Migration to Ground Water (MGW) pathway. In this case, the SESOIL/AT123D model would be used to model transport down to and within this surficial aquifer, and the low permeability layer will not be part of the unsaturated zone portion of the model. If a water bearing zone is not observed on top of the low permeability layer, the layer may be fractured or discontinuous, and preferential downward water infiltration pathways may exist around these low permeability areas. In this case, the SESOIL/AT123D model should be used to simulate transport to the underlying surficial water bearing zone, and the low permeability layer should be assumed to be absent. If, however, the low permeability layer is continuous, and is also in the unsaturated zone above the water bearing zone of interest, it may be considered when determining the soil texture used in the model. It may be modeled either as a separate soil layer or factored in when determining a single median soil texture as discussed above.

For additional information on methods for determination of soil texture, see Appendix C.

(5) *SESOIL-specific soil parameters* - When using a single median soil texture (as discussed above), look up the soil parameter values for intrinsic permeability, soil pore disconnectedness index and effective porosity as recommended in the SEVIEW model documentation. These tables are reproduced below. The soil bulk density has only a minor effect on model results and should be set to 1.5 g cm^3. The cation exchange capacity is not used in the model and should be set to zero. The Freundlich exponent should be set to one since values for this parameter are not generally available. The soil pH is not used and therefore may be set to 7.0 for all layers. When using a single median soil texture, the same soil properties are to be used for all soil layers in the SESOIL model, with the exception of percent soil organic carbon content, which may be varied (see below).

When using more than one type of soil texture, enter the appropriate intrinsic permeability for each soil layer. SESOIL calculates a weighted mean intrinsic permeability for the entire soil column in order to calculate soil moisture movement, in effect determining a weighted mean soil texture. The following formula is used:

$$k_z = \frac{d}{\sum_{i=1}^{n} \frac{d_i}{k_i}}$$ Equation (11)

where

k_z = depth-weighted average permeability (cm^2)
k_i = permeability for layer i (cm^2)
d = depth from soil surface to water table (cm)
d_i = thickness of layer i (cm)

The SESOIL model accepts only a single value for the disconnectedness index and effective porosity. To determine these values, one of two approaches may be used. The first approach is to determine the depth-weighted intrinsic permeability that SESOIL will use in the simulation, and look up the "effective" soil texture corresponding to that permeability using the table below. That soil texture can then be used to look up the other two parameters using the other two tables. In this manner, the three soil parameters will correspond to the same effective soil texture. The second approach is to calculate weighted mean values for the effective porosity and disconnectedness index using the formula above, substituting the disconnectedness index and effective porosity for *k*. Caution should be utilized when using these procedures, especially with widely disparate soil types. If the two approaches yield substantially different values for the soil parameters, they may be averaged, but professional judgment should be exercised as to the reasonableness of the modeled results, and to whether it is advisable to simulate multiple soil texture layers or to use the SESOIL/AT123D model when this condition exists at the AOC.

Default Values For Intrinsic Permeability

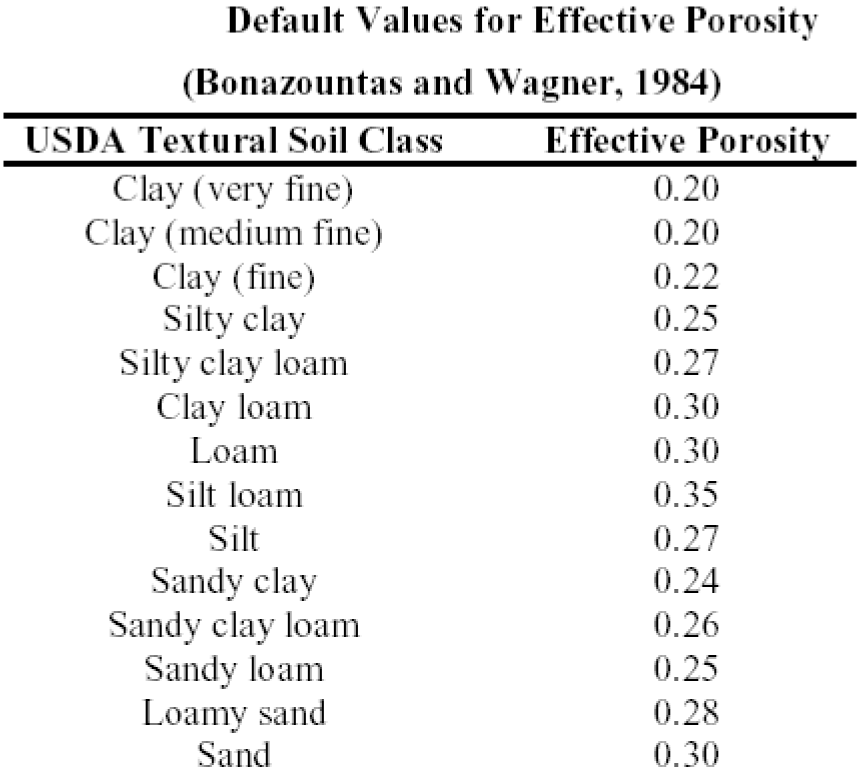
(Bonazountas and Wagner, 1984)

USDA Textural Soil Class	**Permeability (cm^2)**
Clay (very fine)	7.5×10^{-11}
Clay (medium fine)	2.5×10^{-10}
Clay (fine)	6.0×10^{-10}
Silty clay	5.0×10^{-11}
Silty clay loam	8.5×10^{-11}
Clay loam	6.5×10^{-10}
Loam	8.0×10^{-10}
Silt loam	3.5×10^{-10}
Silt	5.0×10^{-11}
Sandy clay	1.5×10^{-9}
Sandy clay loam	2.5×10^{-9}
Sandy loam	2.0×10^{-9}
Loamy sand	5.0×10^{-8}
Sand	1.0×10^{-8}

Default Values for Soil Pore Disconnectedness Index

(Bonazountas and Wagner, 1984)

USDA Textural Soil Class	Soil Pore Disconnectedness Index
Clay (very fine)	12
Clay (medium fine)	12
Clay (fine)	12
Silty clay	12
Silty clay loam	10
Clay loam	7.5
Loam	6.5
Silt loam	5.5
Silt	12
Sandy clay	6
Sandy clay loam	4
Sandy loam	4
Loamy sand	3.9
Sand	3.7



Default Values for Effective Porosity

(Bonazountas and Wagner, 1984)

USDA Textural Soil Class	Effective Porosity
Clay (very fine)	0.20
Clay (medium fine)	0.20
Clay (fine)	0.22
Silty clay	0.25
Silty clay loam	0.27
Clay loam	0.30
Loam	0.30
Silt loam	0.35
Silt	0.27
Sandy clay	0.24
Sandy clay loam	0.26
Sandy loam	0.25
Loamy sand	0.28
Sand	0.30

In addition to the indirect determination of the SESOIL soil parameters using the procedures described above, it is possible to determine the intrinsic permeability, disconnectedness index and the effective porosity directly through the use of appropriate laboratory tests (see Appendix D), although these analyses may be costly and time-consuming.

(6) *Percent soil organic carbon* - This parameter must be measured using soil samples from the site. 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. Either a representative percent organic carbon value may be assigned to the entire soil column, or up to four separate values may be used for different depth intervals in the soil column (maximum of four depth intervals). A separate soil layer (not sublayer) must be used in the SESOIL model for each organic carbon value. Since organic carbon content often decreases with depth, and since soil leachate concentrations for organic contaminants are affected by the organic carbon content of the soil, it may be advantageous in some cases to have separate values for surface and subsurface soil layers, depending on the location of the contaminant. If multiple layers with different organic carbon values are to be used, organic carbon is determined separately for each layer. The following procedure is used to determine an AOC- or site-specific percent organic carbon value:

Collect a minimum of 3 soil samples from locations at the site that are representative of the AOC and the vadose zone underlying the contamination. 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. Analyze the samples for soil organic carbon content using the Lloyd Kahn or equivalent method. The sample results are entered into the NJDEP fraction organic carbon spreadsheet in the MGW calculator located at https://www.nj.gov/dep/srp/guidance/rs/, which determines the appropriate organic carbon content value to use in SESOIL and AT123D.

Use the average percent soil organic carbon content in the SESOIL model (percent organic carbon = fraction organic carbon x 100, or mg/kg organic carbon x 10,000). If the values vary by more than an order of magnitude, they may not be averaged. In this case, the highest percent organic carbon content is used in the model, in order to obtain a conservative estimate of the time needed for contaminant to be eliminated from the soil/ground water system. (NOTE: This is in contrast to the Soil Water Partition Equation (SWPE) and SESOIL guidance contained in Sections 4 and 7, where the lowest organic carbon value is used when the samples are not averaged, in order to obtain a conservative estimate of the concentration of contaminant in the leachate.)

The investigator may consider whether it is advantageous to run the SESOIL model with multiple vertical soil layers, if organic carbon contents vary by more than an order of magnitude due to substantial vertical variation in this parameter. This may result in each layer exhibiting a different and more uniform organic carbon content (less than an order of magnitude variation). A minimum of three soil samples should be used to determine the organic carbon content of each layer.

Additional soil samples should be collected when soil types vary across the AOC or for larger AOCs.

When entering variable organic carbon content, the surface layer organic carbon content is entered directly (under the “Soil” tab in the SEVIEW model), and the values for subsequent layers are entered as ratios relative to the surface layer (under the “Application” tab, “Ratios” subtab) as described in the SEVIEW model documentation.

(7) *Sediment washload* - The sediment washload (surface runoff) option is not used unless adequate site-specific information is available for determination of the necessary input parameters.

(8) *Depth to water table* - When the SESOIL model is used, the vadose zone must be divided into layers and/or sublayers from the soil surface to the water table. For this reason, the depth to the water table must be known and documented. The average water table depth should be used if adequate data are available. If data are inadequate to determine the average water table depth, the depth determined during site investigation/delineation may be used.

(9) *Sublayer thickness* - When dividing the vadose zone into layers/sublayers, one-foot soil sublayers are recommended to be used with the model and should cover the entire soil column from the soil surface to the water table. Sublayer thicknesses greater than 1 foot will dilute

calculated leachate concentrations in those sublayers and are generally not accepted. Sublayer thicknesses less than one foot may be used, but this will result in somewhat higher leachate concentrations reported by the model for the thinner sublayers in the vadose zone. The SESOIL model allows a maximum of 40 sublayers. If the depth to water table is greater than 40 feet, 40 sublayers should be used, with the total depth evenly divided over the layers. When setting the number of sublayers, "instantaneous release" of contaminant should be selected on this screen, however this selection does not affect the applied contaminant loadings as explained subsequently.

(10) *Source Size* – The Source Size in the model must be set equal to the size of the AOC. It is set on the SEVIEW project map and on the "Source Size" tab.

(11) *Soil contamination concentrations* - Prepare a table showing results from all soil borings for the AOC arranged in columns, with the SESOIL modeled concentrations in the final column, as illustrated below. The concentrations for the various borings should be the existing concentrations in the soil (if no remediation is proposed), or concentrations that are proposed to be left behind after remediation.

Soil Boring Table/SESOIL model table
Site-specific screening level = 30 mg/kg

Depth Interval (sublayer interval) (ft)	Boring #1	Boring #2	Boring #3	SESOIL model concentrations
0-1	-	-	-	74.1
1-2	-	74.1	-	74.1
2-3	-	-	-	487
3-4	487	-	-	487
4-5	-	-	-	487
5-6	-	nd	-	0
6-7	-	-	-	0
7-8	-	1.2	-	0
8-9	-	-	-	0
9-10	-	27	-	0
10-11	89.5	-	-	89.5
11-12	-	-	283	283
12-13	-	-	669	669
13-14	-	-	-	669
14-15	-	-	226	226
15-16	-	-	-	226
16-17	-	nd	183	183
17-18	342	-	-	342
18-19	-	-	-	342

- = not determined
nd = not detected

Since the SESOIL model is one-dimensional in the unsaturated zone (vertical only), the results from the various soil borings within the AOC must be compiled into one profile for modeling purposes. When entering contaminant concentrations into the SESOIL model (labeled a SESOIL source in SEVIEW 7), a value must be entered at each one-foot depth interval (that is, for each sublayer) between the soil surface and the water table. To fill in the SESOIL modeling column, the highest concentration observed from the various soil borings for a particular depth interval should be entered in the SESOIL model column. If this concentration is below the SRS-MGW or the ARS-MGW (e.g. from SPLP results), zero may be entered in the SESOIL column for that depth interval. Note in the above table, that the 1.2 and 27 mg/kg results are below the screening level. Generally, there will be depth intervals for which no sample results are available from any boring (as illustrated in the above table). To fill in these values, inspect the existing concentrations in the SESOIL model column for the vertically closest soil sample results above and below the depth range of interest. The higher of the two results should be used to fill in the missing depth interval. As an example from the above table, notice that 487 mg/kg is determined to be the appropriate value for the 2-3 and 4-5 foot depth interval. If contamination above the SRS-MGW or site-specific ARS-MGW does not extend to the soil surface or the water table, zeros may be entered above and below the delineated extent of contamination. Note that if delineation does not include samples above or below the boundaries of the contamination, this may result in modeled contamination extending to the water table or to the soil surface, as illustrated in the above example. One exception is for a subsurface discharge at a known depth, such as from an underground storage tank. In this case, contamination does not need to be delineated above the discharge point.

(12) *Ratios* - Except for the soil organic carbon ratio, all other soil property ratios between soil layers should be set to “1”, since layer-specific values for these parameters are not generally available. The soil organic carbon ratios may be varied as discussed above if separate organic carbon contents are determined for some or all of the soil layers.

(13) *Layer Parameters* - The contaminant load parameters POLIN, TRANS, LIG, ISRM and ASL must be set to zero, since they are not used. The VOLF parameter is set to one (volatilization allowed), since soil texture must be determined for the unsaturated soil zone. Check that the factor is set to one for each soil layer, for each month, and for years 1 and 2 (year 2 values are used for the remainder of the SESOIL model run).

(14) *AT123D tab* - “Initial Concentration” and “Single Mass Load” are not used (should be set to zero if not greyed out). “Continuous” release is selected, and for “Continuous=0, >1 Varying”, enter the number of months of the run. This should be equal to the duration of the CEA for the AOC or site and the length of the SESOIL model run. The load release rates will be calculated when the SESOIL model is run. For the “Aquifer and Chemical” tab, enter parameters as described in Section 8.4 below.

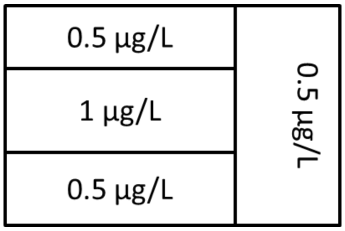
8.4 Setting up the AT123D Model

If desired, “Default AT123D Parameters” in the SEVIEW software may be selected and entered prior to completing the AT123D parameters, because several of these parameters will then already be filled in on subsequent data entry tabs in the software.

(1) Add one or more “AT123D” sources in the SEVIEW program, representing the existing ground water contamination source. This will include the area under the contaminated soil zone, and also include any other areas where a contamination source is located in the ground water. Adjust the location and size of each of these sources by dragging it to the proper location on the SEVIEW project map, and adjusting it to the appropriate size (x, y and z dimensions) in the “Source size” tab. For the ground water source under the Area of Concern, the x and y dimensions should correspond to the size of the AOC, if a single source concentration is used (see next paragraph). The plume thickness (z dimensions) would be set at zero meters starting depth and the measured thickness of the plume (in meters) as the ending depth. The ending depth should not be less than 3.05 m (10 feet) because well screens are commonly 10 feet long and AT123D results are averaged over this interval (see Section 8.5 below).

The measured or estimated contaminated ground water concentration for each source area must be entered into AT123D. The simplest approach is to use a single AT123D source for each ground water contamination source area and use the highest observed ground water concentration within the source as the representative value. While this initial condition is conservative, it may have only a minor effect on the concentrations observed at the end of the simulation run, which will be many years later at the end of the CEA time period, and may be more influenced by the soil contamination source, rather than the initial ground water concentration. Alternatively, multiple AT123D source blocks may be designated in the SEVIEW model for each ground water contamination source area in order to allow for entry of different initial concentrations in different areas of the contamination source. The contaminant concentration of each AT123D source should be set at the highest ground water concentration observed for that portion of the source (see example below). Since each AT123D source has a uniform concentration, a complex source area would take many of these sources to achieve detailed resolution of the concentration variations within a plume. Again, since the final concentrations at the end of the model run are of primary interest, how finely the initial ground water conditions are resolved is not likely to be critical, so it is suggested that only a few AT123D source blocks be used at most for each ground water contamination source area. A maximum of 15 total AT123D source blocks may be used for all ground water source areas combined.

Example ground water source area in AT123D



Note: The remaining instructions in this section are used for AT123D inputs for both the

SESOIL source (in the AT123D Aquifer and Chemical Tab) and each AT123D source that is entered. (The SESOIL source AT123D "LOAD" tab, however, should be filled in using the instructions in item (14) in section 8.3.)

(2) *Hydraulic conductivity* - Determine the hydraulic conductivity of the aquifer from field measurements pursuant to the Department's Monitored Natural Attenuation Technical Guidance Document at http://www.nj.gov/dep/srp/guidance/srra/mna_guidance_v_1_0.pdf. Submit results of slug tests and or pumping tests as an attachment to the submitted documentation.

(3) *Hydraulic gradient* - Determine the hydraulic gradient of the aquifer from field measurements pursuant to the Department's Monitored Natural Attenuation Technical Guidance Document at http://www.nj.gov/dep/srp/guidance/srra/mna_guidance_v_1_0.pdf.
Submit site map with ground water contours as an attachment to submitted documentation.

(4) *Effective porosity* - This parameter may be determined on a site-specific basis but is not commonly done because it is difficult to measure. If AOC- or site-specific values are not available, documentation for the SEVIEW modeling package states that a value of 0.25 is commonly used for silt and sand aquifers. This value is acceptable for use in the AT123D model. The SEVIEW documentation also lists ranges of effective porosities for different aquifer textures that are more up-to-date than those originally reported in the AT123D documentation:

Texture	Effective Porosity
Clay	0.01-0.20 (0.10)
Silt	0.01-0.030 (0.20)
Fine Sand	0.10-0.30 (0.20)
Medium Sand	0.15-0.30 (0.22)
Coarse Sand	0.20-0.35 (0.28)
Gravel	0.10-0.35 (0.22)

The average values (in parentheses) may be used if the aquifer texture is determined and corresponds to one of those listed above.

(5) *Bulk density* - This parameter may be determined on a site-specific basis. If site-specific values are not available, a value of 1,500 kg/m^3 (equivalent to 1.5 kg/L may be used. Alternatively, an average value based on aquifer texture (if determined) may be used. Typical values for bulk density relative to soil texture are given in Table I of the AT123D documentation (Yeh 1981):

Texture	Bulk Density (kg/m^3)
Sand	1,180~1,580 (1,400)
Silt	1,290~1,800 (1,500)
Clay	1,400~2,200 (1,800)

Average values (in parentheses) from this table may be used for these aquifer materials if the default value of 1,500 kg/m^3 is not satisfactory.

(6) *Dispersivities* - Longitudinal dispersivity should be estimated based on the measured plume length using the following equation (Xu and Eckstein 1995):

$$\alpha_L = 0.83(\log_{10} L)^{2.414} \qquad \text{Equation (12)}$$

where:
α_L = longitudinal dispersivity
L = length of contaminant plume (meters)

Transverse dispersivity should be calculated as 1/10th the longitudinal dispersivity (Gelhar et al. 1992)

Vertical dispersivity should be calculated as 1/100th the longitudinal dispersivity (Gelhar et al. 1992)

(7) *Aquifer dimensions* - If contaminated ground water extends to the bottom of the affected aquifer, aquifer thickness (depth) shall be measured in the field using appropriate methods or shall be determined using available data from the New Jersey Geological Survey or the United States Geological Survey when appropriate (e.g., assuming aquifer thickness determinations by the NJGS or USGS are at or in close proximity to the subject site). It is recommended that the aquifer thickness be set to “infinite” in the model unless it is known that the vertical extent of the contaminated plume reaches the bottom of the aquifer. In these cases, a finite aquifer thickness should be entered but results should be checked for reasonableness by comparison with an infinite aquifer thickness run. In some cases, it may be difficult to achieve a stable model run with a finite aquifer thickness. In these cases, aquifer width should be set to “infinite”.

(8) *Eigenvalues* - Eigenvalues are normally set between 500 and 1,000 but may be set outside this range if an error is reported. In the SEVIEW software package, the default value is 500, which is the recommended value.

(9) *Organic carbon content* - Organic carbon content of the aquifer material must be measured as described above in the SESOIL instructions. The unsaturated zone value used in the SESOIL model may not be used since organic carbon content in the aquifer will generally be lower than that of the vadose zone. Furthermore, lower organic contents will accelerate natural attenuation, which is a desired outcome under the SESOIL/AT123D option. Only one organic carbon content value may be used in the AT123D portion of the model. If measured values vary by more than an order of magnitude, they may not be averaged, and the highest measured value is used.

(10) *Chemical Properties* - Should be set to the same values used in the SESOIL model (Section 8.3(3), above). Note that if the soil partition coefficient, K_d, is directly entered, the units (m^3/kg) are different than the SESOIL K_d parameter (ml/g). The SESOIL K_d must be divided by a factor of 1000 to convert to the AT123D units. Also, the SESOIL water diffusion coefficient (units of cm^2/sec) must be multiplied by a factor of 3,600/10,000 to convert it to AT123D units (m^2/hour).

(NOTE: In the SEVIEW software package, chemical properties may be carried over from the SESOIL model. If enabled, unit conversion is done automatically when copied into the AT123D model). If a first order decay constant is to be used, it is handled differently than the instructions above for the SESOIL model. The first-order decay coefficient should be set to zero unless first-order biodegradation rate constants (not attenuation or decay constants) have been determined using ground water monitoring data and procedures such as those described by Buscheck and Alcantar (1995). Other relevant references are Newell et al (2002) and USEPA (1998). Attenuation/decay constants are calculated from plots of concentration vs. time at a source area monitoring well and include all in-situ natural attenuation processes; they are valuable in estimating plume duration, but not biodegradation processes across the extent of the plume. Biodegradation rate constants are estimated through tracer studies or solute transport modeling (incorporating dispersion and retardation/sorption) through iterative variation of the rate constant to achieve calibration with field data within the plume.

(11) *Load parameters, AT123D Source (initial aquifer concentrations)* - An initial concentration in the ground water should be entered for each AT123D source. The "single mass load" parameter should be set to zero if it is not greyed out. Instantaneous release should be selected for each ground water source. The NSOUS variable (labeled as "Continuous=0, >1 Varying") in the SEVIEW software should be set to zero for AT123D sources. The load release rate window is not used for AT123D ground water contamination sources.

8.5 Adding Points of Compliance to the Project Map

In order to complete this task, the ground water plume must be delineated in accordance with guidelines described in the Technical Regulations at 7:26E-4.3, the NJDEP Ground Water Site Investigation/Remedial Investigation Technical Guidance Document (http://www.nj.gov/dep/srp/guidance/srra/gw_inv_si_ri_ra.pdf) and the Ground Water Monitored Natural Attenuation Guidance Document (http://www.nj.gov/dep/srp/guidance/srra/mna_guidance_v_1_0.pdf). Normally, this will have been undertaken as one of the steps necessary to obtain a Classification Exception Area (CEA) for the ground water. The dimensions of the delineated plume will be estimated by the extent of ground water contamination exceeding the GWRS. The plume must include the area directly under the AOC of the contaminated soil.

In SEVIEW 7, ground water concentrations at various points within the plume are monitored by adding "Points of Compliance" to the project map for the site. These should be added in appropriate locations within the ground water plume. For purposes of this guidance, the primary points of concern are along the centerline of the plume that will be generated by the contaminant within the vadose zone source AOC being modeled. Locations to be included are as follows:

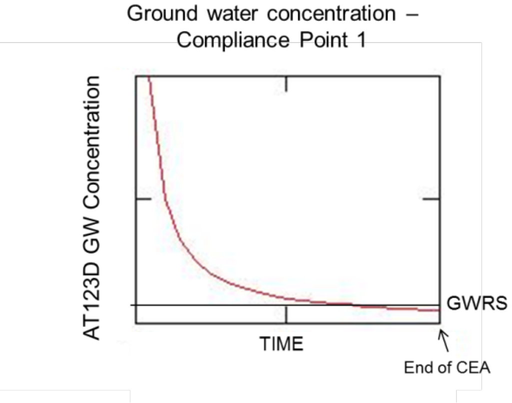
- Compliance Point 1: A location at the centerline of the plume at the downgradient edge of the AOC.

- Compliance Point 2: A location at the centerline of the plume at the maximum extent of the plume.

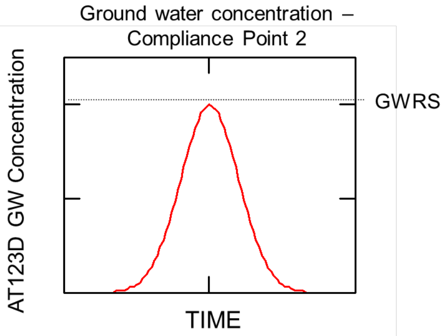
- If the existing ground water plume is complex or large and/or has ground water sources other than that from the soil AOC, additional points of compliance may be added to monitor intermediate points and the most contaminated areas within the plume.

For all points of compliance, predicted concentrations may be averaged over a 3.05 m (10-foot) depth interval, which corresponds to a commonly used well screen length. AT123D does not model "diving" plumes, so points of compliance downgradient from the vadose zone source are normally set to monitor the top ten feet of the aquifer, even though the actual plume may sometimes be below the surface of the aquifer as distance from the source increases. To do this for points of compliance along the centerline of the plume, click on the added point of compliance to open the point of compliance window. For the Z-distance, enter 0, 0.76, 1.52, 2.29 and 3.05 m. The SEVIEW software will average these five points to obtain a representative concentration for the depth interval. AT123D does not have the ability to model curving plumes, so plumes that are curved must be assumed to be straight when locating points of compliance in AT123D.

The model simulation run should show that contaminant concentrations are below the ground water remediation standards at all points of compliance at the end of the model simulation period, which is normally set for the duration of the CEA. An example figure is shown for Compliance Point 1:



The model simulation run should also show that at Compliance Point 2, the predicted ground water concentrations never exceed the GWRS, as illustrated in the following figure:



If model simulation results are acceptable, the ARS-MGW is the vertical concentration distribution used in the SESOIL model run. If results are not acceptable, additional remediation may be required. The model may be rerun in an iterative manner using alternative vertical soil concentration distributions in order to identify the distribution that achieves the compliance point conditions identified above. This distribution will determine the extent of remediation necessary.

8.6 SESOIL/AT123D Model Reporting Requirements

A separate report (or separate section in a larger report such as RIR, RAR) should be prepared with a narrative of the model simulation. A SESOIL model table (as described in Section 8.3.(11) above) should be submitted showing the measured contaminant concentrations as a function of depth and the modeled SESOIL concentrations. The modeled SESOIL concentration distribution as a function of depth that yields acceptable results becomes the ARS-MGW. When filling out the Remediation Standard Notification Spreadsheet for the Alternative Remediation Standard Form, "Alternative" is selected as the type of standard, "range" is entered as the proposed remediation standard, and the columns containing the depth ranges and the modeled concentrations from the SESOIL model table should be attached to the spreadsheet. A map of the delineated ground water plume should be submitted, showing how the AT123D source blocks are laid out on this plume. A table of the source concentration and dimensions used for each AT123D source block should be provided. Alternatively, screenshots of the relevant input pages from the SEVIEW software may be submitted. To indicate ground water source block concentrations, the concentrations may be added to the source description on the SEVIEW project map. Supporting documentation must be provided for the depth to ground water, the vadose zone soil texture, and vadose zone organic carbon. Ground water supporting documentation must be submitted showing the determination of the site-specific hydraulic conductivity and gradient for the site. The calculation of the longitudinal dispersivity should be included, and data supporting the saturated zone organic carbon content must be supplied. Any other parameters for which default values are not used will also need supporting documentation, such as SPLP data for a site-specific K_d value. In addition, the following model output must be submitted:

1. The four output pages from the SESOIL portion of the model run must be submitted to the Department. These pages show the appropriate model input and output information for the SESOIL source on the project map.

2. The Point of Compliance report from the SEVIEW program should be submitted for each

point of compliance.

3. For each Point of Compliance report, the final concentration of the contaminant at the last time step (end of the CEA time period) should be shown. To do this, click twice on the point of compliance graph, and then click again on the graph to bring up the small EXCEL window that shows contaminant concentrations as a function of time. Scroll down to the last time point (end of the CEA), and then print the screen showing the EXCEL window and point of compliance graph together.

4. Electronic submission – The project file (*.prj) containing the simulation run should be submitted to the department.

8.7 Ground Water and Soil Monitoring Requirements

A Department approved ground water monitoring program designed to monitor the predictions of the AT123D model must be implemented. If observed ground water concentrations have not decreased as expected at the end of the CEA time period, soil sampling may be required to evaluate whether contaminated soil is still of concern at the site. Consult the Monitored Natural Attenuation Technical Guidance Document at https://www.nj.gov/dep/srp/guidance/#mon_nat_atten for further details.

8.8 Additional Considerations

1. Compliance averaging of soil concentrations is not applicable to SESOIL or AT123D modeling at this time.

2. The SESOIL model can be used in three ways. First, an existing concentration distribution may be modeled <u>before</u> remediation, to determine if the impact-to-ground water pathway is of concern. Second, the model can be used to model proposed contaminant concentrations that will be left behind <u>after</u> remediation, to determine if the proposed remediation plan is acceptable. Third, the model can be used to model a <u>theoretical</u> concentration distribution, such as a proposed maximum allowed concentration at each depth interval. If a theoretical concentration distribution is shown to be acceptable as an impact-to-ground water standard, then soil concentrations at a particular depth interval <u>may not exceed</u> the modeled concentration for that particular depth.

3. The SESOIL option results in an allowed vertical contaminant <u>distribution</u> in soil, rather than a discrete number. When using the SESOIL option, a soil concentration is entered for each 1-foot interval between the soil surface and the water table. This concentration may be different for each depth interval. The entered concentration distribution may be either existing concentrations or proposed concentrations to be left behind after remediation. If this distribution yields acceptable SESOIL results (specifically, the leachate criterion is not exceeded), the distribution of chemical concentrations in the soil is acceptable as an ARS-MGW.

9.0 ADDRESSING THE MGW PATHWAY USING THE IMMOBILE CHEMICAL OPTION

9.1 Overview

Contaminants that have low transport potential due to their high soil adsorption coefficients, may, over time, become irreversibly adsorbed to soil and therefore "immobile" under normal conditions. If an adequate zone of clean soil exists between the contamination and the water table, these contaminants may not pose a contamination threat to the underlying ground water.

Contaminants that are not on the immobile chemical list in section 9.2 below may not be considered for this option unless the SPLP procedure has been used and results in an AOC- or site-specific K_d greater than 100 L/kg. If SPLP testing is conducted, the highest contaminant concentration proposed to be left on site must be included in the SPLP sampling, for reasons discussed in Section 6.6 above.

This section describes the necessary conditions and provides procedures to determine that immobile contaminants do not pose a risk of contaminating underlying ground water. If an immobile chemical does not meet the requirements described in this section, or if conditions at the site could cause the contaminant to become mobile, the SRS-MGW must be used, or an AOC- or site-specific ARS-MGW for the Migration to Ground Water pathway must be developed using other guidance contained in this document.

Due to the information that is required to use this guidance, it is only appropriate to conduct this immobile chemical evaluation when the remedial investigation has been completed.
It is important to note that this option does not give a numerical standard.

9.2 Determination of Chemicals Qualifying for the Immobile Chemicals Option

The approach to determine the list of immobile chemicals that may qualify for this option remains the same as for the 2008 version of this guidance, but an updated assessment was conducted because the regulated list of chemicals has changed, some of the chemical properties have been updated, and newer climate data are available. A chemical is classified as an immobile chemical if a 2-foot clean zone between the contamination and the water table exists which provides - an adequate separation distance to prevent contaminant transport to the water table over a 100-year time period. To simulate contaminant transport, the Department used the Seasonal Soil Compartment Model (SESOIL), with the requirement that a chemical should be transported less than two feet over a simulation period of 100 years (detailed in the "Soil and Soil Leachate Remediation Standards for the Migration to Ground Water Exposure Pathway, Basis and Background" document, located at https://www.nj.gov/dep/srp/guidance/rs/). SESOIL simulation results are affected by the depth of the water table, the depth of the contaminant below the soil surface, location in the state, and soil texture. However, the results indicated that under most conditions, chemicals with K_{oc} values greater than 50,000 L/kg (equivalent to a K_d value greater than 100 L/kg) vertically moved less than 24" downward during a 100-year simulation period. Therefore, the conditions to qualify for an immobile chemical remain unchanged from those specified in 2008. The eligible chemicals are listed below.

List of Immobile Chemicals

Lead
Aldrin
Benzo(a)anthracene
Bis(2-ethylhexyl phthalate)
Chlordane
DDD
DDE
DDT
PCBs
2,3,7,8 -Tetrachlorodibenzo-p-dioxin
Toxaphene

Some chemicals have been eliminated from the list provided with the 2008 guidance document because they are no longer regulated or have updated K_{oc} or K_d values that are now lower than the cutoff values stated above.

9.3 Procedures for the Evaluation of Immobile Chemicals

Remediation of soils for the Migration to Ground Water (MGW) pathway will not be required if the following can be demonstrated:

1. The contaminant is an immobile chemical listed above;

2. There is a clean zone of at least 2 feet between the soil contamination and the seasonally high ground water. Sampling must be conducted to demonstrate that contamination is not present at concentrations above the SRS-MGW or ARS-MGW within 2 feet of the water table; and

3. No conditions are present on the site that may increase the normal mobility of the contaminant, as discussed below.

<u>Site conditions not compatible with the immobile chemical option</u>

There are several site conditions that can affect the ability of immobile chemicals to migrate to ground water. A contaminant is not considered an immobile chemical when any of the following conditions exists:

1. The contaminant was discharged as part of a mixture that could affect the mobility of the contaminant;

2. A co-solvent is present that could affect the mobility of the contaminant;

3. Soil pH has been altered by the discharge of acids or bases: or

4. The contaminant of concern is present at levels associated with free or residual product.

9.4 Submission Requirements

The investigator responsible for conducting the remediation must submit the following information to support their evaluation of immobile chemicals at the site:

- Soil boring logs;
- Analytical results from all soil samples, including samples collected from the 2-foot zone between the contamination and the seasonally high water table;
- A table comparing analytical results with the SRS-MGW or site-specific ARS-MGW; and
- Discussion and evaluation of all conditions identified in this guidance, including supporting documentation.

10.0 ADDRESSING THE MIGRATION TO GROUND WATER PATHWAY VIA SITE SOIL & GROUND WATER DATA EVALUATION

10.1 Overview

This section describes the use of site soil and ground water data evaluation to demonstrate that the MGW exposure pathway has been addressed for an Area of concern (AOC) or site-. This section replaces the previous guidance titled “Site Soil and Ground Water Analytical Data Evaluation, Metals & Semi-Volatile Organic Compounds Contamination” dated January 25, 2009. This option may be applied to all contaminants including volatile organic compounds (VOCs). This guidance should not be applied for AOCs or sites where recent discharges where maximum contaminant concentrations have likely not yet migrated to the water table.

When the current contaminant distribution represents the worst-case conditions with respect to the potential for ground water contamination, and when the ground water is still uncontaminated, there is no further need to investigate the MGW pathway. This narrative option is the only option to address the MGW pathway using current ground water conditions. It may be used for all contaminants.

It is important to note that this option does not generate a numerical standard.

10.2 Procedure

At AOCs where the highest concentration of soil contamination is present at the water table and ground water quality does not exceed the associated Ground Water Remediation Standard (GWRS), no remediation for the MGW pathway is required. Pertinent site conditions include the depth to ground water, the location of the highest soil contamination in relation to the ground water table and the age of the discharge. No ARS-MGW is developed using this option, and no further action is required for the MGW pathway.

1. For each AOC, collect and analyze soil samples in accordance with the appropriate Department guidance to demonstrate that delineation to the SRS-MGW or ARS-MGW has been completed. In order to proceed further, it must be clear that the highest contaminant concentrations are located at the water table.

2. For each AOC, obtain a minimum of two ground water samples, in accordance with the appropriate Department guidance, biased towards the location of the soil sample with the highest soil contaminant concentration. The samples must be collected no sooner than thirty days apart and exhibit no exceedances of the applicable GWRS.

10.3 Submission Requirements

The report submitted under this option must include a description and discussion of how all soil and ground water sample results were used to demonstrate compliance with the MGW exposure pathway, including all related tables, figures and laboratory results. Specifically, the following elements should be provided:

1. A scaled map indicating the locations of all soil and ground water samples.

2. A table containing all soil and ground water results. The table must include the following for each sample:

    - sample number,
    - sample date,
    - contaminant concentrations for all contaminants of concern
    - sample depth (soil samples), and
    - depth to water/ground water elevation (ground water samples)
    - the well screen interval (depth below grade)
    - depth of ground water sample taken, if applicable (for example using low flow techniques or targeting samples in a well with a long well screen).

3. Soil boring logs.

4. The method used to obtain the ground water samples shall be provided. If a permanent well was installed, then Monitoring Well Certification Form A found at http://www.nj.gov/dep/srp/srra/forms shall be submitted.

5. Site history, including date and volume of the discharge, if known.

REFERENCES

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ASTM D425. Standard Test Method for Centrifuge Moisture Equivalent of Soils. ASTM International, West Conshohocken, PA. https://www.astm.org/Standard/standards-and-publications.html.

ASTM D1587. Standard Practice for Thin-Walled Sampling of Soils for Geotechnical Purposes. ATSM International, West Conshohocken, PA. https://www.astm.org/Standard/standards-and-publications.html.

ASTM D3550. Standard Practice for Thick Wall, Ring-Lined, Split Barrel, Drive Sampling of Soils. ASTM International, West Conshohocken, PA. https://www.astm.org/Standard/standards-and-publications.html.

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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 (2010). Recommended Toxicity Equivalence Factors (TEFs) for Human Health Risk Assessments of 2,3,7,8-Tetrachlorodibenzo-p-dioxin and Dioxin-like Compounds. December 2010. https://archive.epa.gov/raf/web/pdf/tefs-for-dioxin-epa-00-r-10-005-final.pdf.

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Appendix A

ACRONYMS

AOC	Area of Concern
ARS	Alternative Remediation Standard
ARS-MGW	Alternative Remediation Standard for the Migration to Ground Water Exposure Pathway
AT123D	Analytical Transient 1-,2-, and 3-Dimensional Ground Water Model
DAF	Dilution-Attenuation Factor
EPH	Extractable Petroleum Hydrocarbons
FSPM	Field Sampling Procedures Manual
GWRS	Ground Water Remediation Standard
LSRP	Licensed Site Remediation Professional
MGW	Migration to Ground Water
$MGW_{LEACHATE}$	Soil Leachate Remediation Standard for the Migration to Ground Water Exposure Pathway
N.J.A.C.	New Jersey Administrative Code
N.J.S.A.	New Jersey Statutes Annotated
NJDEP	New Jersey Department of Environmental Protection
RL	Reporting Limit
SESOIL	Seasonal Soil Compartment Model
SPLP	Synthetic Precipitation Leaching Procedure
SRS	Soil Remediation Standard
SRS-MGW	Soil Remediation Standard for the Migration to Ground Water Exposure Pathway
SWPE	Soil Water Partition Equation
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Contaminant

Appendix B

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

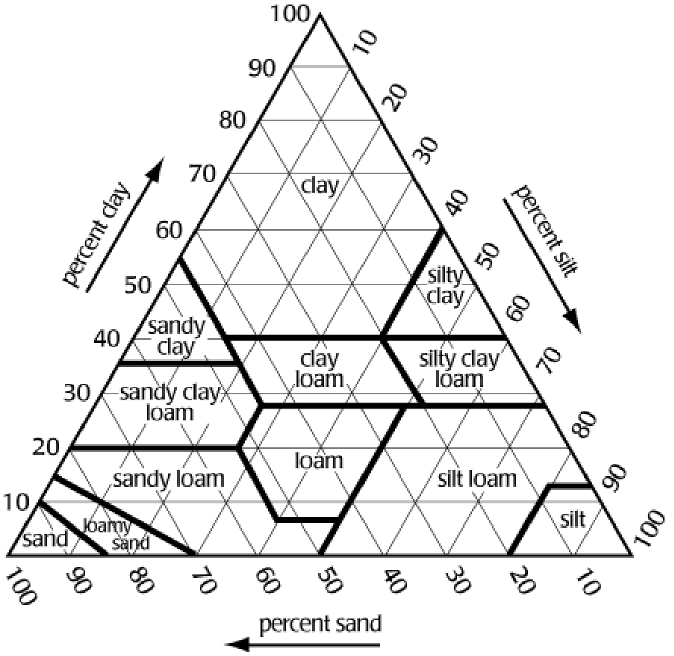
Schumacher (2002) has compared dry combustion, wet oxidation, furnace (loss on ignition) and hydrogen peroxide treatment techniques for determination of total organic carbon in soils and sediments. The furnace and hydrogen peroxide treatments are best considered to be semi quantitative techniques since 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 Department 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 methods are designed for water and liquid wastes, and do not discuss the analysis of soil samples.

Appendix C

METHODS FOR DETERMINATION OF SOIL TEXTURE

A variety of methods exist to determine soil texture. Sieve analysis alone is generally not adequate, because it does not separate the silt and clay fractions. The Department will consider any of the following techniques acceptable: the hydrometer method; sieve analysis for the sand and gravel portions of a given sample with pipette or hydrometer measurements of the silt and clay fractions; rapid sediment analyzers; or electro-resistance multichannel particle size analyzers. The percentages of sand, silt and clay determined by the chosen analysis technique are then compared to the USDA Soil Texture Triangle to determine the soil texture classification (see figure below). Under the USDA classification, sands are considered particles between 0.05 and 2 mm in size, silts are between 0.05 mm and 0.002 mm and clays are less than 0.002 mm in size.



USDA Soil Triangle (Bonazountas and Wagner 1984)

Among the standard methods for determining particle size distribution, two methods from ASTM International are commonly employed and deserve further discussion. The full names of these methods are listed in the reference section of this document as cited below.

The most commonly used method is ASTM D422 which is a sieve and hydrometer-based method. The sand fraction is determined using a 0.075 mm sieve. Then, the remaining sample is suspended in water and the density of the suspension is measured after the silt has settled, which allows determination of the silt and clay fractions of the sample. This method uses a 0.075 mm cutoff for the sand fraction, rather than the USDA 0.05 mm cutoff. It is recommended, although not required, that a 0.05 mm sieve be substituted. The default hydrometer analysis for this method determines <0.001 mm (colloids) and <0.005 mm fractions, while the USDA clay fraction is <0.002 mm. If the <0.002 mm fraction is not determined directly, it may be estimated by averaging the results from the <0.001 mm and <0.005 mm fractions.

Because Method D422 was not reapproved within an eight-year window as required by ASTM, it is currently withdrawn as an approved method, as per policy of ASTM International. However, the method is still satisfactory, and many laboratories continue to routinely run the method.

The other method for determining particle size distribution is ASTM F1632 which is a sieve and pipette-based method. This method has the advantage of properly determining the sand, silt and clay percentages according to the USDA particle size definitions. Sand is first separated using a 0.05 mm sieve. Then, the remaining sample is suspended in water, and the suspended clay is sampled with a pipette after allowing the silt fraction to settle. The clay is determined by weight after drying, and the silt content is then determined by subtracting the sand and clay weight from the total sample weight.

Appendix D

DIRECT DETERMINATION OF INTRINSIC PERMEABILITY, DISCONNECTEDNESS INDEX, AND EFFECTIVE POROSITY FOR THE SESOIL MODEL FROM SITE SOIL SAMPLES

While direct determination of SESOIL-specific input parameters is possible, the procedures required are likely to be fairly expensive and time consuming. Methods are available to collect soil core samples and to conduct the appropriate laboratory measurements, but the method results typically require additional measurements and calculations in order to obtain values for the SESOIL input parameters. Therefore, a substantial level of expertise will be required to determine site-specific values for these parameters, and the effort will likely be worthwhile only for larger hazardous waste sites that would exhibit substantial economic savings from determining site-specific values for these parameters.

Several methods from ASTM International are discussed in this appendix. The full names of these methods are listed in reference section of this document as cited below. The investigator may work with the NJDEP on a site-specific basis if it is felt that a site-specific method is necessary other than those mentioned in this section.

Generally, intact, undisturbed soil cores will need to be collected from the field and brought into the laboratory. Two methods are available for the collection of soil cores (ASTM D3550; ASTM D1587).

Pore Disconnectedness Index

The pore disconnectedness index may be determined using the following formula:

$$c = \frac{2+3m}{m}$$ Equation (D1)

where *c* is the pore disconnectedness index and *m* is the pore size distribution index (Brooks and Corey 1964). The pore size distribution index, in turn, may be measured from the soil moisture retention curve as the negative slope of the effective degree of saturation versus matric suction on the midpoint of the curve. Standard procedures have not been published for determining the pore disconnectedness index, but a method for determining the soil moisture retention curve from which the calculation is made is available (ASTM D6836).

Intrinsic Permeability

Intrinsic permeability may be calculated from the saturated hydraulic conductivity of the soil:

$$k = \frac{K\mu}{\rho g} \qquad \text{Equation (D2)}$$

where k is the intrinsic permeability, K is the saturated hydraulic conductivity of the soil, μ is the dynamic viscosity of water, ρ is the density of water and g is the gravitational constant (Freeze and Cherry 1979). A standard method is available to determine saturated hydraulic conductivity (ASTM D5084).

Effective Porosity

Obtaining accurate effective porosity values in the field or laboratory has historically been difficult and time consuming. Effective porosity may be thought of as the fractional air content of soil after soil moisture has drained to its field capacity. Field and laboratory methods are available, but field methods are not likely to be practical during site investigation. A laboratory method is available to determine effective porosity (ASTM D425), but it is not specifically designed for undisturbed soil cores. It is suggested that a modified version of the method be used which allows for the use of undisturbed soil cores. Check with specific laboratories to ascertain whether or not they have developed specific expertise in the determination of this parameter.

Appendix E

MAJOR CHANGES FROM PREVIOUS IMPACT TO GROUND WATER GUIDANCE DOCUMENTS

There are two major changes from previous guidance documents. Both are reflective of the Remediation Standards at N.J.A.C.7:26 D.

First, all Soil Remediation Standards for the Migration to Ground Water exposure Pathway (SRS-MGW) were developed to protect the ground water from future exceedances of Ground Water Remediation Standards (GWRS) that may result from leaching of contaminants from the unsaturated soil zone to the underlying ground water. Previously, the end point for ground water protection used for all calculations was the health-based Ground Water Quality Criterion for the contaminant in question. The end point has been changed to the GWRS, which takes into account not only the health-based Ground Water Quality Criterion but the Practical Quantitation Limit as well and uses the higher of the two when calculating a SRS-MGW. Second, the Migration to Ground Water pathway no longer needs to be addressed for contaminants with default Migration to Ground Water Soil-Water Partition Equation Criteria that are higher than their default soil saturation limits. This has resulted in fewer contaminants that need to be considered for this pathway than previously. Free and residual product must still be addressed for all contaminants.

Table 1

SOIL REMEDIATION STANDARDS FOR THE MIGRATION TO GROUND WATER EXPOSURE PATHWAY

Contaminant	CAS No.	Ground Water Remediation Standard (µg/L)	Migration to Ground Water Soil Criterion (mg/kg)	Soil Saturation Limit (C_{sat}) (mg/kg)	Soil Reporting Limit (RL) (mg/kg)	Migration to Ground Water Soil Remediation Standard (SRS-MGW) (mg/kg)
Acenaphthene	83-32-9	400	82	40	0.17	NA[1]
Acetone (2-Propanone)	67-64-1	6,000	19	160,000	0.010	19
Acetophenone	98-86-2	700	3.6	1,600	0.33	3.6
Aldrin	309-00-2	0.04	0.13	2.8	0.0017	0.13
Aluminum (total)	7429-90-5	NA	NA	NA	20	NA[2]
Anthracene	120-12-7	2,000	1,300	1.4	0.17	NA[1]
Antimony (total)	7440-36-0	6	5.4	NA	1.0	5.4
Arsenic (total)	7440-38-2	3	1.6	NA	0.50	19[3]
Atrazine	1912-24-9	3	0.036	21	0.33	0.33[4]
Barium (total)	7440-39-3	6,000	2,100	NA	5.0	2,100
Benzaldehyde	100-52-7	NA	NA	1,200	0.33	NA[5]
Benzene	71-43-2	1	0.0094	850	0.0050	0.0094
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.1	0.71	3.3	0.17	0.71
Benzo(a)pyrene	50-32-8	0.1	2.3	1.9	0.17	NA[1]
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	205-99-2	0.2	4.8	1.8	0.17	NA[1]
Benzo(k)fluoranthene	207-08-9	0.5	12	0.94	0.17	NA[1]
Beryllium	7440-41-7	1	0.70	NA	0.50	0.70
1,1'-Biphenyl	92-52-4	400	83	78	0.17	NA[1]
Bis(2-chloroethoxy)methane	111-91-1	NA	NA	1,400	0.17	NA[5]
Bis(2-chloroethyl)ether	111-44-4	7	0.030	3,700	0.33	0.33[4]
Bis(2-ethylhexyl)phthalate	117-81-7	3	14	65	0.17	14
Bromodichloromethane (Dichlorobromomethane)	75-27-4	1	0.0045	690	0.0050	0.0050[4]
Bromoform	75-25-2	4	0.018	680	0.0050	0.018

Contaminant	CAS No.	Ground Water Remediation Standard (µg/L)	Migration to Ground Water Soil Criterion (mg/kg)	Soil Saturation Limit (C_{sat}) (mg/kg)	Soil Reporting Limit (RL) (mg/kg)	Migration to Ground Water Soil Remediation Standard (SRS-MGW) (mg/kg)
Bromomethane (Methyl bromide)	74-83-9	10	0.043	3,300	0.0050	0.043
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	300	0.98	36,000	0.010	0.98
Butylbenzyl phthalate	85-68-7	100	29	39	0.17	29
Cadmium	7440-43-9	4	1.9	NA	0.50	1.9
Caprolactam	105-60-2	4,000	16	160,000	0.33	16
Carbon disulfide	75-15-0	700	3.7	580	0.0050	3.7
Carbon tetrachloride	56-23-5	1	0.0075	300	0.0050	0.0075
Chlordane (alpha and gamma forms summed)	57-74-9	0.5	1.4	7.6	0.0017	1.4
4-Chloroaniline	106-47-8	30	0.23	1,500	0.17	0.23
Chlorobenzene	108-90-7	50	0.64	320	0.0050	0.64
Chloroethane (Ethyl chloride)	75-00-3	NA	NA	1,700	0.0050	NA[5]
Chloroform	67-66-3	70	0.33	1,900	0.0050	0.33
Chloromethane (Methyl chloride)	74-87-3	NA	NA	1,200	0.0050	NA[5]
2-Chloronaphthalene	91-58-7	600	61	60	0.17	NA[1]
2-Chlorophenol (o-chlorophenol)	95-57-8	40	0.76	11,000	0.17	0.76
Chrysene	218-01-9	5	36	0.72	0.17	NA[1]
Cobalt (total)	7440-48-4	100	90	NA	0.50	90
Copper (total)	7440-50-8	1,300	910	NA	1.0	910
Cyanide	57-12-5	100	20	NA	0.50	20
Cyclohexane	110-82-7	NA	NA	65	0.0050	NA[5]
4,4'-DDD (p,p'-TDE)	72-54-8	0.1	0.47	21	0.0033	0.47
4,4'-DDE (p,p'-DDX)	72-55-9	0.1	0.47	9.4	0.0033	0.47
4,4'-DDT	50-29-3	0.1	0.67	1.9	0.0033	0.67
Dibenz(a,h)anthracene	53-70-3	0.3	23	9.5	0.17	NA[1]
Dibromochloromethane (Chlorodibromomethane)	124-48-1	1	0.0044	600	0.0050	0.0050[4]
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.00015	470	0.0050	0.0050[4]
1,2-Dibromoethane (Ethylene dibromide)	106-93-4	0.03	0.00014	920	0.0050	0.0050[4]
1,2-Dichlorobenzene (o-Dichlorobenzene)	95-50-1	600	11	140	0.0050	11

Contaminant	CAS No.	Ground Water Remediation Standard (µg/L)	Migration to Ground Water Soil Criterion (mg/kg)	Soil Saturation Limit (C_{sat}) (mg/kg)	Soil Reporting Limit (RL) (mg/kg)	Migration to Ground Water Soil Remediation Standard (SRS-MGW) (mg/kg)
1,3-Dichlorobenzene (m-Dichlorobenzene)	541-73-1	600	11	110	0.0050	11
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	75	1.4	74	0.0050	1.4
3,3'-Dichlorobenzidine	91-94-1	30	3.9	20	0.33	3.9
Dichlorodifluoromethane (Freon 12)	75-71-8	1,000	38	540	0.0050	38
1,1-Dichloroethane	75-34-3	50	0.24	1,200	0.0050	0.24
1,2-Dichloroethane	107-06-2	2	0.0095	2,000	0.0050	0.0095
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	1	0.0069	830	0.0050	0.0069
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	70	0.35	1,600	0.0050	0.35
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	100	0.56	1,300	0.0050	0.56
2,4-Dichlorophenol	120-83-2	20	0.19	2,600	0.17	0.19
1,2-Dichloropropane	78-87-5	1	0.0058	810	0.0050	0.0058
1,3-Dichloropropene (total)	542-75-6	1	0.0063	880	0.0050	0.0063
Dieldrin	60-57-1	0.03	0.024	7.9	0.0033	0.024
Diethylphthalate	84-66-2	6,000	44	390	0.17	44
2,4-Dimethylphenol	105-67-9	100	2.3	8,900	0.17	2.3
Di-n-butyl phthalate	84-74-2	700	35	28	0.17	NA[1]
2,4-Dinitrophenol	51-28-5	40	0.12	430	0.33	0.33[4]
2,4-Dinitrotoluene/2,6-Dinitrotoluene (mixture)	25321-14-6	10	0.27	360	0.17	0.27
Di-n-octyl phthalate	117-84-0	100	560	6.2	0.33	NA[1]
1,4-Dioxane	123-91-1	0.4	0.0013	160,000	0.067	0.067[4]
Endosulfan I and Endosulfan II (alpha and beta) (summed)	115-29-7	40	11	4.4	0.0033	NA[1]
Endrin	72-20-8	2	1.6	10	0.0033	1.6
Ethylbenzene	100-41-4	700	15	180	0.0050	15
Extractable Petroleum Hydrocarbons (Category 1)	various	NA	NA	NA	80	NA[5]
Extractable Petroleum Hydrocarbons (Category 2)	various	NA	NA	NA	80	NA[5]
Fluoranthene	206-44-0	300	670	29	0.33	NA[1]
Fluorene	86-73-7	300	110	31	0.17	NA[1]

Contaminant	CAS No.	Ground Water Remediation Standard (µg/L)	Migration to Ground Water Soil Criterion (mg/kg)	Soil Saturation Limit (C_{sat}) (mg/kg)	Soil Reporting Limit (RL) (mg/kg)	Migration to Ground Water Soil Remediation Standard (SRS-MGW) (mg/kg)
alpha-HCH (alpha-BHC)	319-84-6	0.02	0.0023	12	0.0017	0.0023
beta-HCH (beta-BHC)	319-85-7	0.04	0.0046	1.4	0.0017	0.0046
Heptachlor	76-44-8	0.05	0.083	15	0.0017	0.083
Heptachlor epoxide	1024-57-3	0.2	0.081	4.1	0.0017	0.081
Hexachlorobenzene	118-74-1	0.02	0.0050	0.078	0.17	0.17[4]
Hexachloro-1,3-butadiene	87-68-3	1	0.038	6.1	0.17	0.17[4]
Hexachlorocyclopentadiene	77-47-4	40	2.5	5.6	0.33	2.5
Hexachloroethane	67-72-1	7	0.079	28	0.17	0.17[4]
n-Hexane	110-54-3	30	5.5	88	NA	5.5
2-Hexanone	591-78-6	40	0.15	3,200	0.010	0.15
Indeno(1,2,3-cd) pyrene	193-39-5	0.2	16	0.74	0.17	NA[1]
Isophorone	78-59-1	40	0.23	3,400	0.17	0.23
Isopropylbenzene	98-82-8	700	22	98	0.0050	22
Lead (total)	7439-92-1	5	90	NA	0.50	90
Lindane (gamma-HCH)(gamma-BHC)	58-89-9	0.03	0.0035	42	0.0017	0.0035
Manganese (total)	7439-96-5	NA	NA	NA	0.50	NA[2]
Mercury (total)	7439-97-6	2	0.014	NA	0.10	0.10[4]
Methoxychlor	72-43-5	40	43	5.4	0.017	NA[1]
Methyl acetate	79-20-9	7,000	22	39,000	0.0050	22
Methylene chloride (Dichloromethane)	75-09-2	3	0.013	2,800	0.0050	0.013
2-Methylnaphthalene	91-57-6	30	3.1	130	0.17	3.1
4-Methyl-2-pentanone (MIBK)	108-10-1	NA	NA	3,400	0.010	NA[5]
2-Methylphenol (o-cresol)	95-48-7	50	0.77	20,000	0.33	0.77
4-Methylphenol (p-cresol)	106-44-5	50	0.75	16,000	0.33	0.75
Methyl tert-butyl ether (MTBE)	1634-04-4	70	0.25	9,100	0.0050	0.25
Naphthalene	91-20-3	300	19	100	0.17	19
Nickel (total)	7440-02-0	100	48	NA	0.50	48
4-Nitroaniline	100-01-6	NA	NA	270	0.33	NA[5]
Nitrobenzene	98-95-3	6	0.073	1,300	0.17	0.17[4]
N-Nitrosodi-n-propylamine	621-64-7	10	0.14	9,200	0.17	0.17[4]
N-Nitrosodiphenylamine	86-30-6	10	1.1	190	0.17	1.1
2,2'-oxybis(1-chloropropane)	108-60-1	300	1.9	540	0.33	1.9
Pentachlorophenol	87-86-5	0.3	0.062	140	0.33	0.33[4]

Contaminant	CAS No.	Ground Water Remediation Standard (µg/L)	Migration to Ground Water Soil Criterion (mg/kg)	Soil Saturation Limit (C_{sat}) (mg/kg)	Soil Reporting Limit (RL) (mg/kg)	Migration to Ground Water Soil Remediation Standard (SRS-MGW) (mg/kg)
Phenol	108-95-2	2,000	21	44,000	0.33	21
Polychlorinated biphenyls (PCBs)	1336-36-3	0.5	1.6	110	0.030	1.6
Pyrene	129-00-0	200	440	15	0.17	NA[1]
Selenium (total)	7782-49-2	40	11	NA	2.5	11
Silver (total)	7440-22-4	40	0.33	NA	0.50	0.50[4]
Styrene	100-42-5	100	2.1	330	0.0050	2.1
Tertiary butyl alcohol (TBA)	75-65-0	100	0.32	160,000	0.10	0.32
1,2,4,5-Tetrachlorobenzene	95-94-3	NA	NA	2.7	0.17	NA[5]
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	0.00001	0.00010	0.10	0.0000010	0.00010[6]
1,1,2,2-Tetrachloroethane	79-34-5	1	0.0069	980	0.0050	0.0069
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	1	0.0086	89	0.0050	0.0086
2,3,4,6-Tetrachlorophenol	58-90-2	200	26	150	0.17	26
Toluene	108-88-3	600	7.8	340	0.0050	7.8
Toxaphene	8001-35-2	2	6.2	85	0.17	6.2
1,2,4-Trichlorobenzene	120-82-1	9	0.52	140	0.0050	0.52
1,1,1-Trichloroethane	71-55-6	30	0.20	420	0.0050	0.20
1,1,2-Trichloroethane	79-00-5	3	0.017	1,300	0.0050	0.017
Trichloroethene (TCE) (Trichloroethylene)	79-01-6	1	0.0065	410	0.0050	0.0065
Trichlorofluoromethane (Freon 11)	75-69-4	2,000	29	790	0.0050	29
2,4,5-Trichlorophenol	95-95-4	700	68	5,800	0.20	68
2,4,6-Trichlorophenol	88-06-2	20	0.86	1,700	0.20	0.86
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon TF)	76-13-1	20,000	1,300	530	0.0050	NA[1]
1,2,4-Trimethylbenzene	95-63-6	NA	NA	80	0.076	NA[5]
Vanadium (total)	7440-62-2	NA	NA	NA	2.5	NA[5]
Vinyl chloride	75-01-4	1	0.0067	2,900	0.0050	0.0067
Xylenes (total)	1330-20-7	1,000	19	100	0.0050	19
Zinc (total)	7440-66-6	2,000	930	NA	1.0	930

NA = Not available/not applicable
1 – Standard not applicable because criterion is above soil saturation limit
2 – Standard not applicable because Ground Water Remediation Standard is a secondary standard
3 – Standard is based on natural background

4 – Standard set to soil reporting limit
5 – Ground Water Remediation Standard not available
6 – This standard is used for comparison to site soil data that have been converted to sample-specific TCDD-TEQ values through application of the Toxicity Equivalence Factor Methodology (USEPA 2010) and using the WHO 2005 Mammalian Toxic Equivalency Factors (TEFs).

Table 2

SOIL LEACHATE REMEDIATION STANDARDS FOR THE MIGRATION TO GROUND WATER EXPOSURE PATHWAY

Contaminant	CAS No.	Ground Water Remediation Standard (GWRS)(µg/L)	Migration to Ground Water Soil Leachate Remediation Standard ($MGW_{LEACHATE}$) (µg/L)
Acenaphthene	83-32-9	400	NA[1]
Acetone (2-Propanone)*	67-64-1	6,000	120,000
Acetophenone	98-86-2	700	14,000
Aldrin	309-00-2	0.04	0.80
Aluminum (total)	7429-90-5	NA	NA[2]
Anthracene	120-12-7	2,000	NA[1]
Antimony (total)	7440-36-0	6	120
Arsenic (total)	7440-38-2	3	60
Atrazine	1912-24-9	3	60
Barium (total)	7440-39-3	6,000	120,000
Benzaldehyde*	100-52-7	NA	NA[3]
Benzene*	71-43-2	1	20
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	0.1	2.0
Benzo(a)pyrene	50-32-8	0.1	NA[1]
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	205-99-2	0.2	NA[1]
Benzo(k)fluoranthene	207-08-9	0.5	NA[1]
Beryllium	7440-41-7	1	20
1,1'-Biphenyl	92-52-4	400	NA[1]
Bis(2-chloroethoxy)methane	111-91-1	NA	NA[3]
Bis(2-chloroethyl)ether*	111-44-4	7	140
Bis(2-ethylhexyl)phthalate	117-81-7	3	60
Bromodichloromethane (Dichlorobromomethane)*	75-27-4	1	20
Bromoform*	75-25-2	4	80

Contaminant	CAS No.	Ground Water Remediation Standard (GWRS)(µg/L)	Migration to Ground Water Soil Leachate Remediation Standard (MGW$_{\text{LEACHATE}}$) (µg/L)
Bromomethane (Methyl bromide)*	74-83-9	10	200
2-Butanone (Methyl ethyl ketone) (MEK)*	78-93-3	300	6,000
Butylbenzyl phthalate	85-68-7	100	2,000
Cadmium	7440-43-9	4	80
Caprolactam	105-60-2	4,000	80,000
Carbon disulfide*	75-15-0	700	14,000
Carbon tetrachloride*	56-23-5	1	20
Chlordane (alpha and gamma forms summed)	57-74-9	0.5	10
4-Chloroaniline	106-47-8	30	600
Chlorobenzene*	108-90-7	50	1,000
Chloroethane (Ethyl chloride)*	75-00-3	NA	NA[3]
Chloroform*	67-66-3	70	1,400
Chloromethane (Methyl chloride)*	74-87-3	NA	NA[3]
2-Chloronaphthalene	91-58-7	600	NA[1]
2-Chlorophenol (o-Chlorophenol)*	95-57-8	40	800
Chrysene	218-01-9	5	NA[1]
Cobalt (total)	7440-48-4	100	2,000
Copper (total)	7440-50-8	1,300	26,000
Cyanide	57-12-5	100	2,000
Cyclohexane*	110-82-7	NA	NA[3]
4,4'-DDD (p,p'-TDE)	72-54-8	0.1	2.0
4,4'-DDE (p,p'-DDX)	72-55-9	0.1	2.0
4,4'-DDT	50-29-3	0.1	2.0
Dibenz(a,h)anthracene	53-70-3	0.3	NA[1]
Dibromochloromethane (Chlorodibromomethane)*	124-48-1	1	20
1,2-Dibromo-3-chloropropane	96-12-8	0.02	0.40
1,2-Dibromoethane (Ethylene dibromide)*	106-93-4	0.03	0.60
1,2-Dichlorobenzene (o-Dichlorobenzene)*	95-50-1	600	12,000
1,3-Dichlorobenzene (m-Dichlorobenzene)*	541-73-1	600	12,000
1,4-Dichlorobenzene (p-Dichlorobenzene)*	106-46-7	75	1,500
3,3'-Dichlorobenzidine	91-94-1	30	600

Contaminant	CAS No.	Ground Water Remediation Standard (GWRS)(µg/L)	Migration to Ground Water Soil Leachate Remediation Standard (MGW_{LEACHATE}) (µg/L)
Dichlorodifluoromethane (Freon 12)*	75-71-8	1,000	20,000
1,1-Dichloroethane*	75-34-3	50	1,000
1,2-Dichloroethane*	107-06-2	2	40
1,1-Dichloroethene (1,1-Dichloroethylene)*	75-35-4	1	20
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)*	156-59-2	70	1,400
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)*	156-60-5	100	2,000
2,4-Dichlorophenol	120-83-2	20	400
1,2-Dichloropropane*	78-87-5	1	20
1,3-Dichloropropene (total)*	542-75-6	1	20
Dieldrin	60-57-1	0.03	0.60
Diethylphthalate	84-66-2	6,000	120,000
2,4-Dimethylphenol	105-67-9	100	2,000
Di-n-butyl phthalate	84-74-2	700	NA[1]
2,4-Dinitrophenol	51-28-5	40	800
2,4-Dinitrotoluene/2,6-Dinitrotoluene (mixture)	25321-14-6	10	200
Di-n-octyl phthalate	117-84-0	100	NA[1]
1,4-Dioxane*	123-91-1	0.4	8.0
Endosulfan I and Endosulfan II (alpha and beta) (summed)	115-29-7	40	NA[1]
Endrin	72-20-8	2	40
Ethylbenzene*	100-41-4	700	14,000
Extractable Petroleum Hydrocarbons (No. 2 Fuel Oil and Diesel)	various	NA	NA[3]
Extractable Petroleum Hydrocarbons (Other)	various	NA	NA[3]
Fluoranthene	206-44-0	300	NA[1]
Fluorene	86-73-7	300	NA[1]
alpha-HCH (alpha-BHC)	319-84-6	0.02	0.40
beta-HCH (beta-BHC)	319-85-7	0.04	0.80
Heptachlor	76-44-8	0.05	1.0
Heptachlor epoxide	1024-57-3	0.2	4.0
Hexachlorobenzene	118-74-1	0.02	0.40
Hexachloro-1,3-butadiene	87-68-3	1	20

Contaminant	CAS No.	Ground Water Remediation Standard (GWRS)(µg/L)	Migration to Ground Water Soil Leachate Remediation Standard ($MGW_{LEACHATE}$) (µg/L)
Hexachlorocyclopentadiene	77-47-4	40	800
Hexachloroethane	67-72-1	7	140
n-Hexane*	110-54-3	30	600
2-Hexanone*	591-78-6	40	800
Indeno(1,2,3-cd)pyrene	193-39-5	0.2	NA[1]
Isophorone	78-59-1	40	800
Isopropylbenzene*	98-82-8	700	14,000
Lead (total)	7439-92-1	5	100
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	0.03	0.60
Manganese (total)	7439-96-5	NA	NA[2]
Mercury (total)	7439-97-6	2	40
Methoxychlor	72-43-5	40	NA[1]
Methyl acetate*	79-20-9	7,000	140,000
Methylene chloride (Dichloromethane)*	75-09-2	3	60
2-Methylnaphthalene	91-57-6	30	600
4-Methyl-2-pentanone (MIBK)*	108-10-1	NA	NA[3]
2-Methylphenol (o-cresol)	95-48-7	50	1,000
4-Methylphenol (p-cresol)	106-44-5	50	1,000
Methyl tert-butyl ether (MTBE)*	1634-04-4	70	1,400
Naphthalene	91-20-3	300	6,000
Nickel (total)	7440-02-0	100	2,000
4-Nitroaniline	100-01-6	NA	NA[3]
Nitrobenzene	98-95-3	6	120
N-Nitrosodi-n-propylamine	621-64-7	10	200
N-Nitrosodiphenylamine	86-30-6	10	200
2,2'-oxybis(1-chloropropane)	108-60-1	300	6,000
Pentachlorophenol	87-86-5	0.3	6.0
Phenol	108-95-2	2,000	40,000
Polychlorinated biphenyls (PCBs)	1336-36-3	0.5	10
Pyrene	129-00-0	200	NA[1]
Selenium (total)	7782-49-2	40	800
Silver (total)	7440-22-4	40	800
Styrene*	100-42-5	100	2,000
Tertiary butyl alcohol (TBA)*	75-65-0	100	2,000
1,2,4,5-Tetrachlorobenzene	95-94-3	NA	NA[3]
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	0.00001	0.00020[4]
1,1,2,2-Tetrachloroethane*	79-34-5	1	20

Contaminant	CAS No.	Ground Water Remediation Standard (GWRS)(µg/L)	Migration to Ground Water Soil Leachate Remediation Standard ($MGW_{LEACHATE}$) (µg/L)
Tetrachloroethene (PCE) (Tetrachloroethylene)*	127-18-4	1	20
2,3,4,6-Tetrachlorophenol	58-90-2	200	4,000
Toluene*	108-88-3	600	12,000
Toxaphene	8001-35-2	2	40
1,2,4-Trichlorobenzene	120-82-1	9	180
1,1,1-Trichloroethane*	71-55-6	30	600
1,1,2-Trichloroethane*	79-00-5	3	60
Trichloroethene (TCE) (Trichloroethylene)*	79-01-6	1	20
Trichlorofluoromethane (Freon 11)*	75-69-4	2,000	40,000
2,4,5-Trichlorophenol	95-95-4	700	14,000
2,4,6-Trichlorophenol	88-06-2	20	400
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon TF)*	76-13-1	20,000	NA[1]
1,2,4-Trimethylbenzene*	95-63-6	NA	NA[3]
Vanadium (total)	7440-62-2	NA	NA[3]
Vinyl chloride*	75-01-4	1	20
Xylenes (total)*	1330-20-7	1,000	20,000
Zinc (total)	7440-66-6	2,000	40,000

* = Contaminant is a volatile
NA = Standard not available/not applicable
1 – Standard not applicable because soil criterion is above soil saturation limit
2 – Standard not applicable because Ground Water Remediation Standard is a secondary standard
3 – Ground Water Remediation Standard not available
4 – This standard is used in conjunction with soil data that have been converted to sample-specific TCDD-TEQ values through application of the Toxicity Equivalence Factor Methodology (USEPA 2010) and using the WHO 2005 Mammalian Toxic Equivalency Factors (TEFs).

Table 3

NEW JERSEY DEP REMEDIATION STANDARDS CHEMICAL PROPERTIES AND SOIL SATURATION LIMITS

Chemical	*CAS No.*	*Molecular Wt.*	*Water Solubility (mg/L)*	*Henry's Law Constant (atm-m^3/mol),25°C (used for SESOIL and SESOIL/AT123D)*	*Henry's Law Constant (dimensionless, 25°C) (used for soil-water partition and SPLP options)*	*Soil Organic Carbon-Water Partition Coefficient, K_{oc} (L/kg)*	*Soil-Water Partition Coefficient, K_d (L/kg)*	*Air Diffusion Coefficient (Air Diffusivity) (cm^2/sec)*	*Water Diffusion Coefficient (Water Diffusivity) (cm^2/sec)*	*Soil Saturation Limit (mg/kg)*
Acenaphthene	83-32-9	154.21	3.9	1.84E-04	7.5224E-03	5027	NA	5.0614E-02	8.3300E-06	40
Acetone (2-Propanone)	67-64-1	58.08	1000000	3.50E-05	1.4309E-03	2.364	NA	1.0592E-01	1.1471E-05	160000
Acetophenone	98-86-2	120.15	6130	1.04E-05	4.2518E-04	51.85	NA	6.5222E-02	8.7228E-06	1600
Aldrin	309-00-2	364.92	0.017	4.40E-05	1.7989E-03	82020	NA	2.2812E-02	5.8402E-06	2.8
Aluminum (total)	7429-90-5	26.982	NA	NA	NA	NA	1500	NA	NA	NA
Anthracene	120-12-7	178.24	0.0434	5.56E-05	2.2731E-03	16360	NA	3.8973E-02	7.8522E-06	1.4
Antimony (total)	7440-36-0	121.76	NA	NA	NA	NA	4.50E+01	NA	NA	NA
Arsenic (total)	7440-38-2	74.922	NA	NA	NA	NA	2.60E+01	NA	NA	NA
Atrazine	1912-24-9	215.69	34.7	2.36E-09	9.6484E-08	224.5	NA	2.6466E-02	6.8378E-06	21
Barium (total)	7440-39-3	137.33	NA	NA	NA	NA	1.70E+01	NA	NA	NA
Benzaldehyde	100-52-7	106.13	6950	2.67E-05	1.0916E-03	11.09	NA	7.4393E-02	9.4627E-06	1200
Benzene	71-43-2	78.11	1790	5.55E-03	2.2690E-01	145.8	NA	8.9534E-02	1.0263E-05	850
Benzo(a)anthracene (1,2-Benzanthracene)	56-55-3	228.3	0.0094	1.20E-05	4.9059E-04	176900	NA	2.6114E-02	6.7495E-06	3.3
Benzo(a)pyrene	50-32-8	252.32	0.00162	4.57E-07	1.8683E-05	587400	NA	4.7583E-02	5.5597E-06	1.9
Benzo(b)fluoranthene (3,4-Benzofluoranthene)	205-99-2	252.32	0.0015	6.57E-07	2.6860E-05	599400	NA	4.7583E-02	5.5597E-06	1.8
Benzo(k)fluoranthene	207-08-9	252.32	0.0008	5.84E-07	2.3875E-05	587400	NA	4.7583E-02	5.5597E-06	0.94
Beryllium	7440-41-7	9.01	NA	NA	NA	NA	3.50E+01	NA	NA	NA
1,1'-Biphenyl	92-52-4	154.21	7.48	3.08E-04	1.2592E-02	5129	NA	4.7059E-02	7.5618E-06	78

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Bis(2-chloroethoxy)methane	111-91-1	173.04	7800	3.85E-06	1.5740E-04	14.38	NA	6.1186E-02	7.1492E-06	1400
Bis(2-chloroethyl)ether	111-44-4	143.01	17200	1.70E-05	6.9501E-04	32.21	NA	5.6719E-02	8.7070E-06	3700
Bis(2-ethylhexyl)phthalate	117-81-7	390.57	0.27	2.70E-07	1.1038E-05	119600	NA	1.7340E-02	4.1807E-06	65
Bromodichloromethane (Dichlorobromomethane)	75-27-4	163.83	3030	2.12E-03	8.6672E-02	31.82	NA	5.6263E-02	1.0731E-05	690
Bromoform	75-25-2	252.73	3100	5.35E-04	2.1872E-02	31.82	NA	3.5732E-02	1.0356E-05	680
Bromomethane (Methyl bromide)	74-83-9	94.94	15200	7.34E-03	3.0008E-01	13.22	NA	1.0050E-01	1.3468E-05	3300
2-Butanone (Methyl ethyl ketone) (MEK)	78-93-3	72.11	223000	5.69E-05	2.3262E-03	4.51	NA	9.1446E-02	1.0193E-05	36000
Butylbenzyl phthalate	85-68-7	312.37	2.69	1.26E-06	5.1513E-05	7155	NA	2.0832E-02	5.1733E-06	39
Cadmium	7440-43-9	112.41	NA	NA	NA	NA	2.30E+01	NA	NA	NA
Caprolactam	105-60-2	113.16	772000	2.53E-08	1.0343E-06	24.5	NA	6.9242E-02	8.9994E-06	160000
Carbon disulfide	75-15-0	76.13	2160	1.44E-02	5.8872E-01	21.73	NA	1.0644E-01	1.2977E-05	580
Carbon tetrachloride	56-23-5	153.82	793	2.76E-02	1.1284E+00	43.89	NA	5.7143E-02	9.7849E-06	300
Chlordane (alpha and gamma forms summed)	57-74-9	409.78	0.056	4.86E-05	1.9869E-03	67540	NA	1.7900E-02	4.3700E-06	7.6
4-Chloroaniline	106-47-8	127.57	3900	1.16E-06	4.7424E-05	112.7	NA	7.0385E-02	1.0253E-05	1500
Chlorobenzene	108-90-7	112.56	498	3.11E-03	1.2715E-01	233.9	NA	7.2130E-02	9.4765E-06	320
Chloroethane (Ethyl chloride)	75-00-3	64.52	6710	1.11E-02	4.5380E-01	21.73	NA	1.0376E-01	1.1619E-05	1700
Chloroform	67-66-3	119.38	7950	3.67E-03	1.5004E-01	31.82	NA	7.6920E-02	1.0891E-05	1900
Chloromethane (Methyl chloride)	74-87-3	50.49	5320	8.82E-03	3.6059E-01	13.22	NA	1.2396E-01	1.3648E-05	1200
2-Chloronaphthalene	91-58-7	162.62	11.7	3.20E-04	1.3082E-02	2478	NA	4.4691E-02	7.7301E-06	60
2-Chlorophenol (o-Chlorophenol)	95-57-8	128.56	11300	1.12E-05	4.5789E-04	398.00	NA	6.6118E-02	9.4784E-06	11000
Chrysene	218-01-9	228.3	0.002	5.23E-06	2.1382E-04	180500	NA	2.6114E-02	6.7495E-06	0.72
Cobalt (total)	7440-48-4	58.93	NA	NA	NA	NA	4.50E+01	NA	NA	NA
Copper (total)	7440-50-8	63.55	NA	NA	NA	NA	3.50E+01	NA	NA	NA
Cyanide	57-12-5	26.0174	NA	NA	NA	NA	9.90E+00	NA	NA	NA
Cyclohexane	110-82-7	84.16	55	1.50E-01	6.1325E+00	145.8	NA	7.9973E-02	9.1077E-06	65
4,4'-DDD (p,p'-TDE)	72-54-8	320.05	0.09	6.60E-06	2.6983E-04	117500	NA	4.0608E-02	4.7447E-06	21
4,4'-DDE (p,p'-DDX)	72-55-9	318.03	0.04	4.16E-05	1.7007E-03	117500	NA	2.3000E-02	5.8592E-06	9.4
4,4'-DDT	50-29-3	354.49	0.0055	8.32E-06	3.4015E-04	168600	NA	3.7933E-02	4.4322E-06	1.9
Dibenz(a,h)anthracene	53-70-3	278.36	0.00249	1.41E-07	5.7645E-06	1912000	NA	4.4567E-02	5.2073E-06	9.5

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Dibromochloromethane (Chlorodibromomethane)	124-48-1	208.28	2700	7.83E-04	3.2011E-02	31.82	NA	3.6636E-02	1.0561E-05	600
1,2-Dibromo-3-chloropropane	96-12-8	236.33	1230	1.47E-04	6.0098E-03	115.8	NA	3.2135E-02	8.9048E-06	470
1,2-Dibromoethane (Ethylene dibromide)	106-93-4	187.86	3910	6.50E-04	2.6574E-02	39.6	NA	4.3035E-02	1.0439E-05	920
1,2-Dichlorobenzene (o-Dichlorobenzene)	95-50-1	147	156	1.92E-03	7.8496E-02	382.9	NA	5.6170E-02	8.9213E-06	140
1,3-Dichlorobenzene (m-Dichlorobenzene)	541-73-1	147	125	2.63E-03	1.0751E-01	375.3	NA	6.9200E-02	7.8600E-06	110
1,4-Dichlorobenzene (p-Dichlorobenzene)	106-46-7	147	81.3	2.41E-03	9.8528E-02	375.3	NA	5.5043E-02	8.6797E-06	74
3,3'-Dichlorobenzidine	91-94-1	253.13	3.1	2.84E-11	1.1611E-09	3190	NA	4.7482E-02	5.5478E-06	20
Dichlorodifluoromethane (Freon 12)	75-71-8	120.91	280	3.43E-01	1.4023E+01	43.89	NA	7.6029E-02	1.0839E-05	540
1,1-Dichloroethane	75-34-3	98.96	5040	5.62E-03	2.2976E-01	31.82	NA	8.3645E-02	1.0621E-05	1200
1,2-Dichloroethane	107-06-2	98.96	8600	1.18E-03	4.8242E-02	39.6	NA	8.5722E-02	1.0995E-05	2000
1,1-Dichloroethene (1,1-Dichloroethylene)	75-35-4	96.94	2420	2.61E-02	1.0670E+00	31.82	NA	8.6311E-02	1.0956E-05	830
1,2-Dichloroethene (cis) (c-1,2-Dichloroethylene)	156-59-2	96.94	6410	4.08E-03	1.6680E-01	39.6	NA	8.8406E-02	1.1335E-05	1600
1,2-Dichloroethene (trans) (t-1,2-Dichloroethylene)	156-60-5	96.94	4520	9.38E-03	3.8348E-01	39.6	NA	8.7609E-02	1.1191E-05	1300
2,4-Dichlorophenol	120-83-2	163	5500	4.29E-06	1.7538E-04	1.59E+02	NA	4.8577E-02	8.6786E-06	2600
1,2-Dichloropropane	78-87-5	112.99	2800	2.82E-03	1.1529E-01	60.7	NA	7.3340E-02	9.7252E-06	810
1,3-Dichloropropene (total)	542-75-6	110.97	2800	3.55E-03	1.4513E-01	72.17	NA	7.6272E-02	1.0123E-05	880
Dieldrin	60-57-1	380.91	0.195	1.00E-05	4.0883E-04	20090	NA	2.3286E-02	6.0062E-06	7.9
Diethylphthalate	84-66-2	222.24	1080	6.10E-07	2.4939E-05	104.9	NA	2.6074E-02	6.7227E-06	390
2,4-Dimethylphenol	105-67-9	122.17	7870	9.51E-07	3.8879E-05	491.8	NA	6.2245E-02	8.3140E-06	8900
Di-n-butyl phthalate	84-74-2	278.35	11.2	1.81E-06	7.3998E-05	1157	NA	2.1436E-02	5.3255E-06	28
2,4-Dinitrophenol	51-28-5	184.11	2790	8.60E-08	3.5159E-06	1.78E-02	NA	4.0670E-02	9.0756E-06	430
2,4-Dinitrotoluene/2,6-Dinitrotoluene (mixture)	25321-14-6	182.14	270	3.97E-07	1.6230E-05	587.4	NA	5.9131E-02	6.9090E-06	360
Di-n-octyl phthalate	117-84-0	390.57	0.022	2.57E-06	1.0506E-04	140800.00	NA	3.5559E-02	4.1548E-06	6.2
1,4-Dioxane	123-91-1	88.11	1000000	4.80E-06	1.9624E-04	2.633	NA	8.7374E-02	1.0541E-05	160000
Endosulfan I and Endosulfan II (alpha and beta) (summed)	115-29-7	406.92	0.325	6.50E-05	2.6574E-03	6761	NA	2.2484E-02	5.7628E-06	4.4
Endrin	72-20-8	380.91	0.25	6.36E-06	2.6000E-04	20090	NA	3.6158E-02	4.2248E-06	10

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Ethylbenzene	100-41-4	106.17	169	7.88E-03	3.2216E-01	446.1	NA	6.8465E-02	8.4558E-06	180
Extractable Petroleum Hydrocarbons (No. 2 Fuel Oil and Diesel)	various	NA	NA	NA	NA	NA	NA	NA	NA	NA
Extractable Petroleum Hydrocarbons (Other)	various	NA	NA	NA	NA	NA	NA	NA	NA	NA
Fluoranthene	206-44-0	202.26	0.26	8.86E-06	3.6222E-04	55450	NA	2.7596E-02	7.1827E-06	29
Fluorene	86-73-7	166.22	1.69	9.62E-05	3.9329E-03	9160	NA	4.3974E-02	7.8890E-06	31
alpha-HCH (alpha-BHC)	319-84-6	290.83	2	6.70E-06	2.7392E-04	2807	NA	4.3284E-02	5.0574E-06	12
beta-HCH (beta-BHC)	319-85-7	290.83	0.24	4.40E-06	1.7988E-05	2807	NA	2.7667E-02	7.3955E-06	1.4
Heptachlor	76-44-8	373.32	0.18	2.94E-04	1.2020E-02	41260	NA	2.2344E-02	5.6959E-06	15
Heptachlor epoxide	1024-57-3	389.32	0.2	2.10E-05	8.5854E-04	10110	NA	2.4001E-02	6.2475E-06	4.1
Hexachlorobenzene	118-74-1	284.78	0.0062	1.70E-03	6.9501E-02	6195	NA	2.8974E-02	7.8497E-06	0.078
Hexachloro-1,3-butadiene	87-68-3	260.76	3.2	1.03E-02	4.2110E-01	845.2	NA	2.6744E-02	7.0264E-06	6.1
Hexachlorocyclopentadiene	77-47-4	272.77	1.8	2.70E-02	1.1038E+00	1404	NA	2.7238E-02	7.2170E-06	5.6
Hexachloroethane	67-72-1	236.74	50	3.89E-03	1.5904E-01	196.8	NA	3.2094E-02	8.8904E-06	28
n-Hexane	110-54-3	86.18	9.5	1.80E+00	7.3590E+01	131.5	NA	7.3108E-02	8.1658E-06	88
2-Hexanone	591-78-6	100.16	17200	9.32E-05	3.8103E-03	14.98	NA	7.0356E-02	8.4404E-06	3200
Indeno(1,2,3-cd)pyrene	193-39-5	276.34	0.00019	3.48E-07	1.4227E-05	1951000	NA	4.4784E-02	5.2327E-06	0.74
Isophorone	78-59-1	138.21	12000	6.64E-06	2.7146E-04	65.15	NA	5.2505E-02	7.5296E-06	3400
Isopropylbenzene	98-82-8	120.2	61.3	1.15E-02	4.7016E-01	697.8	NA	6.0304E-02	7.8566E-06	98
Lead (total)	7439-92-1	207.2	NA	NA	NA	NA	9.00E+02	NA	NA	NA
Lindane (gamma-HCH) (gamma-BHC)	58-89-9	290.83	7.3	5.14E-06	2.1014E-04	2807	NA	4.3284E-02	5.0574E-06	42
Manganese (total)	7439-96-5	54.94	NA	NA	NA	NA	6.50E+01	NA	NA	NA
Mercury (total)	7439-97-6	200.59	NA	NA	NA	NA	2.00E-01	NA	NA	NA
Methoxychlor	72-43-5	345.66	0.1	2.03E-07	8.2993E-06	26890	NA	2.2085E-02	5.5926E-06	5.4
Methyl acetate	79-20-9	74.08	243000	1.15E-04	4.7016E-03	3.064	NA	9.5776E-02	1.1008E-05	39000
Methylene chloride (Dichloromethane)	75-09-2	84.93	13000	3.25E-03	1.3287E-01	21.73	NA	9.9936E-02	1.2512E-05	2800
2-Methylnaphthalene	91-57-6	142.2	24.6	5.18E-04	2.1177E-02	2478	NA	5.2432E-02	7.7811E-06	130
4-Methyl-2-pentanone (MIBK)	108-10-1	100.16	19000	1.38E-04	5.6419E-03	12.6	NA	6.9780E-02	8.3477E-06	3400
2-Methylphenol (o-cresol)	95-48-7	108.14	25900	1.20E-06	4.9060E-05	306.5	NA	7.2835E-02	9.3168E-06	20000

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4-Methylphenol (p-cresol)	106-44-5	108.14	21500	1.00E-06	4.0883E-05	300.4	NA	7.2394E-02	9.2397E-06	16000
Methyl tert-butyl ether (MTBE)	1634-04-4	88.15	51000	5.87E-04	2.3998E-02	11.56	NA	7.5267E-02	8.5904E-06	9100
Naphthalene	91-20-3	128.18	31	4.40E-04	1.7988E-02	1544	NA	6.0499E-02	8.3770E-06	100
Nickel (total)	7440-02-0	58.69	NA	NA	NA	NA	2.40E+01	NA	NA	NA
4-Nitroaniline	100-01-6	138.13	728	1.26E-09	5.1513E-08	109.1	NA	6.3660E-02	9.7545E-06	270
Nitrobenzene	98-95-3	123.11	2090	2.40E-05	9.8119E-04	226.4	NA	6.8054E-02	9.4494E-06	1300
N-Nitrosodi-n-propylamine	621-64-7	130.19	13000	5.38E-06	2.1995E-04	275.4	NA	5.6440E-02	7.7580E-06	9200
N-Nitrosodiphenylamine	86-30-6	198.23	35	1.21E-06	4.9468E-05	2632	NA	5.5886E-02	6.5299E-06	190
2,2'-oxybis(1-chloropropane)	108-60-1	171.07	1700	7.42E-05	3.0335E-03	82.92	NA	3.9889E-02	7.3606E-06	540
Pentachlorophenol	87-86-5	266.34	14	2.45E-08	1.0016E-06	5.10E+03	NA	2.9520E-02	8.0121E-06	140
Phenol	108-95-2	94.11	82800	3.33E-07	1.3614E-05	187.2	NA	8.3398E-02	1.0254E-05	44000
Polychlorinated biphenyls (PCBs)	1336-36-3	variable	0.7	4.15E-04	1.6966E-02	78100	NA	2.4340E-02	6.2671E-06	110
Pyrene	129-00-0	202.26	0.135	1.19E-05	4.8651E-04	54340	NA	2.7787E-02	7.2479E-06	15
Selenium (total)	7782-49-2	78.96	NA	NA	NA	NA	1.40E+01	NA	NA	NA
Silver (total)	7440-22-4	107.87	NA	NA	NA	NA	2.60E-01	NA	NA	NA
Styrene	100-42-5	104.15	310	2.75E-03	1.1243E-01	446.1	NA	7.1114E-02	8.7838E-06	330
Tertiary butyl alcohol (TBA)	75-65-0	74.12	1.00E+06	9.05E-06	3.6996E-04	2.111	NA	9.8500E-02	1.1400E-05	160000
1,2,4,5-Tetrachlorobenzene	95-94-3	215.89	0.595	1.00E-03	4.0883E-02	2220	NA	3.1896E-02	8.7531E-06	2.7
2,3,7,8-Tetrachlorodibenzo-p-dioxin	1746-01-6	321.98	0.0002	5.00E-05	2.044E-03	249100	NA	4.7028E-02	6.7568E-06	0.1
1,1,2,2-Tetrachloroethane	79-34-5	167.85	2830	3.67E-04	1.5004E-02	94.94	NA	4.8921E-02	9.2902E-06	980
Tetrachloroethene (PCE) (Tetrachloroethylene)	127-18-4	165.83	206	1.77E-02	7.2363E-01	94.94	NA	5.0466E-02	9.4551E-06	89
2,3,4,6-Tetrachlorophenol	58-90-2	231.89	23	8.84E-06	3.6140E-04	3140	NA	5.0338E-02	5.8816E-06	150
Toluene	108-88-3	92.14	526	6.64E-03	2.7146E-01	233.9	NA	7.7804E-02	9.2043E-06	340
Toxaphene	8001-35-2	413.82	0.55	6.00E-06	2.4530E-04	77200	NA	3.2439E-02	3.7902E-06	85
1,2,4-Trichlorobenzene	120-82-1	181.45	49	1.42E-03	5.8054E-02	1356	NA	3.9599E-02	8.4033E-06	140
1,1,1-Trichloroethane	71-55-6	133.41	1290	1.72E-02	7.0319E-01	43.89	NA	6.4817E-02	9.5990E-06	420
1,1,2-Trichloroethane	79-00-5	133.41	4590	8.24E-04	3.3688E-02	60.7	NA	6.6890E-02	1.0026E-05	1300
Trichloroethene (TCE) (Trichloroethylene)	79-01-6	131.39	1280	9.85E-03	4.0270E-01	60.7	NA	6.8662E-02	1.0221E-05	410
Trichlorofluoromethane (Freon 11)	75-69-4	137.37	1100	9.70E-02	3.9657E+00	43.89	NA	6.5356E-02	1.0048E-05	790

Chemical	***CAS No.***	***Molecular Wt.***	***Water Solubility (mg/L)***	***Henry's Law Constant (atm-m^3/mol),25°C (used for SESOIL and SESOIL/AT123D)***	***Henry's Law Constant (dimensionless, 25°C) (used for soil-water partition and SPLP options)***	***Soil Organic Carbon-Water Partition Coefficient, K_{oc} (L/kg)***	***Soil-Water Partition Coefficient, K_d (L/kg)***	***Air Diffusion Coefficient (Air Diffusivity) (cm^2/sec)***	***Water Diffusion Coefficient (Water Diffusivity) (cm^2/sec)***	***Soil Saturation Limit (mg/kg)***
2,4,5-Trichlorophenol	95-95-4	197.45	1200	1.62E-06	6.6230E-05	2.34E+03	NA	3.1394E-02	8.0893E-06	5800
2,4,6-Trichlorophenol	88-06-2	197.45	800	2.60E-06	1.0630E-04	9.99E+02	NA	3.1395E-02	8.0896E-06	1700
1,1,2-Trichloro-1,2,2-trifluoroethane (Freon TF)	76-13-1	187.38	170	5.26E-01	2.1504E+01	196.8	NA	3.7566E-02	8.5920E-06	530
1,2,4-Trimethylbenzene	95-63-6	120.2	57	6.16E-03	2.5184E-01	614.3	NA	6.0675E-02	7.9208E-06	80
Vandium (total)	7440-62-2	50.94	NA	NA	NA	NA	1.00E+03	NA	NA	NA
Vinyl chloride	75-01-4	62.5	8800	2.78E-02	1.1365E+00	21.73	NA	1.0712E-01	1.2004E-05	2900
Xylenes (total)	1330-20-7	106.17	106	6.63E-03	2.7105E-01	382.9	NA	6.8515E-02	8.4640E-06	100
Zinc (total)	7440-66-6	65.38	NA	NA	NA	NA	2.30E+01	NA	NA	NA

Table 4

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

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*
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

Table 5

LOCATION OF SESOIL CLIMATE STATIONS

County	*Municipality*	*Climate Station*	*Latitude*	*Longitude*
Atlantic	Egg Harbor	ATLANTIC CITY AIRPORT	39.450	74.567
Atlantic	Hamilton	MAYS LANDING I W	39.450	74.750
Atlantic	Hammonton Town	HAMMONTON 2 NNE	39.650	74.800
Bergen	Bergenfield	BERGENFIELD	40.924	73.999
Bergen	Cliffside Park	CLIFFSIDE PARK	40.821	73.989
Bergen	Englewood	ENGLEWOOD	40.893	73.973
Bergen	Fair Lawn	FAIR LAWN	40.936	74.120
Bergen	Fort Lee	FORT LEE	40.849	73.974
Bergen	Garfield	GARFIELD	40.880	74.108
Bergen	Lodi	LODI	40.882	74.083
Bergen	Lyndhurst	LYNDHURST	40.808	74.122
Bergen	Mahwah	MAHWAH	41.100	74.167
Bergen	Oradell Boro	NEW MILFORD	40.950	74.033
Bergen	Paramus	PARAMUS	40.945	74.072
Bergen	Ridgewood	RIDGEWOOD	40.979	74.117
Bergen	South Hackensack	HACKENSACK	40.866	74.049
Bergen	Teaneck	TEANECK	40.897	74.016
Bergen	Woodcliff Lake Boro	WOODCLIFF LAKE	41.017	74.050
Bergen	Wyckoff	MIDLAND PARK	40.983	74.150
Burlington	Moorestown	MOORESTOWN	39.967	74.967
Burlington	Shamong	INDIAN MILLS 2W	39.800	74.783
Burlington	South Hampton	PEMBERTON 3 S	39.933	74.700
Burlington	Willingboro	WILLINGBORO	40.028	74.869
Camden	Camden	CAMDEN	39.926	75.120
Camden	Camden	PENNSAUKEN	39.954	75.054
Camden	Cherry Hill	CHERRY HILL	39.907	75.004
Camden	Gibbsboro	CAMDEN	39.844	74.964
Camden	Mount Ephram Boro	AUDUBON	39.883	75.083
Cape May	Dennis	BELLEPLAIN ST FOREST	39.250	74.867
Cape May	Lower	CAPE MAY 2 NW	38.950	74.933
Cumberland	Bridgeton	BRIDGETON	39.438	75.231
Cumberland	Millville City	MILLVILLE FAA AP	39.367	75.067
Cumberland	Vineland	VINELAND	39.465	74.997
Essex	Belleville	BELLEVILLE	40.794	74.164

County	*Municipality*	*Climate Station*	*Latitude*	*Longitude*
Essex	Bloomfield	BLOOMFIELD	40.807	74.187
Essex	East Orange	EAST ORANGE	40.767	74.205
Essex	Essex Fells Boro	ESSEX FELLS SERV BLDG	40.833	74.283
Essex	Irvington	IRVINGTON	40.725	74.231
Essex	Livingston	LIVINGSTON	40.796	74.315
Essex	Maplewood	MAPLEWOOD	40.731	74.273
Essex	Millburn	CANOE BROOK	40.750	74.350
Essex	Millburn	SUMMIT	40.741	74.360
Essex	Montclair	MONTCLAIR	40.813	74.217
Essex	Newark	NEWARK, INTERNATIONAL AIRPORT	40.700	74.167
Essex	Nutley	NUTLEY	40.820	74.159
Essex	Orange	ORANGE	40.770	74.240
Essex	West Orange	WEST ORANGE	40.798	74.239
Gloucester	Glassboro Boro	GLASSBORO	39.700	75.117
Hudson	Bayonne	BAYONNE	40.666	74.119
Hudson	Hoboken	HOBOKEN	40.746	74.035
Hudson	Jersey City	JERSEY CITY	40.733	74.050
Hudson	Kearny	KEARNY	40.762	74.123
Hudson	North Bergen	NORTH BERGEN	40.804	74.012
Hudson	Union City	UNION CITY	40.780	74.024
Hudson	West New York	WEST NEW YORK	40.787	74.014
Hunterdon	East Amwell	WERTSVI LLE	40.450	74.800
Hunterdon	Lambertville City	LAMBERTVI LLE	40.367	74.950
Hunterdon	Raritan	FLEMINGTON 5 NNW	40.567	74.883
Mercer	East Windsor	HIGHTSTOWN 2 W	40.267	74.567
Mercer	Ewing	EWING	40.270	74.800
Mercer	Ewing	TRENTON	40.274	74.817
Mercer	Princeton	PRINCETON WATERWORKS	40.333	74.667
Middlesex	Carteret	CARTERET	40.583	74.233
Middlesex	East Brunswick	EAST BRUNSWICK	40.430	74.407
Middlesex	East Brunswick	OLD BRIDGE	40.414	74.365
Middlesex	Edison	EDISON	40.504	74.354
Middlesex	North Brunswick	NEW BRUNSWICK 3 SE	40.467	74.433
Middlesex	North Brunswick	NORTH BRUNSWICK	40.447	74.489
Middlesex	Perth Amboy	PERTH AMBOY	40.510	74.270
Middlesex	Sayreville	SAYREVILLE	40.464	74.345
Middlesex	South Plainfield	PLAINFIELD	40.600	74.400
Middlesex	South Plainfield	SOUTH PLAINFIELD	40.580	74.415
Middlesex	Woodbridge	WOODBRIDGE	40.558	74.285
Monmouth	Freehold	FREEHOLD	40.267	74.250

County	***Municipality***	***Climate Station***	***Latitude***	***Longitude***
Monmouth	Long Branch City	LONG BRANCH OAKHURST	40.267	74.000
Morris	Boonton Town	BOONTON I SE	40.900	74.400
Morris	Dover	DOVER	40.890	74.560
Morris	Jefferson	OAK RIDGE RESERVOIR	41.033	74.500
Morris	Parsippany-Troy Hills	MORRIS PLAINS I W	40.833	74.500
Morris	Parsippany-Troy Hills	PARSIPPANY	40.862	74.406
Morris	Rockaway	CHARLOTTEBURG RESVOIR	41.033	74.433
Morris	Rockaway	SPLIT ROCK POND	40.967	74.467
Morris	Roxbury	WEST WHARTON	40.900	74.600
Morris	Washington	LONG VALLEY	40.783	74.783
Morris	Washington	POTTERSVILLE 2 NNW	40.733	74.733
Ocean	Berkeley	TOMS RIVER	39.950	74.217
Ocean	Brick	BRICK	40.052	74.107
Ocean	Lakewood	LAKEWOOD	40.084	74.207
Ocean	Tuckerton Boro	TUCKERTON	39.600	74.350
Passaic	Little Falls	LITTLE FALLS	40.883	74.233
Passaic	Passaic	PASSAIC	40.858	74.131
Passaic	Paterson	CLIFTON	40.879	74.144
Passaic	Paterson	PATERSON	40.907	74.150
Passaic	Ringwood Boro	RINGWOOD	41.133	74.267
Passaic	Wanaque Boro	WANAQUE RAYMOND DAM	41.050	74.300
Passaic	West Milford	GREENWOOD LAKE	41.133	74.333
Passaic	West Milford	WEST MILFORD	41.131	74.367
Salem	Woodstown Boro	WOODSTOWN	39.650	75.317
Somerset	Bridgewater	BOUND BROOK 2 W	40.550	74.567
Somerset	Bridgewater	SOMERVILLE 3 NW	40.600	74.633
Somerset	Franklin	SOMERSET	40.479	74.488
Somerset	Hillsboro	BLACKWELLS MILLS	40.467	74.583
Sussex	Branchville Boro	BRANCHVILLE	41.150	74.750
Sussex	Fredon	NEWTON ST PAULS ABBEY	41.033	74.800
Sussex	Hardyston	CANISTEAR RESERVOIR	41.100	74.500
Sussex	Wantage	HIGH POINT PARK	41.300	74.667
Sussex	Wantage	SUSSEX I SE	41.200	74.600
Union	Cranford	CRANFORD	40.650	74.300
Union	Elizabeth	ELIZABETH	40.666	74.178
Union	Hillside	HILLSIDE	40.696	74.230
Union	Linden	LINDEN	40.636	74.256

County	Municipality	Climate Station	Latitude	Longitude
Union	Linden	NORTH PLAINFIELD	40.630	74.247
Union	Rahway	RAHWAY	40.607	74.282
Union	Roselle Park	ROSELLE	40.664	74.263
Union	Scotch Plains	SCOTCH PLAINS	40.655	74.390
Union	Union	UNION	40.699	74.266
Union	Westfield	WESTFIELD	40.658	74.347