New Jersey
Department of Environmental Protection

Site Remediation and
Waste Management Program

Characterization of Contaminated Ground Water Discharge to Surface Water Technical Guidance

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Version 1.0

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List of Acronyms

DNAPL	Dense Non-Aqueous Phase Liquid
DTS	fiber-optic Distributed Temperature Sensing
ESC	Ecological Screening Criteria
ESNR	Environmentally Sensitive Natural Resource as defined in N.J.A.C. 7:1E-1.8
EETG	The Department's Ecological Evaluation Technical Guidance Document
FSPM	The Department's 1992 Field Sampling Procedures Manual
GPS	Global Positioning System
GW	Ground Water
GWQS	N.J.A.C. 7:9C-1 *et seq*. The Department's Ground Water Quality Standards
GWRS	N.J.A.C. 7:26D-2 *et seq*. The Department's Minimum Ground Water Remediation Standards
GWTG	The Department's Ground Water Technical Guidance: Site Investigation, Remedial Investigation, Remedial Action Performance Monitoring
LNAPL	Light Non-Aqueous Phase Liquid
MNA	Monitored Natural Attenuation
MNR	Monitored Natural Recovery as described in the US Department of Defense *Monitored Natural Recovery at Contaminated Sediment Sites* guidance document
NAPL	Non-Aqueous Phase Liquid
RI	Remedial Investigation as defined in the TRSR
SI	Site Investigation as defined in the TRSR
SW	Surface Water
SWQS	N.J.A.C. 7:9B, The NJDEP Surface Water Quality Standards
SWRS	N.J.A.C. 7:26D-3 *et seq*. The Department Minimum Surface Water Remediation Standards
TRSR	N.J.A.C. 7:26E-1 *et seq*. The Department's Technical Requirements for Site Remediation

1.0 Intended Use of Guidance Document

This guidance is designed to help the person responsible for conducting the remediation to comply with the Department's requirements established by the Technical Requirements for Site Remediation (Technical Rules), N.J.A.C. 7:26E, dated May 2012. This guidance will be used by many different people involved in the remediation of a contaminated site; such as Licensed Site Remediation Professionals (LSRP), Non-LSRP environmental consultants and other environmental professionals. Therefore, the generic term "investigator" will be 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 a person to vary from the technical requirements in regulation are outlined in the Technical Rules at N.J.A.C. 7:26E-1.7. Variances from a technical requirement or departure from guidance must be documented and adequately supported with data or other information. In applying technical guidance, the Department recognizes that professional judgment may result in a range of interpretations on the application of the guidance to site conditions.

This guidance supersedes previous DEP 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 6-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 who prepared this document:

Dan Cooke, AMEC Foster Wheeler Environment & Infrastructure, Inc.
Bill Cordasco, TRC Environmental Corporation
Scott Drew, Geosyntec
Nancy Grosso, DuPont Corporate Remediation Group
Bill Hanrahan, NJDEP, Bureau of Environmental Measurements and Site Assessment
Ward Ingersoll, NJDEP, Bureau of Environmental Measurements and Site Assessment
Jill Monroe, NJDEP, Bureau of Ground Water Pollution Abatement
Christina Page, NJDEP, Bureau of Inspection and Review
John Ruhl, NJDEP, Bureau of Environmental Evaluation and Risk Assessment
Terrance Stanley, Langan Engineering and Environmental Services, Inc.

2.0 Purpose

The purpose of this document is to provide guidance for the identification, characterization and monitoring of contaminated ground water impacts to surface water bodies and thereby assist in complying with the TRSR (N.J.A.C. 7:26E-1 et seq.). Specifically, this guidance provides tools for complying with the following rules when contaminated ground water has the potential to impact surface water:

- N.J.A.C. 7:26E-3.6(a); how to determine if there is a potential that ground water contamination from a site has reached surface water;
- N.J.A.C. 7:26E-4.4(a)1, how to determine if ground water contamination is a source of contamination in surface water and the migration pathway; and
- N.J.A.C. 7:26E-5.2(a)2 considerations for developing and implementing a monitoring program to effectively monitor the performance of the remedial action for contaminated ground water discharges to surface water.

3.0 Document Overview

This guidance provides tools and methods to characterize the ground water to surface water pathway to obtain the data necessary to evaluate contaminated ground water discharges to surface water. The document describes the following:

- an approach for conducting an investigation of contaminated ground water discharges to surface water;
- conceptual models of the ground water migration to surface water pathway;
- tools that are available to investigate the pathway; and
- remedial action performance monitoring considerations.

New Jersey has surface water bodies that range from intermittent streams to large river systems. The state also has ponds, lakes, and miles of coastal and estuarine water resources. Freshwater and saltwater wetland areas are found near many surface waters. New Jersey's surface water systems are located in a variety of geologic settings, from the glaciated regions of northern New Jersey to the coastal plain of southern New Jersey, and include ecologically unique and/or protected areas such as the Pinelands and the Highlands regions.

Being a densely populated state with a long development history, surface water has been historically used for a variety of purposes such as recreation, water supply and even dumping of pollutants. Because of the dense population and variable land uses, the State's streams, lakes, ponds, bays, ocean and ground water are impacted to varying degrees by point and nonpoint sources of pollution. Some contaminants affecting surface water come from non-point sources such as overland flow or storm water collection systems. Others come from point source discharges (e.g., wastewater effluent) or from contaminated ground water that discharges to surface water. The discharge of contaminated ground water is the focus of this document.

Sources of ground water contamination are highly variable. Some may be as simple as a single leaking residential heating oil tank, while others may be from petrochemical complexes in operation since before World War I. The end result is that the contaminants identified in ground water can be significantly different between sites in terms of plume size (horizontal and vertical extent), magnitude (contaminant concentrations), chemical composition (classes of contaminants), and chemical complexity (single source or multiple sources).

Based on the variability of ground water hydrogeology and surface water hydrology across the state, the ground water to surface water migration pathways for each site are unique. The magnitude of impact from a contaminant discharge to surface water also varies, and is affected by surface water flow, sediment characteristics and ecological communities at the discharge zone. Therefore, a site-specific investigation is required to characterize the contaminated ground water discharge and identify adverse impacts to surface water, sediment, and ecological receptors associated with that discharge.

3.1 Approach for Evaluating Contaminated Ground Water Discharge to Surface Water

When there is the potential that ground water contaminated above the Surface Water Quality Standards may discharge to surface water, the contaminated ground water to surface water discharge pathway should be characterized, and a Site Investigation (SI) of surface water and ecological receptors is required pursuant to 7:26E-3.6(a) and (b). A conceptual model should be developed to assist in determining if there is a potential that contaminated ground water is discharging to surface water, the following should be considered:

- The distance from the location of ground water contamination to the surface water body;
- The velocity and direction of ground water and contaminant flow;
- The estimated length of time that ground water contamination has been migrating; and
- Preferential flow paths.

A conceptual model that incorporates physical, hydraulic, and chemical aspects of the system should be developed to support a decision regarding the potential for ground water contamination to impact surface water. In addition, the conceptual model will support a sound field investigation approach. Guidance on conceptual models can be found in the Department's "Technical Guidance for the Preparation and Submission of a Conceptual Site Model" and the "Ground Water Technical Guidance: Site Investigation; Remedial Investigation; and Remedial Action Performance Monitoring" (GWTG).

The objective of the investigation is to sufficiently characterize the contaminated ground water discharge zone(s) and determine if the ground water contaminant migration pathway to surface water is complete. Impacts to surface water, sediment, and ecological receptors will need to be characterized in accordance with the TRSR and the Ecological Evaluation Technical Guidance (EETG). The investigator must be familiar with the provisions of the Surface Water Quality Standards (SWQS) at N.J.A.C. 7:9B-1.5 and 1.14 that are incorporated into N.J.A.C. 7:26D, the Department's Remediation Standards, including the antidegredation policies and surface water classifications that may influence remedial actions in different parts of the state. The goal of the SWQS is to restore waters that exceed criteria, maintain waters that are better than criteria, and preserve those waters determined to be of outstanding natural resource value.

3.1.1 Ground Water Remedial Investigation Approach

Pursuant to 7:26E-4.3(a)4 and 4.3(b)1, the person responsible for the remediation shall delineate the horizontal and vertical extent of ground water contamination. Technical guidance concerning delineation of ground water contamination is available in the Department's GWTG.

When there is the potential that a ground water contaminant plume discharges to surface water, the contaminated ground water discharge zone(s) must be located so that surface water, sediment pore water, and sediment sampling can be biased to the area that is most contaminated in accordance with the SI requirements for all media in the TRSR N.J.A.C. 7:26E-3.3(a). Identification of the groundwater discharge areas can be achieved by utilizing the methods and tools outlined in Section 6 of this document.

3.1.2 Surface Water SI and Ecological Evaluation

After the contaminated ground water discharge zone has been located, surface water samples are collected from the area to assess potential surface water impacts, to compare to SWQS and assess risk to water column receptors. The EETG should be consulted for characterization of sediment and sediment pore water to assess risk to the benthic community. The most contaminated portion of the discharge zone will be targeted for sampling to assess worst case conditions. Sampling locations should be selected in accordance with the TRSR, this guidance and the guidance provided in the Department's EETG.

3.1.3 Investigation Results

Sample results are compared to the applicable Remediation Standard (N.J.A.C. 7:26D-1 *et seq*.) and are evaluated using the EETG. Where standards or criteria are exceeded, a remedial investigation of surface water or ecological receptors is required in accordance with the TRSR. Guidance on complying with the Department's Remediation Standards and Criteria may be found in the Department's *Technical Guidance for the Attainment of Remediation Standards and Site-Specific Criteria* and EETG.

Where surface water or ecological samples do not exceed the applicable SWRS or ESC, no remedial investigation concerning the ground water impact to surface water pathway is required. However, the ground water contaminant plume and surface water may need to be monitored to ensure that contaminated ground water does not impact surface water at a future time as discussed in Section 7. Monitoring should continue until there is no longer the potential for ground water contamination to impact surface water. Table 1 provides a general outline for the evaluation of ground water, pore water and surface water data.

4.0 Conceptual Models of GW-SW Interaction

The development of an investigation approach should begin with a representative ground water to surface water conceptual model. Guidance on developing a conceptual model of site hydrogeology may be found in the Department's GWTG at http://www.nj.gov/dep/srp/guidance/srra/gw_inv_si_ri_ra.pdf . The initial conceptual model of ground water surface water interaction should begin with a desktop review of available data for the location of interest. General resources include the following:

- Topographic Map http://topomaps.usgs.gov/
- Geologic Map http://www.state.nj.us/dep/njgs/pricelst/geolmapquad.htm
- Stratigraphic Cross Section: Use data from site related and nearby boring logs http://datamine2.state.nj.us/DEP_OPRA/OpraMain/categories?category=WS+Well+Permits
- Estimate of Hydraulic Conductivity: site specific tests or estimated from the New Jersey Geological Survey hydro database http://www.state.nj.us/dep/njgs/geodata/dgs02-1.htm
- Real time ground water and surface water data: http://nj.usgs.gov/
- Streamflow: http://nj.usgs.gov/

Several conceptual models of ground water surface water interaction will be briefly discussed in this section. For a more comprehensive discussion of ground water to surface water conceptual models, including extensive illustrations, see the USGS Circular 1139 "Ground Water and Surface Water A Single Resource" available at http://pubs.usgs.gov/circ/circ1139/. In addition, Conant (2004) outlines the following 5 types of ground water interaction with surface water based on sediment and aquifer characteristics:

- Short circuit discharge: An area where natural or man-made conduits exist in the subsurface deposits that allow ground water from depth to rapidly reach the surface water.

- High Discharge: Areas of preferred ground water flow where streambed deposits with high hydraulic conductivity connect with aquifer deposits with high hydraulic conductivity.

- Low to Moderate Discharge: Areas where low to medium hydraulic conductivity streambed deposits are present relative to similar aquifer deposits or there is a low hydraulic gradient, or both.

- No Discharge: Areas where the hydraulic gradient between streambed deposits and aquifer is zero and no discharge to surface water occurs.

- Recharge areas: Areas where the hydraulic gradient between the streambed and aquifer is downward (surface water is recharging the aquifer).

4.1 Ground Water - Stream Interaction

Ground water interacts with streams depending on geologic and hydrologic conditions. Ground water flow can infiltrate through a streambed and become surface water and vice versa. When the elevation of a stream is lower than adjacent ground water elevations, ground water will flow to the stream and is known as a gaining stream. Under gaining conditions, base flow exists when ground water provides all inflow to a stream. Streams where surface water elevations are greater than ground water elevations and surface water recharges ground water are known as losing streams. Gaining and losing conditions can vary both spatially and over time. Spatially, a stream may be gaining along one stretch and transition to losing at another. This may be caused by changing geologic terrain or ground water withdrawal wells. Temporal changes in gaining or losing conditions may be due to rainfall events which increase stream stage relative to ground water elevation or droughts which can decrease stream stage relative to ground water elevation.

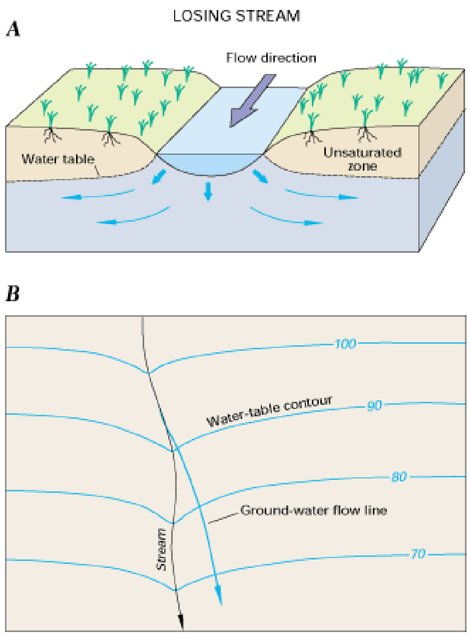

Figure 1. Losing Stream: Losing streams lose water to the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the downstream direction where they cross the stream (B)

Figure and Text courtesy of the U.S. Geological Survey (U.S.G.S. 1998)

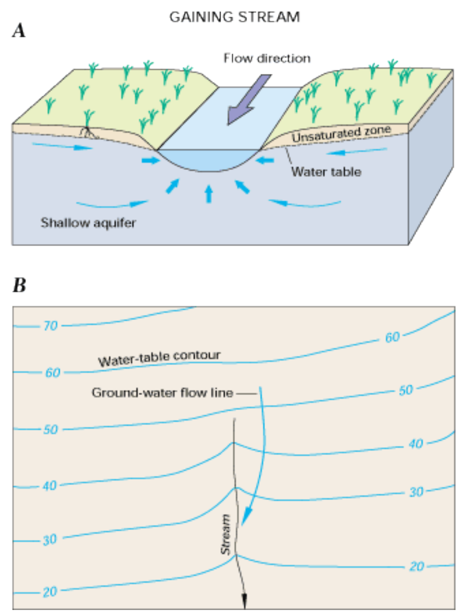

Figure 2. Gaining Stream: Gaining streams receive water from the ground-water system (A). This can be determined from water-table contour maps because the contour lines point in the upstream direction where they cross the stream (B)

Figure and Text courtesy of the U.S. Geological Survey (U.S.G.S. 1998)

The scale of gaining and losing can also vary. An entire reach of a stream may be considered typically either gaining or losing. Conversely, a stream may be losing along small portions of its path such as in the outside of a meander where swift running surface water may rise slightly above the adjacent ground water. Under certain conditions, one side of a stream may be gaining while losing on the opposite side. Identifying gaining or losing conditions along a stream reach influences the potential contaminant flux from ground water to surface water.

Natural losing stream conditions are rare in New Jersey. However, large scale losing stream conditions exist in coastal plain streams and rivers where ground water is depleted as the result of pumping for municipal drinking water supply. Temporary "losing" conditions caused by natural events, (e.g., associated with storm flows discharging to unsaturated bank soils), do not result in a net reversal of flow from streams to adjacent aquifers.

4.1.1 Ground Water and Streams Special Case: The Hyporheic Zone

The subsurface zone where stream water flows through short segments of its adjacent bed and banks is referred to as the hyporheic zone (USGS, 1998). Ground water and surface water mixing in this zone occurs in coarse-grained higher permeability sediments. Because of this mixing, the chemical and biological character of the hyporheic zone may differ from

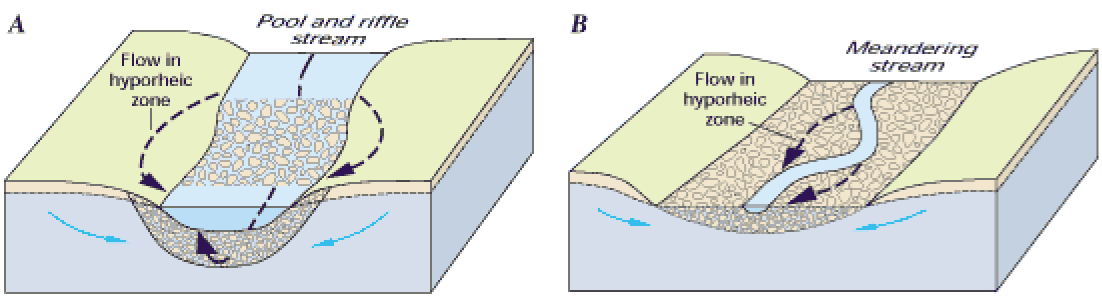

Figure 3. Hyporheic Zone: *Surface-water exchange with ground water in the hyporheic zone is associated with abrupt changes in streambed slope (A) and with stream meanders (B).*

Figure and Text courtesy of the U.S. Geological Survey (U.S.G.S. 1998)

adjacent surface water and ground water (USGS, 1998). Within the hyporheic zone a complex interaction between biology, geology and hydrology may take place creating unique ecological conditions that do not exist in either surface water or ground water. The zone provides a porous matrix where ground water flux and mass exchange occur, in addition to performing important biological functions. The size and geometry of hyporheic zones vary greatly with respect to the specific features of a fluvial system. With respect to the ground water to surface water migration pathway, the hyporheic zone provides a matrix where biogeochemical effects can be evaluated along the path of ground water flow. Conditions in the hyporheic zone can be very dynamic, exhibiting both temporal and spatial variation depending upon specific components of the drainage basin. For more information on the hyporheic zone see USGS (1998), USEPA (2008) and Environment Agency UK (2005).

4.2 Ground Water-Wetlands Interaction

Wetland hydrology may be sustained by ground water discharging as surface seepage or present as a perennially shallow water table. Wetlands may also be sustained by surface water, precipitation and topographic depressions or by a combination of these influences. It should be noted that wetlands do not always occupy low points and depressions, seepage wetlands can be present on slopes USGS as depicted in B below (1998).

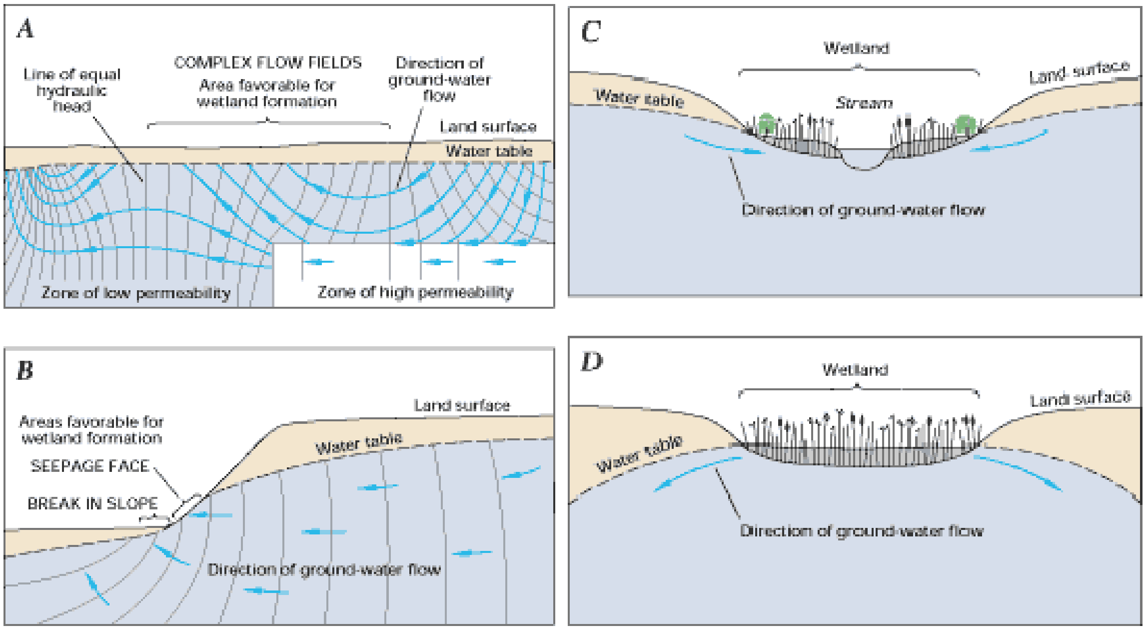

Figure 4. Wetlands and Ground Water

The source of water to wetlands can be from ground-water discharge where the land surface is underlain by complex ground-water flow fields (A), from ground-water discharge at seepage faces and at breaks in slope of the water table (B), from streams (C), and from precipitation in cases where wetlands have no stream inflow and ground-water gradients slope away from the wetland (D).

Figure and Text courtesy of the U.S. Geological Survey (U.S.G.S. 1998)

4.2.1 Tidal Fluctuations

Tidal fluctuation affects wetland hydrology in coastal wetlands and riverine aquatic environments by influencing the direction of ground water/surface water exchange. The extent of tidal influence on ground water/surface water exchange depends upon several factors including: the hydraulic gradient between the adjacent aquifer and wetland, lithology, tidal range, or nearby ground water withdrawals. Although local effects may be significant, the overall net ground water flow in aquifers proximal to tidal water bodies is seaward. However, a careful evaluation of tidal effects is needed in such areas to determine local ground water flow patterns and the likely route of associated contaminant flow to the surface water body.

4.3 Ground Water and Lake Interaction

Lakes interact with ground water in three basic ways: ground water may discharge to the lake; ground water may receive recharge from the lake; or ground water will discharge through part of the lake bed and be recharged by other parts (USGS, 1998). Lake sediments commonly have greater volumes of low permeability organic deposits than streams. These low permeability materials affect the distribution of seepage and biogeochemical exchanges of water and solutes more in lakes than in streams (USGS, 1998). Identifying the location of the ground water seepage areas is important for determining the location of contaminated ground water discharge zones.

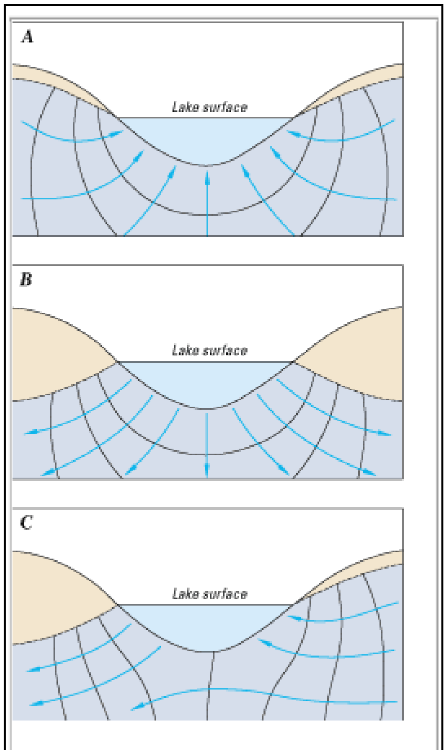

Figure 5. Lakes and Ground Water
Lakes can receive ground-water inflow (A), lose water as seepage to ground water (B), or both (C).
Figure and Text courtesy of the U.S. Geological Survey (U.S.G.S. 1998)

5.0 Site Specific Conceptual Model Development

A conceptual site model (CSM) is a representation of the conditions and the physical, chemical and biological processes that control the transport, migration and potential impacts of contamination (in soil, air, ground water, surface water and/or sediments) to human and/or ecological receptors (NJDEP, 2011- technical guidance for Conceptual Site Models). A technically sound conceptual model incorporates the important physical, biogeochemical, and chemical system parameters and integrates those parameters with consideration of the dynamic environment in space. The development of a CSM helps ensure consistency of a particular interpretation of the existing data set. The presentation of a CSM can be diagrammatic or a written description. For ground water and surface water interaction, diagrams and cross sections are often developed parallel to the direction of ground water flow as part of the ground water discharge to surface water conceptual model to illustrate important contaminant fate and transport pathways and processes.

5.1 Ground Water Flow and Discharge Parameters

Synoptic water table and river stage elevation measurements are used to determine whether a stream is gaining or losing at the time of the measurement. Although these measurements are critical for determining general ground water flow direction, other parameters can affect when and where ground water discharges to, or is recharged by, surface water on a local scale. The rate of ground water to surface water flow can vary from slow diffuse seepage to rapid concentrated flow. Parameters that affect the nature of the exchange at the ground water discharge to surface water transition zone include the following:

- ground water hydraulic gradient and aquifer hydraulic conductivity
- stream hydraulic gradient and stream bed hydraulic conductivity
- hydraulic gradient between ground water and surface water
- aquifer and stream bed sediment permeability
- geometry of stream bed at or near the ground water discharge zone
- sediment bedforms

5.1.1 Hydraulic Head Gradient

Ground water flows from areas of high hydraulic head to areas of lower hydraulic head. The quantity of ground water discharge (i.e., flux) to and from surface water bodies can be determined for a known aquifer cross section using Darcy's equation by multiplying the hydraulic gradient by the hydraulic conductivity and the cross sectional area of the discharge.

If necessary, more detailed evaluations can be made through sensitivity analysis and/or mathematical modeling. Hydraulic factors that can affect ground water volumetric and/or constituent mass flux, such as tidal variations in the receiving water, should also be considered.

Hydraulic head and surface water stage vary seasonally; therefore, ground water to surface water discharge patterns can vary in magnitude and direction throughout the year. Examples of seasonal influences include ground water mounding due to enhanced recharge or ground water depressions caused by evapotranspiration during the growing season. Seasonal conditions should be considered when head measurements are taken and interpreted. In addition, collecting hydraulic head data at multiple depths adjacent to the surface water body may be useful to determine vertical gradient.

5.1.2. Aquifer Hydraulic Conductivity and Stratigraphy

Geologic units with different hydraulic conductivities also have variable spatial ground water discharge (seepage distribution) in surface water beds. For example, a highly permeable sand layer within an aquifer consisting largely of silt transmits water preferentially into surface water as a subaqueous spring. An extreme case demonstrating this process is preferential flow in karst terrain or fractured bedrock.

5.1.3 Sediment Hydraulic Conductivity

Varying hydraulic conductivities of bed sediments can affect where ground water discharges to the surface water body. If a sediment bed consists of one sediment type such as sand, ground water discharge is generally greatest at the shoreline and decreases in a nonlinear pattern away from the shoreline toward the middle of the stream (USGS, 1998). However, if the sediment bed is mantled by a finer grained material such as silt or "river mud," most ground water seepage will occur in those areas with higher permeability. For streams with very coarse bed sediments, hyporheic flow may occur.

5.1.4 Geometry and Gradient of the Receiving Water Body

Meandering streams are one example of stream flow in and out of porous media (e.g., alluvial plain, floodplain deposits). Stream meanders and regions of locally high slope drive the exchange process between stream water and pore water. Woessner (1998) studied the flow paths of a meandering mountain stream that lies on sediment of fine sand and some gravel layers. At high stream discharge, flow is primarily in a downstream direction; at low discharge, more flow occurs in and out of the stream bank. Other considerations when developing the conceptual model are the size of the receiving body, surface water flow characteristics and the bathymetry of the surface water body.

5.1.5. Sediment Bedforms

In some cases, the morphology of the sediment bed influences the hydraulics of a system. Dunes and ripples similar to those seen in natural river deposits were reproduced in flume studies. The studies show that as stream flow proceeds over a dune, flow is induced under the bedform in such a way that surface water can flow into the porous media (bedform) and out into the stream again (Thibideaux and Boyle, 1987). For gravel, the depth of this pumping exchange can extend well below the base of the dune or ripple. Pumping is defined as the exchange due to advective pore water flow. Smaller pore spaces in sand streambeds restrict stream pore water flow coupling to a more shallow depth in the dune.

5.2 Modeling Tools to Help Constrain the Problem: Ground Water to Surface Water Discharge Modeling

A model is "any device that represents an approximation of the field situation" (Anderson and Woessner, 1992). While models are useful tools, they do not substitute for sampling to characterize the ground water to surface water pathway. A model may not be used to determine compliance with N.J.A.C. 7:26D, the Department's Remediation Standards, or ecological criteria.

In general, modeling requires the investigator to focus on the most important aspects of the field situation and can result in more efficient data collection and remedial action. There are two main types of mathematical models that are derived from a conceptual site model: analytical models and numerical models. Analytical models typically consist of a mathematical equation for which the user supplies the required input values and then manually (hand calculator or spreadsheet) calculates the result. Numerical models are more computationally complex and often require extensive input data and are processed using a computer. The advantage of numerical models over analytical models is that they can be used to simulate complex site conditions.

An overview of several models, including general advantages and limitations, that can be used for simulating discharge to surface water and ground water-surface water exchange is presented in Appendix 1.

5.3 Contaminant Fate and Transport Considerations

The transition from ground water to surface water may be considered to occur in one or more of the following three broader zones:

- Surface Water Column

  This can include the near-field (close to the area of ground water discharge) and far-field surface water (some distance downstream of the discharge zone where substantial mixing may have occurred).

- Biologically Active Zone

  This zone is generally located in surficial sediments, extending approximately 0 – 6 inches beneath the sediment surface. The biologically active zone is generally considered the exposure point for benthic organisms.

- Transition zone

  This is the zone where physical mixing and geochemical interaction of ground water and surface water may occur. The transition zone can be important in some settings (e.g., rivers, streams, lakes, wetlands) because it can store and retain nutrients and retain ground water contaminants through adsorption or biological and chemical transformations. The transition zone can be an important natural attenuation zone for contaminated ground water. In some cases, the transition zone and the biologically active zone can be the same zone or intersect one another.

If the transition zone is at a different redox state than the discharging ground water, the mixing of redox conditions can affect the discharging contamination plume. Variations in redox chemistry, surface water chemistry, and microbial communities can occur along gradients determined by ground water and surface water mixing. In some cases, these gradients are very steep over a relatively small distance. Due to these gradients, the dominant contaminant fate pathways may change. Conditions in the transition zone may be conducive to transforming or destroying contaminants, resulting in the attenuation of contaminant plumes at or before they reach the sediment surface water interface. Consequently, a ground water discharge from a contaminated plume into surface water does not necessarily translate to an impact to surface water quality. The role of the transition zone should be identified when evaluating the potential environmental fate of the contaminants of concern.

The processes responsible for in-situ contaminant attenuation can be divided into the following three categories:

1. Transformative: Transformative processes can be biotic or abiotic and represent a net chemical change and accompanying changes in contaminant toxicity or mobility. Examples of such processes are microbially mediated dechlorination reactions found in reducing environments. However, transformative processes do not always result in a toxicity decrease. For example, when perchloroethylene (PCE) degrades to vinyl chloride or mercuric ions biotransform to methylmercury, the products of the transformative reaction are more toxic than the parent contaminants.

2. Destructive: Destructive processes can be biotic or abiotic; however, these processes represent a net mineralization (i.e., breakdown of the compound to carbon dioxide, water, and other inorganic metabolites). In this way, transformative changes can be part of a sequential series of reactions leading to destructive processes. For example, the sequential reductive dechlorination of chlorinated ethenes to vinyl chloride can be followed by the oxidation of vinyl chloride to ethene and chloride under iron-reducing conditions.

3. Nondestructive/Retarding: Nondestructive/retarding attenuation processes are often the result of physical environmental characteristics such as organic carbon content and include reversible processes that affect contaminant transport through the transition zone (e.g., adsorption, precipitation/dissolution, ion exchange).

Under in-situ conditions, it is possible for all three of these mechanisms to play a role in contaminant fate and transformation.

- Organic-rich bottom sediment and mud typically produce highly reducing conditions and have a high sorption capacity for organic contaminants. When a high redox (oxidizing conditions) plume enters a transition zone characterized by low redox (reducing conditions), a zone of accelerated biodegradation of highly chlorinated compounds may result.

- Surface water flow through coarse bed material sometimes can maintain aerobic conditions, even when discharging ground water is anaerobic. When a low redox plume enters a zone of high redox (oxidizing) conditions, a change in degradation pathways from sequential reductive dechlorination to anaerobic and/or aerobic oxidation of the lower chlorinated daughter products may be produced by transformative reductive dechlorination processes. Tidal pumping can also deliver oxygenated water to the aquifer potentially enhancing oxidation of contaminants.

Not all contaminant transformations are desirable and, if the ground water is actively loading the transition zone with contaminants, it may cause the sediments to become reservoirs of contamination (Conant, 2000). Examples of transformation processes within the transition zone are presented in Appendix B.

5.3.1 Organic compounds

Biodegradation of organic compounds vary under differing redox conditions. Anaerobic degradation of certain compounds such as chlorinated ethenes is well established. There are numerous documented cases of aerobic degradation of other organics such as petroleum hydrocarbons. Refer to the Department's *Monitored Natural Attenuation Technical Guidance* (2012) for more discussion.

Individual compounds can degrade with differing efficiencies depending on the specific anaerobic redox conditions (e.g., iron reduction, sulfate reduction, methanogenesis) or aerobic conditions. Therefore, when developing the contaminant fate conceptual model, it is important to identify the range of redox conditions present within the transition zone.

5.3.2 Inorganic compounds

In the case of a ground water plume with inorganic contaminants, chemical reactions at the transition zone may also occur. Most metals are in a dissolved state at low pH and anaerobic conditions, and form a precipitate at higher pH or aerobic conditions. Anaerobic ground water containing dissolved metals discharging into an aerobic streambed or stream channel can result in precipitation of metals. Petroleum hydrocarbon plumes frequently contain dissolved iron and precipitation of the iron in surface water is not uncommon. Additionally, if ground water is characterized by low pH and high dissolved metals, infiltration of high pH seawater could cause precipitation of metals from solution.

The presence of a sulfate-reducing zone in the transition zone intercepting a low-redox ground water plume containing soluble reduced metals can result in metal contaminant attenuation by metal sulfide precipitation. An example of this process is the treatment of acid mine drainage through pH neutralization and insertion of a sulfate-reducing zone (usually by addition of a source of organic matter and sulfate) to intercept the contaminant plume. Under anoxic conditions, the metal sulfide precipitates should be effectively immobilized. However, if the redox conditions in the transition zone were to change, the metal precipitates can become oxidized and the metal contaminants remobilized.

5.4 Special Case: Non-Aqueous Phase Liquid seeps

The investigation and evaluation of NAPL seeps into waterways adjacent to contaminated underground storage tanks and above ground storage tanks have become an area of specific attention in New Jersey. Removing the free and residual product source will reduce mass loading of contamination to ground water, however, residual contamination in the aquifer may discharge to surface water. Depending on the hydrogeological setting, continued investigation and/or further remedial measures may be warranted.

The initial slug of contamination that reaches a water body through a preferential pathway can be trapped in the soil matrix of a stream bank or river bank. In this case, the continued release of NAPL may occur in the form of NAPL seeps. Specific concern arises during storm events when flushing of the aquifer matrix can result in increased seepage rates at the bank. Site specific evaluation should be undertaken to determine the significance of the migration and exposure pathways. Where there is a concern that NAPL has migrated to a water body, investigation and remediation of NAPL impacted sediment is required pursuant to the Department's TRSR.

6.0 Characterization Methods and Tools

A variety of methods and equipment have been developed to identify the location of ground water discharge zones in surface water and to evaluate the quality of ground water, sediment pore water, and surface water. . Rigorous delineation and characterization of groundwater discharges to aquatic receiving environments can be technically challenging. Therefore a tiered investigative strategy is acceptable. Professional judgement should be used to guide the investigation based on the complexity of the site and the potential impact from the groundwater pathway. Multiple lines of evidence should be evaluated to determine if contaminated ground water is discharging to surface water. The investigation of contaminated ground water discharge to surface water may be approached as follows:

- Determine the Location of Ground Water Discharge Zones in Surface Water
  - Examination of Existing Information
    - Hydrogeology
    - Ground Water Plume Orientation Relative to the Surface Water Body
    - Hydraulic Head
  - Reconnaissance and Investigation
    - Visual Inspection
      - Seeps/visual contamination
    - Thermal measurements
    - Conductivity and Resistivity Measurements
- Determine the Quality of Sediment Pore Water in the areas identified as potential contaminated GW Discharge Zones
  - Screening Techniques
  - Laboratory Chemical Analysis; and
- Determine SW Quality at GW Discharge Zones
  - Screening Techniques
  - Laboratory Chemical Analysis

The methods selected to evaluate the GW-SW migration pathway should reflect site-specific factors including:

- Hydrogeological setting (aquifer properties, ground water flow direction, etc.)
- Anthropogenic influences (fill, ground water diversion structures, buried utilities, etc.) and
- Surface water hydrology (drainage pattern, stream morphology, tidal influence seasonality, etc.)

The following sections summarize methods described in the FSPM, the EETG or that have been shown to be effective in peer reviewed literature. The discussion of the methods and equipment presented here is not exhaustive. NJDEP, USEPA, USGS and peer reviewed sources should be consulted for greater detail, and for technology updates and emerging technologies. Table 2 provides a brief description of each assessment technology identified in the following sections and includes references for further information along with respective pros and cons.
An evaluation of methods and techniques was conducted by Kalbus (2006) and includes an extensive reference list. The article is available at the following link: http://www.hydrol-earth-syst-sci.net/10/873/2006/hess-10-873-2006.pdf. The USGS also operates a National Research

Program concerning "Hydrologic and Chemical Interactions between Surface Water and Ground Water" at http://water.usgs.gov/nrp/science.php?sciArea=Groundwater-Surface%20Water%20Interactions. The program presents reports and methods to document ground water/surface-water interaction and is testing new field methods and models to evaluate those interactions.

6.1 Locating Ground Water Discharge Zones in Surface Water

A number of noninvasive methods based on visual and physicochemical properties are available for surveying areas to locate ground water discharge zones. Multiple lines of evidence may be necessary and will be contingent upon the size and depth of the water body.

6.1.1 Remote Sensing Data Inventories

Review of existing aerial imagery including; high resolution satellite imagery, black and white aerial photographs, color aerial photographs, near infrared imagery, and infrared imagery may reveal locations of potential ground water discharge zones. The investigator should closely examine the imagery for drainage networks and changes in vegetation. Examples of evaluating ground water discharge to surface water using remote sensing may be found in "Potential for Satellite Remote Sensing of Ground Water" (Becker 2006). An example of nighttime thermal infrared imaging used to identify submarine ground water discharge is available from the Woods Hole Oceanographic Institute at http://www.whoi.edu/page.do?pid=17135.

6.1.2 Visual Inspections

Visual inspections can be performed to identify seepage areas along surface water bodies. Visual inspections should be performed during low flow conditions after several days without precipitation and during low tide conditions (where the water body is tidal). Indicators can include the following:

- Active flow discharging from stream banks in micro-channels
- Areas of algal growth or wetland vegetation in otherwise upland areas above surface waters
- Areas of stressed or dead vegetation either above or below the water line
- Visible discoloration of soil along banks or sediment in the surface water body (e.g., natural oxides, contaminant staining, etc.)
- Chemical-related sheens, foam, etc. on the water body surface
- Existence of contaminant-related odors

Seepage faces, broad areas of saturated soil below the ordinary high-water line, may be evident during low water periods. Discrete discharges include distinct areas of ground water discharge surrounded by otherwise dry soils. Although seepage faces and discrete discharges are obvious target areas for sampling, additional deeper subaqueous discharge zones may also be present. For areas affected by tides, the visual inspection is most productive during low water/low tide conditions.

During winter months, ground water discharge points or seepage areas may be evidenced by ice free areas in frozen water bodies caused by ground water temperatures above freezing. Discoloration or staining of surface water, snow, ice, or exposed sediment due to

oxide/ferrihydroxide precipitates, may be encountered along the shores of surface waters, and may be evidence of ground water discharges and localized reducing conditions.
Depending upon the quantity and properties of the discharged contaminant(s), sheens, foam, or odors may be present at locations where the ground water contaminant plume is discharging to surface water.

6.1.3 Temperature Surveys

The transport of natural heat by flowing water has been used to evaluate the interaction of ground water and surface water. The contrast in temperature can be used to detect ground water seeps. This contrast is most evident during the winter (when comparatively warmer ground water is discharging to colder surface water) or summer (when the temperature contrast is reversed). By measuring the temperature of surface water and the temperature at shallow depths in sediments, Silliman and Booth (Silliman 1993) mapped gaining and losing reaches of a stream in Indiana. Sediment temperatures had little diurnal variability in areas of ground water inflow because of the stability of ground water temperatures. Sediment temperatures had much more variability in areas of surface water flow to ground water because they reflected the large diurnal variability of temperature in the surface water. This approach is useful for determining flow direction. Lapham (USGS 1989) used sediment temperature data to determine flow rates and hydraulic conductivity of the sediments based on fundamental properties of heat transport. Equipment that may be used to determine temperature variation includes the following:

- Thermal imaging cameras
  - Thermal Infrared Multispectral Scanner (TIMS)
  - Forward Looking Infrared Cameras (FLIR)
- Thermometers, Thermocouples, and Thermistors
- Fiber-Optic Surveys

This equipment is described further in Appendix 3.

6.1.4 Electrical Conductivity and Resistivity

Electrical conductivity of earth materials including soil, ground water and surface water varies with the physicochemical characteristics of each medium. Ground water flowing into surface water can sometimes be detected if its natural or altered electrical conductivity is measurably different from that of the receiving waters. For example, where ground water contains contaminants, such as dissolved metals, that increase its conductivity, or where ground water discharges to saline surface waters where a large difference in conductivity would be apparent.

In addition, resistivity measurements may be used to determine the location of ground water flowing into surface water. Detail on using conductivity and resistivity measurements is included in Appendix 4.

6.1.5 Hydraulic Head

Piezometers may be used to identify gaining and losing areas within a surface water body by comparing water level in the piezometer with the surface water level. This evaluation should be made during low flow conditions after several days without precipitation. The screened interval of the piezometers should be selected based on soil characteristics and lithology, and water levels observed in open boreholes or temporary wells advanced in areas proximal to the stream. Water level elevation data should be collected during base flow conditions after several days of dry weather to avoid measuring temporary increases in ground water elevation from precipitation events. Periodic depth to water measurements can be made in the piezometers while synoptic readings of water levels are made in stilling wells installed within the stream or on the immediately adjacent stream bank. Consistently higher elevations in the stream versus the adjacent wells indicate losing stream conditions, whereas the reverse condition indicates gaining stream conditions.

Hydraulic head can also be measured using a manometer board, or a potentiomanometer (a differential pressure gauge) hooked in line between the piezometer and a stilling well (or current damper) on the stream bed. Gaining is indicated when the hydraulic gradient is positive (USGS, 2005; USEPA, 2008).

6.2 Determining Sediment Pore Water Quality in Ground Water Discharge Zones

Sediment and pore water sampling may be conducted to delineate the extent of the contaminated ground water discharge zones. A variety of sampling equipment exists for the collection of pore water samples, as described further in this section and in Table 1. Note that elevated pore water concentrations may be due to ground water discharge or it may be due to partitioning of constituents from contaminated sediments. It is important to develop the conceptual model to the extent that the source of contamination is understood.

6.2.1 Pore Water Sampling Frequency

The frequency of pore water sampling will depend on the following:

- Streambed/bottom heterogeneity
- Location of temperature/conductivity anomalies
- Size of surface water body
- Size of potential discharge zones

Generally, more pore water samples are needed where bed materials are heterogeneous, where multiple temperature and/or conductivity anomalies are present, and where the surface water body or potential discharge zone is large.

Pore water samples collected from multiple depths beneath the bottom of the surface water body may be warranted to demonstrate the extent of biogeochemical changes occurring as ground water passes from deeper to shallower sediments, or conversely, changes in pore water quality with depth in losing reaches. The horizontal extent of contaminated pore waters can be determined by collecting a sufficient number of samples within the sediments until the contaminants are consistently detected below the SWQS or at background concentrations in both upstream and downstream locations with respect to the discharge zone.

6.2.2 Pore Water Sampling Equipment and Procedures

Equipment specifications and use recommendations are summarized in Table 1, and are described in greater detail in the EETG and the published technical literature, including that referenced in this guidance. Equipment that can be used for evaluating pore water quality includes:

Diffusion Based Samplers

- Dialysis Bags
- Peepers
- Diffusion Equilibrium in Thin Films (DET)
- Diffusive Gradient in Thin Films (DGT)
- Vapor Diffusion Samplers
- Semi-Permeable Membrane Devices (SPMD)

Direct Pore Water Samplers

- Pore Water Piezometers
- Syringe Samplers
- Push-Point Samplers
- Trident Probe
- Ultraseep

Equilibrium Samplers

- Solid Phase Micro-Extraction (SPME)
- Polyethylene and Polyoxymethylene Samplers (PE and POM)

6.3 Multi-parameter characterization tools

6.3.1 Trident Probe

The Trident Probe was developed by the United States Navy in cooperation with Cornell University to characterize sediment pore water in coastal water bodies such as harbors. The Trident probe contains a temperature probe, a conductivity probe and a sampling tube. The device can be installed by wading in shallow waters and pushed by hand, with a slide hammer, or an air hammer to the desired depth. In deeper waters it may be installed by divers.

6.3.2 Ultraseep

The most accurate method of determining GW-SW flux is quantification of seepage and measurement of contaminant concentrations leaving the transition zone. Seepage and flux meters are designed to sit on the surface of the sediment and collect the discharging water and contaminants for analysis.

The Navy designed the Ultraseep meter to allow simultaneous measurement of ground water and contaminant discharges and real-time measurements of temperature and conductivity across the sediment-surface water interface (Chadwick, 2008). The meter consists of a funnel that sits over the sediment and feeds water to an ultrasonic flow meter for ground water flow measurements; a water sampler; and probes for temperature and conductivity. The water sampler is equipped with a feedback control system that collects water at a rate less than the discharge rate into the chamber to avoid creation of artifacts associated with restricted flow. The Ultraseep meter has been successfully tested at several sites. In Eagle Harbor (WA), the meter detected low levels of tidally driven seepage (-5 to 5 cm/day) at all sites tested. The simultaneous measurement of conductivity showed evidence of fresh water discharge associated with tidal action. Combination seepage/flux chamber systems such as the Ultraseep meter are useful tools because they allow direct measurement of contaminant flux and yield data allowing accurate calculations of contaminant releases and dilution.

6.4 Determining Surface Water Quality at Ground Water Discharge Zones

Surface water samples should be collected from the 0 to 6 inch interval above the sediment surface where contaminated ground water discharge has been identified to determine worst case surface water quality. In the case of tidal waters, surface water samples should be collected at low tide when ground water discharge is most likely. The number and distribution of samples depends upon the size of the contaminated ground water discharge zone.
The type of sampling device, the number of samples, and the sample locations and depths are dependent upon the physical nature of the surface water body, accessibility, the contaminants of concern, and means of deployment. The NJDEP's FSPM and Table 1 of this document list a number of sampling devices.

Where there is a potential that off-site upstream contamination may be impacting the surface water body, surface water samples should be collected upstream and beyond the influence of discharges related to the site. The EETG recommends that 3 to 5 background samples be collected to refine the list of potential contaminants, determine if they are site-related, and assess site-related contaminants relative to regional conditions.

Analysis of surface water samples should be performed based on the individual targeted constituents or contaminant suite. An array of sample locations along the stream should be established to provide a density of data sufficient to evaluate the extent to which contaminants in ground water are impacting surface water quality. In addition to analysis of surface water samples for the anticipated contaminant suite, each sample should be collected in tandem with analysis of the field parameters including temperature, conductivity, pH, dissolved oxygen, turbidity, and in coastal waters, salinity.

7.0 Remedial Action and Performance Monitoring Program

A performance monitoring program is necessary to evaluate the selected remedial technology to assure that it is operating as designed and the Department's Remediation Standards and/or ecological goals are being met. Depending on the contaminated media of concern, performance monitoring may be accomplished through monitoring of ground water quality, sediment quality, sediment pore water quality and/or surface water quality. In addition, it is important to monitor the volume of flow and to account for dilution effects when monitoring quality parameters.

7.1 Remedial Action Strategies for Ground Water Plume Discharge

The remedial strategy for the ground water discharge should be planned and coordinated with the overall remediation strategy for the site. For example, if the remediation of sediments in the discharge zone is planned, it should be coordinated with the remedial action strategy for the contaminated ground water discharge to insure that the strategies are compatible. Ground water remediation strategies are discussed in a number of available references such as the U.S. EPA Contaminated Site Cleanup Information (CLU-IN; http://www.clu-in.org). There have been some recent demonstrations of technologies developed specifically for the mitigation of contaminated ground water discharge to surface water that are mentioned briefly in this section.

In general, ground water contaminant mitigation options on the land side may include the following:

- Treatment of the contaminated plume prior to the discharge using amendments
- Containment of ground water contamination hydraulically or physically
- Monitored Natural Attenuation

Ground water mitigation options on the surface water side or in the transition zone include the following:

- Amendments to enhance natural attenuation processes within the transition zone
- Treatment of the ground water plume at the sediment bed using amendments or permeable reactive caps
- Monitored Natural Attenuation

7.1.1 Ground Water Plume Treatment Amendments

Treatment technologies for the ground water plume along the discharge pathway may include a number of conventional approaches, including biostimulation, bioaugmentation, chemical oxidation or reduction, air sparging and other in situ technologies. When adding reagents to ground water, it is important to evaluate the potential physical/chemical impact of the remedial action on the receptor or on the ESNR.

Remedial technologies that require the injection of a reagent (liquid or gas) into the discharge pathway must be designed to control the application to avoid additional impact on the receptor in accordance with N.J.A.C. 7:26E-5.1(d). If a treatment technology is likely to produce intermediate or daughter compounds, the list of the compounds of concern to be monitored should be expanded to include these additional compounds.

7.1.2 Permeable Reactive Barriers in Ground Water or Sediment

Flow-through barriers placed perpendicular to the flow of ground water may also be an effective mitigation strategy. Barriers using zero valent iron, enhanced biological degradation, and air sparging have been used effectively in the treatment of chlorinated volatile organic compounds, metals and other contaminants. Engineering concerns include the assurance that the hydraulic conductivity of the barrier is greater than the native aquifer to encourage the flow of contaminated ground water through the barrier and not around it.

An innovative approach to the permeable barrier technology was demonstrated by USGS (Majcher 2009) at the West Branch of Canal Creek at Aberdeen Proving Grounds, MD. A permeable reactive mat was placed horizontally in the creek at the point of discharge to the creek. The mat included peat and compost and was bioaugmented with a bacterial culture. The system effectively degraded CVOCs prior to discharge in the creek.

7.1.3 Ground Water Containment

Physical and hydraulic barriers may be used to prevent or reduce discharge of ground water contaminant plumes to surface water. The ESNR should be considered when evaluating ground water containment options since reducing ground water discharge may adversely affect the natural recharge of a wetland, pond or small stream. Impermeable barriers include slurry walls and sheet pile barriers keyed into the appropriate aquitard. Physical barriers usually require active pumping and treatment of ground water to prevent migration of contaminated water around the barrier.

Hydraulic containment for ground water plume control is based on manipulating the subsurface hydraulic gradient usually through withdrawal of water. Ground water pumping and treatment may provide an effective way to mitigate discharges, but may impact an ESNR by reducing recharge from ground water and should be used with caution.

Recently, the USGS has evaluated the potential use of plants, shrubs and trees planted along the discharge pathway as a hydraulic containment technology (see http://sc.water.usgs.gov/projects/phreatophytes/). Plants that use sub-surface ground water (e.g., hybrid poplars, willows, etc.) may be effective during the growing season to reduce the discharge of contaminated ground water. In some cases, plants may also metabolize or mineralize contaminants in the root zone or other parts of the plant, adding a treatment element to the remedial approach.

7.1.4 Monitored Natural Attenuation and Recovery

Monitored natural attenuation (MNA) strategies as a sole remedy for a ground water contaminant plume that is causing surface water or an ESNR to be contaminated above standards or criteria may not be appropriate. In general, MNA remedies are precluded from being used as a sole ground water remedy when contamination has impacted a human and/or ecological receptor (see Section 4.2 of the NJDEP Monitored Natural Attenuation Technical Guidance) (NJDEP, 2012). However, a remedial action that controls ground water discharge to surface water may allow for implementation of an MNA remedy for the onsite plume. Refer to the NJDEP Monitored Natural Attenuation Technical Guidance for additional information on monitored natural attenuation of ground water plumes.

Natural attenuation of a ground water plume onsite may be appropriate where the source of the plume is removed, treated or contained and the biogeochemical conditions in the transition zone effectively treat the ground water contamination prior to discharge to surface water/sediment. In this case regular sampling of surface water and sediment should be conducted to assure that contaminants are degrading and will meet the remediation standards or ecological criteria.

By containing or treating the ground water contaminant plume prior to discharge to the surface water body Monitored Natural Recovery (MNR) of sediments may be appropriate when sediment has been impacted by the ground water contaminant plume, provided that sediment or pore water contaminant concentrations decrease over time to the applicable ecological criteria developed for the site. Refer to published guidance for more information on MNR (ESTCP, 2009; USEPA, 2005; USEPA, 2014; ASTSWMO, 2009).

7.2 Performance Monitoring

When a remedial action is selected and implemented, a performance monitoring program must be implemented pursuant to N.J.A.C. 7:26E- 5.2(a)2 to effectively monitor the performance of the remedial action. The design of the program should allow for the collection of samples in a manner that ensures reproducibility and allows for the development of a robust database appropriate for decision-making. Temporal factors, flow rates, tidal influences, storm water runoff and additional ground water or surface water discharges are all considered as part of the performance monitoring program.

7.2.1 General Considerations for Monitoring Ground Water and Surface Interaction

A remedial action performance monitoring plan should be site-specific and should address sources of hydrologic, spatial and temporal variability. The monitoring program should consider existing and designated uses of the surface water and its classification. The program needs to be protective of potential receptors (e.g., swimming areas, surface water intakes).

Fate and transport modeling may be used, as appropriate, to estimate mass flow and rate of ground water flow, to design a network of monitoring points and/or to develop a sampling regime. A monitoring/sampling regime may also address ecological factors. For guidance regarding ecological aspects, investigators should consult the EETG.

7.2.1.1 Climate/Weather

Seasonal and short-term weather effects on a site's hydrology should be considered when developing a monitoring program. For monitoring of contaminated sites, the hydrologic cycle should be viewed at a localized scale appropriate to the scale of the site (USGS 1998). Some hydrogeological settings are simpler than others, making them easier to characterize and monitor. The climate in some regions is less variable and easier to characterize and monitor (USEPA 2000).

Depending on the frequency, magnitude, and intensity of precipitation and on the related magnitude of the increase in stream stage, surface waters and adjacent shallow aquifers may be in a near-constant state of flux relative to ground water discharge to the stream (USGS 1998). Precipitation can result in the development of transient water table mounds at the edge of surface water bodies.

Evapotranspiration caused by trees and plants near the shores of a water body can cause a depression in the water table, particularly during the summer months, causing a losing condition in the stream. The resultant reversal in flow is most pronounced seasonally, but variability can be significant on a diurnal cycle (USGS 2008).

Extreme weather events (e.g., droughts and floods) can have a significant impact on a site. Rearrangement of bed sediments, changes in water flow paths, mass-transport of chemicals, and impacts to the biological conditions of a surface water body can significantly alter the hydrologic conditions of the site. Depending upon the temporal aspects of the conceptual model, sampling plans may include contingencies for data collection, during and/or after extreme events (USEPA 2000), although safety must be considered during the planning phase.

Stream gauging stations around the country are maintained by the USGS. The real-time or recent surface water and ground water flow and levels for the state of New Jersey are available, free of charge, online (http://waterdata.usgs.gov/nj/nwis/rt). The USGS also maintains 29 tidal stations in NJ to provide current conditions (http://waterdata.usgs.gov/nj/nwis/current/?type=tide;group_key=basin_cd).

NJDEP maintains numerous stream monitoring stations throughout the state, including the Ambient Surface Water Monitoring Network and the Ambient Biomonitoring Network which are all available online (http://www.nj.gov/dep/wms//bfbm/).
Precipitation data, flood data, and drought data for the New Jersey area are available through the National Weather Service (http://www.erh.noaa.gov/phi/hydrology.html).

7.2.1.2 Topography

Topography of the site and contributing drainage areas should be evaluated with respect to fluctuating stream flow conditions (e.g., hydrographic impacts of steep sided valleys versus broad lowlands). The duration of flooding at a site is largely determined by on-site and surrounding topographic features. The anticipated influence of topography should be factored into the remedy design and the monitoring plan.

7.2.1.3 Stream/Surface Water Morphology

The morphologic condition of a surface water body can affect the timing of sample collection. Variability of stream substrates (such as relatively competent bedrock or clay with limited permeability versus permeable granular sediments) can affect the selection and use of monitoring devices and the duration of monitoring. Additionally, flow across the sediment-water interface changes direction and velocity both spatially and temporally. Low permeability sediment may require longer residence time for passive sampling devices (days), whereas for more permeable substrates the diffusion membrane may be the controlling factor.

7.2.1.4 Tidal Influence

Tidal surface waters, particularly tidal streams, are more complex than non-tidal surface waters since their temporal changes occur hourly. This is significant because flow reversals can impact the distribution of contaminants, so a monitoring program should consider the variability over complete tide cycles. Timing of sample collection should be carefully timed with tidal conditions to provide representative data.

7.2.1.5 Urbanization

Urban development at the site and in the surrounding watershed can significantly impact the ground water to surface water flow regime. Landscape transition from open land to largely impervious surfaces not only produces greater runoff, but often collects and focuses that runoff at point source discharges (e.g., storm water infrastructure). The hydrography of surface waters in urban areas is similar to that of lesser developed areas with steep topography, in that both are more likely to "flash flood" during storms.

Diversion of ground water due to the presence of pumping wells and reduction in base flow to surface water can also result from urbanization. Monitoring programs should consider timing to capture base flow conditions that represent ground water contribution and not surface runoff.

It is also often necessary to monitor ambient background water quality conditions because of other potential pollutant sources to the system. These inputs may be temporally variable, occurring, for example after a significant rain event.

7.3 Developing a Remediation Monitoring Program

Remedial action performance monitoring is conducted to ensure that remedial system is operating as designed; to assess whether the remedy is effective in meeting the short-term remedial objectives; and to demonstrate compliance with the Remediation Standards or ecological risk-based remediation goal in accordance with N.J.A.C. 7:26E-5.2(a)3. The monitoring programs will be based on the specific performance objectives of the remedy. For long term monitoring the duration and frequency will be established in a Remedial Action Permit.

Depending upon the remedial action and the remedial action objectives, media that will be sampled may include the following:

- ground water elevations
- ground water quality
- surface water elevations
- surface water quality
- sediment quality
- pore water quality; and
- other physical or biological media

For example, if the selected remedy is hydraulic ground water containment, the monitoring program should include a network of wells that would demonstrate adequate control of the plume under the range of likely hydraulic conditions and with a frequency that considers natural variability of the system.

A Sampling and Analysis Plan (SAP) and a Quality Assurance Project Plan (QAPP) should be prepared to capture the key elements and protocols of the program. A monitoring program includes the following key elements:

- overall objectives and expected outcomes of the monitoring
- sampling media

- locations and depths
- frequency (consider seasonal and flow conditions/tidal cycles)
- constituent parameters and analytical methods
- sampling protocol (for consistency and comparability of results)
- duration of the program needed in order to make a decision

During the remediation design, it is important to understand how monitoring data will be used for decisions following implementation of the remedy. For almost all monitoring programs, baseline (pre-remedy) conditions should be well characterized to allow for comparison of pre- and post-remedy conditions or trends (USEPA, 2005).

The conceptual model and remedial objectives serve as the basis for defining the selection of media, location, number and frequency of the samples. Depending on the media that will be sampled, a statistical evaluation of the pre- and expected post-remedy conditions will ensure that adequate sampling is conducted in order to make decisions at any point in the process. Short term monitoring should allow assessment of whether the remedy was constructed as designed. Longer-term, monitoring data will be assessed to evaluate possible trends in the data, whether the monitoring program should be modified or optimized and when monitoring may be stopped. According to the NJDEP Attainment Technical Guidance, the remedy is complete when the Remediation Standard or ecological criteria is attained.
Below are some general guidelines that should be considered when developing a performance monitoring program:

- Existing or designated uses of the surface water (e.g., residential neighborhoods with kids in the water, designated swimming areas, potable water intakes).

- Ground water performance monitoring points should be located appropriately to adequately evaluate the impact of the remedial action on the ground water plume.

- For ground water flow control measures, wells should be located to assess potential lateral movement of the plume.

- To discern trends in ground water data, generally eight quarters of data are required, but duration of monitoring should be based on site-specific ground water velocities.

- For surface water monitoring, refer to the EETG. Collect samples in the water column based on the conceptual model, pre-remedy sampling and the remedy objectives.

- To the extent possible, note locations of surface water samples to ensure that monitoring samples will be collected from the same location during future events. Placing a permanent marker on the shoreline of the surface water body is good practice to assist the samplers.

- To aid in the evaluation of the impact of the discharge and the impact of background on surface water quality, collect a sufficient number of surface water samples in areas outside of the influence of the discharge point. The samples should not be collected in areas that may be impacted by other sources of surface water impacts (e.g., other contaminated sites, sewer or storm water discharge points, tributaries and other point and non-point sources).

- Consider monitoring flow and hydraulic head continuously to characterize variability on a daily, seasonal or annual scale prior to initiating the remedy (pre-remedy conditions) in order to develop an appropriate monitoring program.

- Generally, more sampling (physical and/or chemical) is needed during the initial phases of the performance monitoring program to determine hydraulic conditions, contaminant trends and the effectiveness of the remedial action. Once the remedial action has been operating properly and successfully, less frequent sampling may be appropriate.

- If a sampling program is to include biological factors (e.g., benthic invertebrates), sampling frequency may need to include organism life-cycle considerations. When this relationship has been determined, the frequency of sampling can be reduced (USEPA 2000). Refer to the EETG for further discussion.

If MNR is selected as the remedy, long-term monitoring plan should include monitoring endpoints that depend upon the processes that are dominant in natural recovery. As with other remedies, the monitoring endpoints will typically be contaminant and media specific. Some typical considerations for sediments, biota, and surface water are included below. For more detail see ASTSWMO, 2009.

- Sediments: If MNR is dependent on the burial of contaminated sediments, the monitoring plan should include measures of sediment deposition and erosion. If the remedial objectives are based on sediment contaminant levels, the sediments should be monitored periodically to determine whether the predicted contaminant reductions are occurring. If MNR is dependent on chemical transformation to achieve remediation goals, monitoring of the breakdown products of the contaminants should be included.

- Biota: If the site risk driver is due to human consumption of fish and/or shellfish, periodic tissue analyses of those organisms may be needed. If the site's risk is due to direct consumption of contaminated sediments by ecological receptors or food web interactions, tissue sampling may also be needed.

- Water: If the sediment remediation objectives for MNR are based on contaminant levels in surface water, those levels should be monitored periodically to determine whether the predicted reductions are occurring. They should be measured over a variety of flow conditions (e.g., high, low and storm event) if possible.

- Pore Water: If the remedial objectives were based on sediment pore-water concentrations, pore water samples should also be collected periodically.

- Monitoring should be continued until compliance with the Remediation Standards or ecological criteria have been attained. Sampling strategies that differ from those described above may be appropriate based on site specific conditions and objectives. There are a number of guidance documents available to help investigators develop an effective monitoring plan. Investigators are referred to the following:

- o Framework for Long-Term Monitoring of Hazardous Substances at Sediment Sites (ASTSWMO, 2009);
- o Guidance for Monitoring at Hazardous Waste Sites: Framework for Monitoring Plan and Implementation (USEPA, 2004)
- o Guidance on Systematic Planning Using the Data Quality Objectives Process. (USEPA 2006).

The Data Quality Objective (DQO) process was developed as a planning tool to help determine when enough data of sufficient quality has been collected to enable sound decision-making (USEPA, 2006).

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Tables

Table 1: Ground Water – Pore Water – Surface Water Data Evaluation

	Ground Water	Pore Water	Surface Water	Action
Is the Contaminant Concentration > the SWQS?	Y	N	N	Contaminants identified in ground water prior to discharge are not identified in pore water or surface water. The pathway is not complete. Remediate ground water contaminant sources and plume pursuant to the TRSR and Remediation Standards. Continue to monitor ground water prior to surface water in accordance with N.J.A.C. 7:26E-5.2(a)2 to ensure conditions improve in response to the remedial action and until there is no potential for violation of the SWRS in accordance with 7:9C-1.7(g).
	Y	N	Y	For site related contaminants, migration pathway sample locations must be re-evaluated. Samples may have been collected outside of the contaminated ground water discharge zone. Characterize ground water discharge zones and re-sample. Determine if there are additional potential AOCs by conducting a Preliminary Assessment. Upstream off-site source - upstream surface water sample locations must be included in the investigation to evaluate whether contaminants in surface water are emanating from an off- site source.
	Y	Y	N	Ground water contaminant migration pathway to pore water and sediment is complete. Attenuation, degradation, dilution between pore water sample zone and surface water sample may be occurring. Delineate ground water discharge zone(s). Evaluate designated surface water uses, actual uses and potential receptors. Evaluate ground water impacts on ecological receptors in accordance with the EETG. Remediate site source(s) pursuant to the TRSR and Remediation Standards – ground water and surface water. Monitor ground water, pore water and surface water as necessary in accordance with N.J.A.C. 7:26E-5.2(a)2 to ensure conditions improve in response to the remedial action and until there is no potential for violation of the SWRS in accordance with 7:9C-1.7(g).
	Y	Y	Y	Ground water contaminant migration pathway is complete: Delineate discharge zone(s); Evaluate surface water quality upstream of discharge zone(s) and site; delineate downstream extent > SWQS; and determine the horizontal extent (across water body) and vertical extent (water column) of impacts > SWQS by sampling at multiple locations and depths along a transect. Evaluate existing and designated surface water uses and complete HH SW receptor evaluation. In accordance with NJAC 7:26C-1.7(l), notify surface water users of exceedances and mitigation steps to limit exposure pending implementation of any remedial actions. Evaluate ground water impacts on ecological receptors in accordance with the EETG. Remediate source(s) pursuant to the TRSR, Remediation Standards – ground water and surface water. Remedial actions must also consider surface water classification, antidegradation policies, existing and designated uses, type of contaminant and concentrations, extent of impacted area, etc. and may require additional actions to prevent/control continuing migration of contaminants to surface water. Monitor environmental media as appropriate pursuant to N.J.A.C. 7:26E-5.2(a)2.

Table 2: Surface Water and Pore Water Assessment Methods

Media	Sampling Method	Device Name	Functional Description	Advantages	Disadvantages	Remarks
Surface Water	**Dip-Grab**	Sample Container	Dipping laboratory clean glassware slowly into surface water to allow filling and transfer to laboratory bottles.	Easily used, inexpensive, rapid sample collection, large volumes.	Only for very shallow waters; NJDEP requires within 6 inches of bed.	
	Pump	Peristaltic pump or other suction device	Uses peristaltic action and disposable tubing to collect samples from throughout water column.	Relatively easy to use and deploy; large volume sampling, rapid collection.	Cannot use for volatile compounds; limited lift capacity; not suitable for fast moving waters without anchorage. Requires power source.	
	Towed Electronic Probe	Electronic Groundwater Probe	Watercraft-towed probe measures and records near-bottom stream temperature, conductivity, and depth to detect groundwater discharge zones. Location logged with GPS.	Continuously records data at intervals of 1 to 3 seconds for temperature and as frequently as 0.05 seconds for conductivity. Suitable for long fluvial systems. Self-contained probe has no cables.	Tow line may become snagged on stream debris.	Electronic Probe is a groundwater probe adapted for in-stream profiling. Determine average velocity of stream segment to be profiled to estimate sample rate based on probe/GPS storage capacity. Preferable to enclose within protective permeable casing.
Sediment Pore Water	**Diffusion Sampling**	**Uses selected media (special water, gel, etc.) and semi-permeable membrane. Functions by allowing equilibrium attainment between surrounding water through diffusion barriers to the capture medium.**				All diffusion samplers can be readily deployed in shallow waters; divers are required for deeper installation/retrieval. There is variability in results obtained from different samplers; therefore great care is required when selecting a particular type.
		Water Dialysis Bags	Permeable membrane bags within protective sheath filled with water of specified quality to attain equilibrium based on pore water chemistry. Inserted into sediment and water retrieved for analysis.	Can be set to specific sediment depth for profiling; inexpensive, easily deployable.	Requires great care in selecting capture medium.	
		Peepers	Rigid permeable containers or perforated containers covered by permeable membrane. Filled with liquid of specified quality to passively attain equilibrium based on pore water chemistry. Inserted into subaqueous sediment retrieved for analysis.	Can be set to specific sediment depth for profiling; inexpensive, easily deployable. Box type allows for shallow transect sampling	Duration until retrieval could be lengthy; small sample volumes.	Suitable for most dissolved-phase organic and inorganic compounds.
		Diffusion Equilibration in Thin Films	Function is comparable to Peepers; however, a thin layer of gel is used as the capture medium.	Can be set to specific sediment depth for profiling; inexpensive, easily deployable. Gel layer results in faster equilibration.	Analysis limited to major element metals, and general constituents (e.g., alkalinity), trace metals, gases.	
		Diffusive Gradient in Thin Films (DGTs)	Casings filled with gels specific to dissolved phase target compound(s). Measure flux *in situ*.	After retrieval, gel can be segmented for multiple analyses. Equilibrates with pore waters within minutes.	Complicated preparation.	Can target metals, sulfide, or phosphorus.
		Vapor Diffusion Sampler	Vapor diffusion samplers consist of a sample vial with outer and inner permeable membrane bags. The inner bag remains on the vial during retrieval and a cap is screwed on over the bag to retain contents, which are then removed for analysis. Another arrangement uses an open vial with internal chemical trap that is inserted inside a polyethylene bag, and buried in the sediments.	Similar to above methods.	Limited to vapor-phase constituents (e.g., volatile compounds).	
		Amplified Geochemical Imaging Passive Sampler	Similar to vapor diffusion sampler but containing a hydrophobic medium in a semi-permeable membrane. Dissolved contaminants partition and cross the membrane to the adsorptive medium. The unit is removed and contents analyzed for volatile organic compounds by GC/MS. https://www.agisurveys.net/.	Can be set to specific sediment depth for profiling; inexpensive, easily deployable.	Limited to volatile organic contaminants.	
		Semi-Permeable Membrane Devices (SPMDs)	Polyethylene tubes filled with distilled water or Uses hydrophobic organic chemical medium (e.g., triolein) to capture hydrophobic constituents like dioxins, PCBs, PAHs, etc.	Similar to above methods.	Results are average concentrations over time.	Attempts to mimic absorption of chemicals to lipids in aquatic organisms.

Table 2: Surface Water and Pore Water Assessment Methods (cont.)

Media	Sampling Method	Device Name		Functional Description	Advantages	Disadvantages
Sediment Pore Water	Direct Pore Water Sampling	**Samples collected similar to ground water sampling.**		No equilibration period, rapid, repeatable sample collection, large sample volumes.	Generally limited to lotic or slow moving surface waters.	
		Pore Water Piezometers	Consist of narrow diameter piezometers inserted into sediments and slowly pumped to obtain pore water volume for analysis.	No equilibration period, rapid, repeatable sample collection, large sample volumes.	Limited to lotic or slow moving surface waters.	
		Syringe Samplers	Syringe samplers consist of stainless steel tubes with retractable plungers inside a stainless steel casing equipped with a flexible septum and filter screen. A vacuum sample vial with a double tipped needle is inserted into the sampler after the plunger is retracted to allow for filling. The needle punctures the flexible septum of the sampler and the attached vial, allowing for sample collection.	No equilibration period, rapid, large sample volumes	May not be amenable to compacted sediments or gravels. May clog in very fine sediments.	
		Push Point Sampler	Push point samplers consist of a slotted-tipped stainless steel rod that fills with water that can be pumped using a peristaltic pump. A solid polyethylene rod is kept in place during sampler advancement to prevent fouling.	No equilibration period, rapid, large sample volumes.	Limited to lotic or slow moving surface waters.	
		Trident Probe	The trident probe consists of three probes, one for measuring temperature, the other for measuring conductivity, and the other for sample collection.	Optimal method for identifying GW-SW interface; easily installed in shallow waters.	Requires using a slide hammer to advance or air hammer at deeper locations.	
		UltraSeep System	Integrated seepage meter and water sampling system for quantifying discharge rates and chemical loading from ground water to surface water.	Allows direct measurement of advective flux and contaminant concentration at a sampling point.		
	Equilibrium Samplers	**Measures pore water concentrations of freely dissolved hydrophobic organic compounds (e.g., PCBs, PAHs).**				
		Solid Phase Microextraction (SPME) Devices	PAH pore water concentrations are sorbed onto thin, organic polymer-coated silica fibers which are injected into a GC/MS.	Used in-situ or in the laboratory		Results correlate well with standard sediment toxicity tests. Has become standardized with USEPA and ASTM.
		Polyethylene (PE), Polyoxymethylene (POM), and Polydimethylsiloxane (PDMS) Samplers	Same as SPME devices.	Come into equilibrium faster than SPMEs.		Uptake of PCBs and PAHs correlates with benthic organism uptake.
	Centrifugation	Centrifuge	Large volumes of bulk sediments centrifuged to extract pore waters.		May result in elevated method detection limits.	

Notes:

1) For all diffusion samplers except the Amplified Geochemical Imaging Passive Sampler®, see USEPA Management and Monitoring Technologies for the 21st Century (21M2), Technology Innovation Program (http://clu-in.org/programs/21m2/)

2) For additional surface, sediment, and pore water sampling methods, see the *Field Sampling Procedures Manual*, New Jersey Department of Environmental Protection (August 2005) and *Ecological Evaluation Technical Guidance*, New Jersey Department of Environmental Protection, August 2012

Appendix A

Appendix A: Ground Water to Surface Water Discharge Models

Ground water to surface water discharge models may be utilized to estimate the impact of contaminated ground water discharges to surface water or evaluate potential remedial actions. However, empirical data are required to verify the estimates and predictions of models.

Analytical Ground Water to Surface Water Discharge Models

As a first approximation, ground water volumetric discharge to the surface water body can be calculated using Darcy's Law:

$Q = K \times i \times A$

Where:

Q = ground water discharge
K = hydraulic conductivity
i = the hydraulic gradient at the point of discharge
A = the discharge area (cross-section of the contaminant plume at the discharge point)

Some of the assumptions associated with this basic version of Darcy's Law include:

1. Flow is not three-dimensional
2. Uniform flow field
3. Homogenous and isotropic soils
4. Aquifer saturated cross section does not vary

The resulting discharge value is the overall seepage calculation for a given hydraulic field situation. If further information is known about fluctuations in surface water and ground water levels or variations in hydraulic conductivity along a bank, a range of discharges can be calculated.

Another simple analytical model for describing mixing (dilution) of ground water and surface water is:

$M_1V_1 = M_2V_2$

where M_1 equals the constituent of concern (COC) ground water concentration V_1 equals ground water discharge rate into the surface water body

V_2 equals surface water flux.

The equation is solved for M_2 which is the diluted COC surface water concentration. Limitations of this model include the following:

1. The assumption that mixing is instantaneous (which may not be reasonable for lakes or large rivers).
2. The ground water-surface water transition zone in sediments has no effect on COC concentration (i.e., transformative, destructive or retarding attenuation processes are not incorporated into the model).
3. No degradation occurs in the water column (such as photolysis or photo oxidation)
4. No upstream sources of the COC are present.
5. Ground water and surface water flux are constant (no daily or seasonal variations).
6. COC concentration in ground water is constant (no daily or seasonal variations; no decaying source).

Surface water mixing zones should be approximated on a site-specific basis. Some sites' hydraulics may justify using the entire width of a surface water body, while at other sites use of only a small fraction of the fresh water flow in a surface water body may be appropriate for mixing with ground water. In some cases a ground water plume will remain near the bank for a distance downstream of the discharge zone. A site-specific approach is recommended when determining the use and size of a mixing zone.

Appropriate surface water flow rates are generally available from US Geological Survey gauging stations. For acute effects (ecological and, if appropriate, human water use) the appropriate flow estimate is generally the $Q_{7\text{-}10}$ value, an estimated 7-day low-flow period anticipated to occur in a 10-year period. For chronic effects (such as carcinogenic effects), a long-term average flow represented by the harmonic mean is most appropriate.

The mixing (dilution) equation can be augmented with terms that account for many of these processes. However, the typical use of such a simple model is as a screening tool which is focused on assessing risk of impact to surface water rather than accurately predicting the fate and transport of contamination.

One example of a more complex analytical wastewater effluent model that can be used to address ground water to surface water discharge is CORMIX (based on the Cornell University Mixing Model). CORMIX is a surface water mixing zone model used to assess potential environmental impact of mixing zones resulting from continuous point source discharges. CORMIX consists of several models for the analysis, prediction, and design of discharges into watercourses (and atmosphere) emphasizing geometry and dilution in the mixing zone. CORMIX can simulate single-port, multiport diffuser and surface discharges. A major limitation for CORMIX is that aside from ground water and contaminant flux, CORMIX does not incorporate any properties of the adjacent aquifer or GW-SW transition into its calculations. http://www.cormix.info/

Assessing discharge of ground water to surface water is sometimes addressed using models developed for the management of effluent from wastewater treatment systems (WTS) such as Pennsylvania Department of Environmental Protection's PENTOXSD model or CORMIX (discussed further below). Such models are typically used to recommend effluent limitations for toxics and other substances. They include total maximum daily loads (TMDL) or wasteload allocations (WLA) discharged to surface water (e.g., streams). Modeling ground water to surface discharge using WTS models requires that impacted ground water discharge replace effluent flux of the WTS. A major drawback of this approach is that simply replacing effluent discharge with ground water discharge does not always adequately represent field conditions. For example, ground water plumes cannot always be represented as a point source or may have different mixing dynamics in surface water compared to effluent waste streams.

Numerical Ground Water to Surface Water Discharge Models

Numerical models are useful when field conditions are complex, such as when aquifers are as follows:

Heterogeneous and/or anisotropic
Have complex boundary conditions;
Ground water sources or sinks strongly influence ground water flow or
Hydraulic stresses vary through time

With these types of conditions most analytical models cannot adequately represent a system's dynamics. Some examples of numerical models are given below, although other appropriate models may also be available.

GSFLOW

The USGS numerical model GSFLOW (Ground-Water and Surface-Water Flow) is a combination of the Modular Ground Water Flow Model (MODFLOW) and Precipitation Run-off Modeling System (PRMS). This model integrates evapotranspiration, surface run-off, soil-zone flow and ground water interactions. This model does not incorporate fate and transport processes such as retardation, biodegradation or biotransformation in surface water or ground water.
http://water.usgs.gov/ogw/gsflow/

MIKE SHE

The Danish Hydraulic Institute's MIKE SHE model (based on the Système Hydrologique Européen modeling system) is a numerical model used to simulate ground and surface water flow during the land based phase of the hydrological cycle. The MIKE SHE model simulates rainfall becoming river flow, through various flow processes such as overland flow, soil infiltration, evapotranspiration, and ground water flow. MIKE SHE has been applied to investigations for the use of surface water and ground water for domestic and industrial

applications, wetland hydrology, and water quality investigations on both regional and local scales. MIKE SHE does not incorporate ground water fate and transport processes such as retardation, biodegradation or biotransformation.
http://www.crwr.utexas.edu/gis/gishyd98/dhi/mikeshe/Mshemain.htm

SHETRAN

SHETRAN, like MIKE SHE, is a numerical model based on the Système Hydrologique Europèen modeling system. SHETRAN was developed by the Water Resource Systems Research Laboratory, School of Civil Engineering and Geosciences, University of Newcastle Upon Tyne, UK. SHETRAN can simulate sediment erosion and transport, and dissolved contaminant transport. SHETRAN can also simulate nitrogen transformations in soils, flows near abstraction wells, has a particle tracking module for mapping ground water protection zones, and integration of a pipe network model for mine water pollution investigation and the management of ground water resources in karst regions. http://research.ncl.ac.uk/shetran/

A major limitation for numerical models is their application tends to be a significant effort. Another drawback is currently available numerical models do not have the capability to explicitly represent the ground water-surface water transition (hyporheic) zone. In general, for many sites a lack of details in the conceptual site model often does not merit the application of a numerical model.

1. Anderson, M.P., and Woessner, W.W. 1991. Applied Ground water Modeling: Simulation of Flow and Advective Transport. Academic Press. 381 pages.
2. PADEP. May 22, 2004. Technical Reference Guide (TRG) PENTOXSD for Windows PA Single Discharge Wasteload Allocation Program for Toxics Version 2.0. Document Number 391-2000-011.

Appendix B

Appendix B: Case Studies of Transformation Processes within the Transition Zone

There are a number of examples of biotransformation of contaminants in the ground water surface water transition zone in the published literature. Some examples are given below. Please see original manuscripts for a description of the methods used to characterize the systems.

Pine River, Angus, Ontario (Conant et al., 2005): High Redox Plume Entering Low Redox GW SW transition: resulting in accelerated degradation of PCE at the GW/SW Interface. The site consists of a ground water PCE plume that discharges into the Pine River. Although the plume was characterized, few contaminants or PCE daughter products were detected in the surface water. Yet, in discrete parts of the GW-SW transition, PCE and dechlorination daughter products were measured at levels above regulatory limits. Based on upland investigations and investigations within the stream bed, it was found that PCE transforms into vinyl chloride in the ground water plume. The vinyl chloride degraded within the GW-SW transition. The hydraulic conductivity through the GW-SW transition was highly variable. This variability, because it controlled residence time of contaminants in the transition zone, turned out to be a key factor in determining the fate of the chlorinated ethene contaminants. Successful transformation of the chlorinated ethenes required residence time in the low redox zone to be sufficient to allow degradation. As a result, the degree and rates of chloroethene transformation/degradation in the GW-SW transition were also spatially variable and inversely proportional to the hydraulic conductivity of the sediments.

Aberdeen Proving Ground, Maryland (Lorah, et al., 2005): A ground water plume of trichloroethene (TCE), 1,1,2,2-tetrachloroethane (PCA), carbon tetrachloride (CT) and chloroform (CF) discharged into a fresh water tidal wetland. The field data indicated transformation of the parent contaminants (TCE and PCA) to less chlorinated daughter products [cDCE, vinyl chloride, and di- and trichloroethane (TCA)] as the ground water moved through iron reducing, sulfate reducing and methanogenic zones in the wetland sediments that comprised the GW-SW transition zone. By the time the plume was within one meter of the surface, the only contaminant remaining was a trace amount of TCA. Breakthrough of the parent contaminants to surface water was not observed using peepers. However, daughter compounds were detected in surface water samples. Using infra-red imaging, discrete ground water seeps were discovered in the wetlands. At these seeps, the short residence time of contaminated ground water in wetland sediment prevented effective degradation and resulted in discharge of the plume to surface water. Laboratory studies determined that organic-rich wetland sediments were more sorptive of the chlorinated solvent contaminants and likely contributed to the overall plume attenuation through sorption reactions as well as longer residence times in the “reactive” wetland sediment. The following case histories occur on sites in which a low redox plume entered a high redox GW-SW transition, resulting in a zone where products of anaerobic transformation reactions are mineralized (i.e., the “polishing zone”).

St. Joseph National Priority List (NPL) Site, Michigan (Lendvay and Adriaens, 1999): Low Redox Plume Entering High Redox GW SW transition. At this site, a ground water plume containing TCE and small amounts of hydrocarbons discharged into Lake Michigan. This site is particularly interesting in light of the seasonal changes in wave action that control the oxygenation (and thus, redox) of the GW-SW transition. The wave water is supersaturated with oxygen and the pounding of the waves drives this oxygenated water into the transition zone, thus controlling the redox chemistry. As a result of winter storms, the wave action effect has strong seasonality. Profiles of contaminants with depth in the transition indicate that TCE is reductively dechlorinated to vinyl chloride and ethene within the deep transition zone (typically methanogenic to sulfate-reducing conditions). In contrast, in the more oxygenated shallow transition zone, TCE appeared to be degraded to cDCE and some vinyl chloride. The vinyl chloride concentrations in this area decreased with decreases in methane as oxygen concentrations increased.

Jonas Superfund Site, Mantua Creek, New Jersey (NJDEP records): At this site, ground water discharging to Mantua Creek was found to contain a plume of benzene, toluene, ethylbenzene, and xylenes (BTEX); chloroform; PCE; TCE; cDCE; and vinyl chloride. The presence of PCE daughter products in the plume indicated that reductive dechlorination processes were likely active in ground water. However, contaminants were present in a shallow, downgradient well between the site and the creek, raising concerns of contaminants reaching the surface waters of Mantua Creek. Although ground water was clearly shown flowing toward the creek along the length of the site, peeper data indicated that contaminant discharges to surficial sediments were limited to three discrete areas and that few or no contaminants were found at the sediment water interface or in the surface water. When contaminants were detected in the GW-SW transition, the peeper data showed contaminant concentrations dropping significantly within 6 centimeters of the sediment water interface. Contaminants were not consistently present in the surficial sediments, suggesting a possible seasonal effect. The transient nature of the contaminant discharge into the GW-SW transition indicates that, to accurately calculate annual flux, using data from several different sampling events may be necessary. The report concluded that aerobic oxidation of vinyl chloride, cDCE, and benzene was responsible for degradation of these compounds within the shallow sediments.

Appendix C

Appendix C: Temperature Measurement Equipment

Thermal imaging cameras

Thermal imaging cameras provide a non-invasive evaluation of temperature variation of the water body/shoreline environment. Light-weight, hand-held, high resolution thermal imaging cameras can be used at ground level to rapidly locate and characterize thermal contrasts in streams, lakes, etc. and their adjoining embankments and point bars. Temperature differences at a scale of centimeters to tens of meters are visualized in color in real time on a small screen on the camera. Thermal imaging is primarily a subjective evaluation, but depending on the sophistication of the camera, temperature differences may be quantifiable. Additional information is available at http://water.usgs.gov/ogw/bgas/thermal-cam/.

Infrared aerial imaging surveys can be implemented to identify ground water plumes discharging into surface water. This technology, which includes Thermal Infrared Multispectral Scanner (TIMS) equipment and commercially available Forward-Looking Infrared (FLIR) cameras (Loheide II and Gorelick, 2006) has made it feasible to monitor stream temperature from aerial-based platforms by distinguishing the heat signature of ground water in surface water bodies. Use of TIMS or other infrared technology is better suited to large study areas and larger surface water bodies where the temperature contrasts are more marked than in a small stream or pond. However, it is less well suited to water bodies where significant wave and rippling effects (ie mixing) can mask the ground water signature.

Thermometers, Thermocouples, and Thermistors

In-situ temperature measurements of sediment pore water and surface water can be both reliable and relatively inexpensive for determining the locations of ground water discharge to surface water, and vice-versa. In general, zones with the greatest temperature contrast between surface water and sediment pore water temperatures infer potential ground water migration pathway discharge locations for future sampling and analysis. Temperature measurements can be made with portable hand-held instruments such as thermometers, thermocouples, or thermistors. It is best to ascertain the strengths and limitations before selecting a device. Information can be obtained from manufacturers and in general, from the internet. Whichever device is selected, it is important for it to be rugged (or capable of being adequately protected), water compatible, and able to be calibrated to expected water temperatures. There are now a multitude of these instruments on the market, or which can be adapted from instruments that were originally engineered for other purposes.

Temperature Measurements along short reaches/smaller water bodies

A hand-held thermocouple probe connected to a hand-held display can be used to make real-time, in-situ temperature measurements of both surface water and underlying sediment. The measurements can be made while standing, or can be collected from a watercraft.

Temperature Measurements in longer reaches/larger water bodies

Thermal profiles of long, multi-kilometer river reaches can be accomplished by towing a light-weight, temperature-measuring probe just above the streambed. A self-contained, temperature measuring and recording probe, normally used for ground water monitoring can be encased in a protective housing and adapted for this use. Probe accuracy can be as sensitive as 0.1°C. When used in conjunction with a Global Positioning System, a thermal profile can be generated to link areas of ground water discharge to surface water. The length and detail of the profile are based on the sample frequency, data storage capacity of the particular probe, and data storage capacity of the GPS. A conductivity probe can also be used simultaneously to generate a conductivity profile.

Fiber-Optic Surveys

For certain applications, the use of standard telecommunications fiber-optic cables positioned singly or in an array along a selected stream reach or other surface water feature may be warranted, in particular, where long reaches of surface waters must be investigated and/or monitored. The method involves anchoring a fiber-optic cable with resilient sheathing (e.g., clad in stainless steel which is commercially available) to the bottom of the surface water body, then use a pulsing laser light along the cable, which is equipped with special sensors. The fiber-optic technology allows for rapid, accurate assessment of temperature within streams to identify areas of ground water inflow.

With fiber-optic distributed temperature sensing (DTS), it is possible to monitor stream temperature continuously at a resolution of 0.01oC, with a temporal resolution of fractions of a minute at a spatial resolution of one meter for distances up 30 km (Selker et al., 2006a). The DTS system is linked to a dedicated desktop computer with built-in data-acquisition and processing software. This technology provides temperature data with minimal setup or interpretation. It must be calibrated by placing the cable in an environment of known constant temperature (Selker et al., 2006b). Fiber-optic DTS uses the temperature dependent backscatter of light along fiber-optic cables to determine temperature at high spatial and temporal resolution. Several fiber optic cables can be connected to a single DTS instrument allowing for multiple longitudinal transects. http://infoscience.epfl.ch/record/97663/files/selkeretal2006.pdf

Additional information regarding the practical use of fiber-optic surveys can be found at http://water.usgs.gov/ogw/bgas/fiber-optics/.

Appendix D

Appendix D Conductivity and Resistivity

Electrical Conductivity along short reaches/smaller water bodies

Hand-held probes for measuring electrical conductivity and resistivity can be employed where surface water is shallow (Rautio, 2011).

Electrical Conductivity along longer reaches/larger water bodies

Measurement of electrical conductivity or resistivity along a streambed or lake bottom can be an effective means to identify ground water discharges in longer stream reaches and lakes where other methods (piezometers, sediment probes, etc.) are neither practical nor cost effective. One method involves towing an array of conductivity probes behind a motorized watercraft while simultaneously recording locations with a GPS unit. The conductivity probes must be kept in contact with the bottom in order to capture data representative of ground water discharges. This arrangement will only work in larger water bodies capable of supporting motorized watercraft, and which have smooth, snag-free bottoms. It is not suitable in water bodies with irregular bottoms or those with heavy vegetation. Data can be continuously generated at intervals of fractions of a second. The use of towed conductivity probes can also be coupled with temperature probes to provide a dual parameter approach to identifying ground water discharge zones. Some case studies demonstrating these techniques are found at Vaccaro and Maloy (2006), Harvey and others (1997).

Resistivity

Another method uses resistivity line(s) anchored to the bottom of the target water body to broadly delineate high-and low-seepage zones. In part, data resolution is determined by electrode spacing, the length of the line(s) arrayed, and spacing between lines. With commercially available resistivity inversion software, resistivity data are interpreted into 2D vertical profiles or 3D earth sections (Gagliano and others, 2009).