United States Environmental Protection Agency | Office of Solid Waste and Emergency Response | Publication 9285.6-17
EPA-540-R-06-072
July 2008

ECO Update/ Ground Water Forum Issue Paper

Intermittent Bulletin

Evaluating Ground-Water/Surface-Water Transition Zones in Ecological Risk Assessments

Joint Document of the Ecological Risk Assessment Forum and the Ground Water Forum

IN THIS BULLETIN

The ECO Update Bulletin series provides technical information and practices to EPA Regions and States on specific components of the ecological risk assessment process at Superfund sites and RCRA Corrective Action facilities. This document does not substitute for CERCLA, RCRA, or EPA regulations, nor is it a regulation. Thus, it cannot impose legally binding requirements on EPA, the States, or the regulated community and may not apply to a particular situation based on the circumstances. The Ecological Risk Assessment Forum and Ground Water Forum identify and resolve scientific and technical issues related to risk assessments and remediation of Superfund and RCRA sites. The Forums are supported by and/or advise OSWER's Technical Support Centers and provide state-of-the-science technical assistance to EPA project managers.

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1. Introduction

1.1 Purpose of This Joint ECO Update/ Ground Water Forum Issue Paper

Currently, there is a common perception that the discharge of contaminated ground-water to a surface-water body does not pose an ecological risk if contaminant concentrations in surface-water samples are below analytical detection limits or at very low concentrations. The transition zone represents a unique and important ecosystem that exists between surface-water and the underlying ground-water, receiving water from both of these sources. Biota inhabiting, or otherwise dependent on, the transition zone may be adversely impacted by contaminated ground-water discharging through the transition zone into overlying surface-waters. Ecological Risk Assessments (ERA) addressing contaminated ground-water discharge to surface-waters typically have not evaluated potential contaminant effects to biota in the transition zone. However, numerous hydrogeological and ecological methods and tools are available for delineating ground-water discharge areas in a rapid and cost-effective manner, and for evaluating the effects of contaminant exposure on transition zone biota. These tools and approaches, which are commonly used in hydrogeological and ecological investigations, can be readily employed within the existing EPA framework for conducting screening- and baseline-level ERAs in Superfund (U.S. EPA 1997) to identify and characterize the current and potential threats to the environment from a hazardous substance release.

This document was initially prepared as an ECO Update/Ground Water Forum Issue Paper to highlight the need to treat the discharge of ground-water to surface-water not as a two-dimensional area with static boundary conditions, but as three-dimensional volumes with dynamic transition zones. This ECO Update applies equally to recharge zones and can be used to evaluate advancing plumes that have not yet reached the transition zone. This document encourages project managers, ecological risk assessors, and hydrogeologists to expand their focus beyond shoreline wells and surface sediments and define and characterize the actual fate of contaminants as they move from a strictly ground-water environment (i.e., the commonly used "upland monitoring well nearest the shoreline") through the transition zone and into a wholly surface-water environment. The approach is presented to help users identify and evaluate potential exposures and effects to relevant ecological receptors within the zone where ground-water and surface-water mix. The transition zone data collected for the ERA may also supplement data collected for the evaluation of potential human health risks associated with the discharge of contaminated ground-water. Should ground-water remediation be warranted (as a result of the risk assessment), the locational, geochemical, and biological aspects of the transition zone can be considered when identifying and evaluating remedial options.

This ECO Update builds on the standard approach to ERA (U.S. EPA 1997), by providing a framework for incorporating ground-water/surface-water (GW/SW) interactions into existing ERAs (see U.S. EPA 1997 and 2001a for an introduction to ecological risk assessment). The purpose of the ERA within the risk assessment process is to:

a. Identify and characterize the current and potential threats to the environment from a hazardous substance release;
b. Evaluate the ecological impacts of alternative remediation strategies; and
c. Establish cleanup levels in the selected remedy that will protect those natural resources at risk (U.S. EPA 1994a).

This ECO Update focuses on the first of these by illustrating how one might consider GW/SW interactions when designing and conducting an ERA, both in terms of characterizing the physicochemical environment of the transition zone and evaluating potential ecological risks that may be incurred by receptors in the transition zone. The discharge of contaminated ground-water to a surface-water body through the underlying sediments is the principal focus of the document but other sources of ground-water contamination are also included that may be contributing potential risks to the biota of the transition zone and the overlying surface-waters (e.g., ground-water moving through contaminated sediment, NAPL discharge to sediment or surface-water, the role of downward vertical gradients). This document also identifies a suite of tools that can be used by all members of a site team (especially ecologists and hydrogeologists) to (1) determine the locations of contaminated ground-water discharging to surface-water; (2) estimate exposure point concentrations at these areas for use in evaluating potential ecological risks; and (3) evaluate actual and/or potential ecological effects of contaminants as they discharge to surface-water. Throughout this document, ecological resources means habitats, species, populations, and communities that occur at or utilize the ground-water discharge areas and the associated transition zones, sediments, and surface-waters, as well as the ecological functions of these entities (e.g., productivity, benthic respiration, biodegradation).

1.2 The Ground-Water/Surface-Water Transition Zone

1.2.1 Definition of the Transition Zone

The GW/SW transition zone represents a region beneath the bottom of a surface-water body where conditions change from a ground-water dominated to surface-water dominated system within the substrate. It is a region that includes both the interface between ground-water and surface-water as well as the broader region in the substrate (and, on occasion, up into the surface-water body) where ground-water and surface-water mix. Transition zones occur in stream, river, estuarine, marine, lake, and wetland settings, and may include the mixing of cold and warm waters, fresh and marine waters, or waters having other physical or chemical differences. The transition zone is not only an area where surface and ground-water mix, but also an ecologically active area beneath the sediment/water interface where a variety of important ecological and physicochemical conditions and processes may occur. Transition zones beneath streams and rivers may be termed hyporheic zones (White 1993) and those beneath lakes and wetlands termed hypolentic zones. A new discipline that studies ground-water relationships to surficial ecological systems is referred to as "ecohydrology" (Wassen and Grootjans, 1996) and has been the subject of recent study (Hayashi and Rosenberry 2002).

The existing and potential ecological effects of contaminated ground-water in the transition zone can be important considerations in site characterization and ecological risk assessment. In the past, ground-water and surface-water were typically viewed as separate compartments of an aquatic ecosystem, connected at the sediment/surface-water boundary. This paradigm ignored (1) the ecosystem that occurs within the transition zone, (2) the important geochemical and biological roles this zone may have in the local ecosystem (i.e., Gibert et al. 1994), and (3) the dynamic nature of this zone that results from the highly variable flow conditions in ground-water and surface-water. The new paradigm in this ECO Update/Issue Paper explicitly includes consideration of the transition zone as a vital habitat that is interconnected with, and supports the surface-water ecosystem (Valiela et al. 1990; Williams 1999).

1.2.2 Spatial and Temporal Variations of Transition Zones

The locations and characteristics of transition zones and associated ground-water discharge areas vary both spatially and temporally. These spatial and temporal variations will affect the occurrence and distribution of habitats dependent on ground-water discharge, and influence the ecological roles that the transition zone may have in maintaining local biotic communities. Not all areas of a surface-water body receive ground-water discharge.

The spatial distribution and the rate and direction of water flow within transition zones will be influenced by the type of water body into which the discharge is occurring, the elevation of surface-water relative to that of ground-water, and the underlying geological conditions. The rate of ground-water discharge may vary among the multiple discharges in direct response to hydraulic conditions and the varied geological characteristics in the discharge areas (Fetter 2000; Winter 1998). When there are large variations within a transition zone, a few preferential discharge areas may account for the majority of the discharge. Ground-water discharge rates also may vary temporally at individual discharge areas, reflecting seasonal changes in hydrogeologic conditions. Precipitation events, surface-water releases at dams or locks, and tidal fluctuations (including the reversal of water flow in the transition zone) also affect the rate of ground-water discharge to surface-water (Tobias et al. 2001).

1.2.3 Ecological Role of the Transition Zone

The understanding of the role that transition zones have in ecosystems directly influenced by ground-water discharges is increasing (Danielopol et al, 2003). Benthic and epibenthic communities (particularly invertebrate larvae, worms, bivalves, and fish) are major components of the transition zone ecosystem and many of these organisms spend part or all of their life cycle in contact with the sediments and ground-water that comprise this zone. These communities are well-known, valued for their ecological roles, and commonly assessed in ERAs. Typically, ERAs evaluate the effects of contaminated sediments on these benthic and epibenthic organisms because they are linked to upper-level trophic organisms via the food chain. However, as discussed in the examples below, other ground-water-influenced habitats within the transition zone as well as other transition zone organisms are ecologically important and therefore may appropriately be considered in the ERA. This document provides a framework to allow an ERA to better evaluate the existing and potential effects of contaminated ground-water on benthic ecosystems.

Although water may flow in either direction in a transition zone (i.e., both ground-water discharge to surface-water and surface-water recharge to ground-water), the transport of contaminants by ground-water discharging to surface-water is the subject of this document. In some aquatic systems, areas of ground-water discharge provide important habitats for a variety of aquatic biota and create thermal refugia for fish by supplying cooler, well-oxygenated waters during summer months or maintaining ice-free habitats in colder climate streams (Power et al. 1999).

Areas of ground-water discharge can create conditions capable of supporting spawning, feeding, and nursery habitats (Dahm and Valett 1996). For example, Geist and Dauble (1998) showed how nest site selection by salmonids is strongly influenced by the location of ground-water discharge zones in streams and estuaries. Ground-water discharge areas in streams may also provide important refugia for fish and invertebrates during the dry phase of intermittent streams and during stream flood events (Stanford and Ward 1993; Power et al. 1999). Algal community structure and recovery following disturbance have been shown to be influenced by ground-water discharge to the surface-water (Grimm 1996). Because of the important ecological role of the ground-water discharge areas, the discharge of contaminated ground-water may result in adverse ecological impacts to biota utilizing those areas (Carls et al, 2003).

In addition to the habitats at the sediment/surface-water interface, transition zones in these discharge areas have been shown to provide direct habitat for a variety of insect and fish larvae (Hayashi and Rosenberry 2002). For example, studies of freshwater hyporheic ecosystems have shown that some invertebrates utilizing the transition zone as a refuge may descend meters into the transition zone on a daily or seasonal basis.

Furthermore, a healthy, diverse flora and fauna in the transition zone is beneficial to basic aquatic ecosystem functioning. The wide array of organisms within the transition zone are critical to nutrient, carbon, and energy cycling in aquatic food webs (Storey et al., 1999; Hayashi and Rosenberry 2002). For example, up to 65 % of invertebrate production in a sandy stream was reported to occur in the hyporheic zone (Smock, et al. 1992; Boulton 2000). The thickness of the transition zone directly affects the amount of habitat available for these organisms. A potential for adverse impacts exists where contaminants, degradation by-products, and/or secondary stressors (such as low dissolved oxygen [DO]) associated with the ground-water come in contact with these biota in transition zone habitats.

The microbial community of the transition zone—via their function in carbon and nutrient cycling—has been shown to play an important, potentially beneficial role at some sites in the biodegradation and attenuation of ground-water contaminants (Lorah et al. 1997; Ford 2005). For example, at a site in Angus, Ontario, a detailed hydrogeological study indicated microbial activity in the thin transition zone of the Pine River to be responsible for significant attenuation of a chlorinated solvent plume (Conant et al. 2004). Microorganisms are often responsible for the very sharp oxidation-reduction (redox) gradients that frequently occur across the transition zone (Fenchel et al. 1988; Wetzel 2001). These biochemical changes may aid the degradation and attenuation of organic contaminants, or may release chemicals (e.g., naturally occurring iron and manganese, degradation products of the organic contaminants) from the transition zone sediments; and these in turn can affect aquatic biota. Ground-water discharge may alter microbial activity in the transition zone, reducing DO levels to the point where habitat quality and biota are adversely affected (Morse, 1995; Pardue and Patrick, 1995).

1.3 Ground-Water and Contaminant Discharges in Transition Zones

Critical to the proper evaluation of ecological risks in the transition zone is an accurate determination of the location of contaminated ground-water discharge, which is expected to occur within a broader discharge zone. Determining contaminant discharge locations may be relatively straightforward or quite complicated, depending on the location of the source(s) of ground-water contamination with respect to a surface-water body, the hydrogeologic complexity of the flow system, the temporal variability in water table and surface-water levels, and the size (both vertically and horizontally) of the plume relative to the general ground-water flow paths. Plumes of contaminants will flow from contaminant source areas to points of discharge along pathways governed by the permeability of materials, the configuration of the hydraulic gradient, and density differential with respect to the surface-water body. One should not assume that a contaminant plume will discharge at a location that represents the shortest distance from a ground-water contaminant source area to the surface-water (Woessner 2000; Conant 2004). For example, contaminants originating from a source located in an upland area adjacent to a highly permeable stream corridor may be transported by ground-water for some distance downgradient (Figure 1, location A), sometimes following ancient paleochannels in the geology, before eventually discharging to the stream.

In contrast, ground-water contamination from a site located directly upgradient and generally in direct line with the stream channel and ground-water flow may be transported to the nearest point in the stream where it may discharge completely (Figure 1, location B). In some cases, ground-water transport of some contaminants may continue on to the next meander, with additional discharge of these contaminants occurring farther downstream. A contaminated ground-water plume may also partially discharge at one location (Figure 1, location C1), with the remainder of the plume discharging at yet another downgradient location (Figure 1, location C2), or the plume may pass under the surface-water body without discharge. Similarly, at any of the discharge locations several different GW/SW exchange conditions are possible that could affect the vertical transport of contaminated ground-water into overlying waters (Figure 2).

Patterns of ground-water discharge and other ground-water/surface-water interactions vary over time. Stream reaches and lakes may change from being locations of ground-water discharge to places of surface-water recharge to the underlying deposits when water levels in the surface-water body suddenly rise or the water table in the adjacent deposits decline below the surface-water level. Daily reversals in flow direction in the transition zone can occur in tidally influenced areas. Annual erosion and deposition of sediments along a riverbed can alter patterns of discharge (such as those shown in Figure 2) by rearranging the configuration of low and high permeability deposits. Even the implementation of remedial actions can alter ground-water/surface-water interactions if they change ground-water levels. For example, pump and treat remedies could cause drawdown of the water table and change ground-water discharge zone in an adjacent surface-water body into areas of induced infiltration (recharge of surface-water into the subsurface). Ground-water/surface-water interactions are dynamic but the transition zone is defined to encompass this full range of temporal and spatial variability.

1.4 Transport and Fate of Contaminated Ground-Water in Transition Zones

Many factors influence the transport and fate of contaminated ground-water as it travels though the subsurface prior to discharging to a surface-water body. Conant (2000) summarizes some of the most important factors in the context of contaminant plumes that discharge to surface-water:

- Physical and chemical characteristics of the contaminants;
- Geometry and temporal variations in the contaminant source zone (release area);
- Transport mechanisms (advection and

dispersion); and
- Reactions (destructive and non-destructive).

The complexity and dynamic conditions of the transition zone can considerably alter the plumes passing through the zone. For example, Conant et al. (2004) found that a tetrachloroethene (PCE) ground-water plume changed its size, shape, and composition as it passed through the transition zone. Biodegradation in the top 2.5 m of the transition zone also reduced the PCE concentrations but created high concentrations of seven different transformation products thereby changing the toxicity of the plume. The biodegradation was spatially variable and concentrations in the streambed varied by a factor of 1 to 5000 over distances of less than 4 m horizontally and 2 m vertically. Widely ranging concentrations of volatile organic contaminants have also been observed in plumes discharging to lakes (Savoie et al, 2000) and wetlands (Lorah et al , 1997). These studies not only demonstrate the spatial variability of contaminant concentrations in the transition zone, but also suggest that aquatic life within the zone can be exposed to relatively high concentrations when the contamination has not yet been diluted by surface-water.

Concentrations in contaminant plume discharges can change over time. Previous discharges may have acted as sources of contamination to the transition zone thus loading the associated sediment with metals or hydrophobic organic compounds. Moreover, the pattern of ground-water flow and contaminated discharge might have been different in the past such that contaminants in those sediments may not be at the locations that current ground-water flow paths would predict. Direct sampling of the transition zone can help identify such suspected conditions. It is important to note that transport and fate factors other than ground-water flow (e.g., sorption, reaction time) need to be considered in the conceptual site model as areas of high ground-water discharge flow may not necessarily be areas where the highest concentrations will be found in the transition zone. Conant et al., (2004) observed that interstitial water having the highest concentrations of organic contaminants and degradation products occurred in low discharge areas of the streambed. This finding likely reflected sorbed, retarded, or slowly advecting plume remnants of past high-concentration discharges that had yet to get all the way through the lower permeability, organic carbon-enriched deposits (Conant et al., 2004).

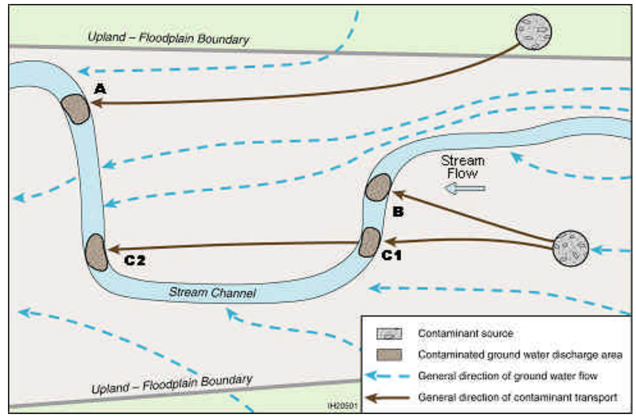

FIGURE 1 Plan View of Ground-Water Flow, Contaminant Transport, and Ground-Water Discharge Areas along a Hypothetical Stream Channel (Modified from Woessner 2000).

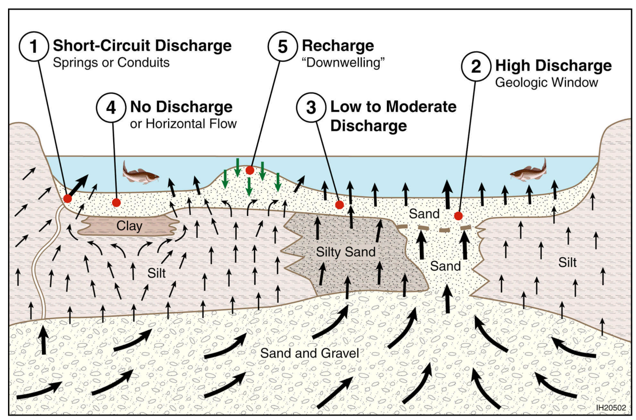

FIGURE 2 Conceptual Model of Different Types of GW/SW Exchange Conditions at the bed of a Surface-Water Body That may Affect the Transport of Contaminated Ground-Water into the Overlying Water (Modified from Conant 2004). (The arrows point in the direction of GW flow, and the arrow size depicts the relative rate of flow.).

2. Framework for Including the Transition Zone in Ecological Risk Assessments

2.1 The Ecological Risk Assessment Process and the Integrated Team

The ERA Guidance identifies an 8-step framework for designing and conducting ecological risk assessments for the Superfund Program (Text Box 1; U.S. EPA 1997). This framework describes the steps and activities needed to design and conduct scientifically defensible risk assessments that will support management decisions regarding site cleanup leading to a Record of Decision. Critical aspects of the framework are problem formulation and the associated development of a conceptual site model (CSM). Problem formulation establishes the goals and focus of the risk assessment, i.e., the ecological components and processes that are potentially harmed or at risk, as well as the assessment endpoints (specific processes, or populations/communities of organisms to be protected). The CSM characterizes the toxicological relationships between the contaminants and the assessment endpoints, as well as the exposure pathways by which the two are potentially linked (i.e., contaminant migration pathways, chemical alterations, and organism life histories; see ERA Guidance Steps 1 and 3). The CSM may also develop the risk questions to be addressed by the assessment (ERA Guidance Step 3), and identify the endpoints that will be measured (measurement endpoints) in order to provide the data necessary to address the risk questions. Because contaminants will partition among water, sediment, and organisms, a holistic CSM that includes all relevant compartments will be the most useful to guide the ERA and help determine how the partitioning has occurred or is occurring within the transition zone. This should help project managers with decisions about source control, which media to remediate, the influence of remedial work on contaminant fate and transport, and the potential for partitioning to alter the effectiveness of a proposed remedy (such as a sediment cap).

In the design and conduct of an ERA that includes transition zones and areas of ground-water discharge, it is critical that the project manager assemble a risk assessment team that is interdisciplinary and includes ecological risk assessors and hydrogeologists at a minimum. For practicality in this paper the term "hydrogeologist" is used to generically include all the team members who work mostly on the physical, hydrologic, and hydrogeologic aspects of site characterization (i.e., hydrologists, hydrogeologists,, etc.). Similarly, the term "ecologist" is used to generically include all the members who work mostly with the biological aspects (risk assessors, biologists, benthic ecologists, ichthyologists, zoologists, botanists, malacologists, limnologists, microbiologists, etc.). These disciplines should work closely together starting as early in the ERA process as possible. To adequately characterize the hydrogeological setting of a site, the hydrogeologists need to understand the local ecosystem, the habitats, the ecological endpoints to be protected from the adverse effects of ground-water-associated contaminants, and the exposure pathways that link the contamination and the endpoints. Similarly, it is critical for the ecological risk assessors to understand the spatial and temporal variability in the transition zone locations and the potential mechanisms for transport of contaminants by ground-water to surface-water. It is important to remember that the ground-water plume may not have reached the surface-water at the time of the assessment, but if it is likely to discharge to the surface-water in the future, there still is a risk of release that needs evaluation. Because, the spatial and temporal variability in ecological systems can be quite different from the hydrogeological system, the integrated team will insure data will be collected on scales useful for all disciplines. This interdisciplinary focus is most effective when initiated during problem formulation (U.S. EPA Guidance Steps 1 and 3). At this stage, the integrated assessment team will address: (1) the hydrologic regime of the site and its context in the watershed, (2) where and when ecological exposures may be occurring, (3) which organisms (and ecosystem functions) may be exposed to contaminants in the ground-water at the transition zone and associated ground-water discharge area, (4) which processes are affecting contaminants during transport (e.g., abiotic transformations, biodegradation, dispersion, diffusion, adsorption, dissolution, volatilization), (5) what additional data may be needed to support the risk assessment, and (6) the appropriate scope to fit project needs.

Text Box 1: The 8-Step Ecological Risk Assessment Process for Superfund (U.S. EPA 1997)

Step 1: Screening-Level Problem Formulation and Ecological Effects Evaluation
Step 2: Screening-Level Exposure Estimate and Risk Calculation
Step 3: Baseline Risk Assessment Problem Formulation
Step 4: Study Design and Data Quality Objectives Process
Step 5: Field Verification of Sampling Design
Step 6: Site Investigation and Analysis Phase
Step 7: Risk Characterization
Step 8: Risk Management

2.2 Including the Transition Zone in Designing and Conducting Ecological Risk Assessments

It is often difficult to describe complete exposure pathways when contaminants move among multiple environmental media and habitats. In aquatic systems, it is critical to recognize the static, dynamic, and interactive aspects of different media and their associated habitats. Currently, with ERAs that have ground-water and surface-water interactions, problem formulation and the CSM typically identify the contaminant source area, the ground-water flow paths from the contaminant source area, the surface-waters that receive discharge of contaminated ground-water, the media that may be contaminated (e.g., ground-water, surface-water, and sediment), and the habitats and ecological receptors that occur in those surface-waters. While these ERAs often include some aspects of the transition zone in the CSM, they more often do not specifically consider the ecological importance of the transition zone nor the relationships and interactions among ground-water flow, surface-water hydrology, sediment dynamics, and the transition zone biota. Rather, these ERAs typically evaluate only the biota associated directly with the sediment/water interface and/or with the overlying water column for adverse ecological impacts**.** In such ERAs, there is no explicit consideration of a transition zone, only a boundary line that separates ground-water and surface-water that is assumed to be the sediment/surface-water interface. Hence, the biota and ecological processes associated with this zone may not be appropriately considered during problem formulation. Appropriate consideration of the transition zone means that exposure, pathways, and potential effects are evaluated in a manner sufficient to meet the purpose of the ERA set forth in EPA guidance as indicated in Section 1.1 above. An effective approach to developing a CSM is illustrated in Figure 3. This can be adapted to accommodate a variety of different ground-water/surface-water settings such as wetlands (Lorah et al. 1997) and estuaries (Fetter 2000).

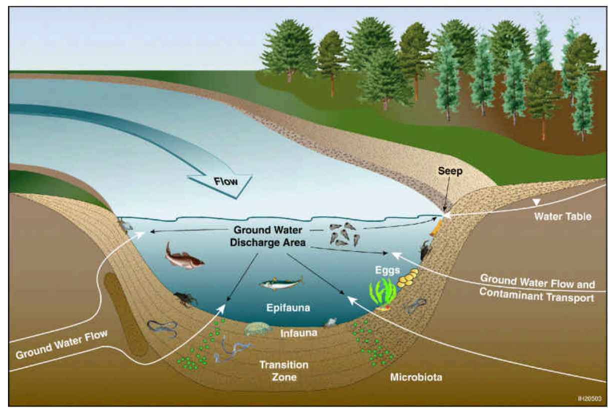

FIGURE 3 Conceptual Site Model Depicting Contaminant Transport via Ground-Water Flow, Followed by Discharge Through the Bedded Sediments in the Transition Zone into Overlying Surface-Water

2.2.1 Framework for Incorporating the Transition Zone into Problem Formulation

Consideration of the transition zone should begin as early as possible in the 8-step ERA process, preferably during problem formulation and CSM development. It cannot be overemphasized that problem formulation and the CSM should be based on the combined knowledge of the interdisciplinary team approach which includes hydrogeologists and ecologists on the team, at a minimum, and preferably should include the critical review of other team members, such as the project manager and a toxicologist. The following 5-step framework has been designed to incorporate the transition zone into problem formulation of the ERA process and to help develop a comprehensive ground-water/transition zone/surface-water CSM for any aquatic ecosystem.

Step 1 Review available site-related chemistry data to identify known or potential contamination
Step 2 Identify the hydrogeological regime and potential fate and transport mechanisms for ground-water contaminants, including (a) identification of areas of contaminated ground-water discharge and (b) the spatial and temporal variability in the magnitude and location of the discharges.
Step 3 Identify ecological resources at areas of ground-water discharge, including associated transition zones.
Step 4 Identify ecological endpoints and surrogate receptors.
Step 5 Develop a dynamic CSM and associated risk hypotheses and questions.

The activities in these steps usually take place during the design and conduct of an ERA, and thus do not necessarily identify activities that would be in addition to those normally developed when following the U.S. EPA 8-step process for an ERA (Text Box 1). In addition, due to the relationship between the CSM and ecological endpoints, the risk assessment team may find it useful to revisit these steps as they refine both the CSM and selection of endpoints.

Step 1 ***Review available site-related chemistry data to identify known or potential contamination***. In this step, the team determines if there is a potential for the ground-water to be contaminated, and, if so, whether the contaminants could be transported through the transition zone into overlying surface-water. Specifically, the team will focus on the question: *Is there known or potential (1) ground-water contamination and/or (2) sediment or surface-water contamination related to ground-water, and, (3) if so, by what contaminants?* The answer to this question will be based on a review of the historical site-related chemistry data regarding the source (i.e., the nature of the release and the known or suspected contaminants), potential contaminant migration pathways, and the affected environmental media (i.e., evidence of contamination in soil, ground-water, sediment, biota, and/or surface-water, including transformation products). This information will also be used to determine which contaminants may be encountered by ecological resources associated with the site. If it is determined that contamination is present or likely, the extent of contamination in discharging ground-water will need to be characterized.

Step 2 ***Identify the hydrogeological regime and potential fate and transport mechanisms for ground-water contaminants, including (a) identification of areas of contaminated ground-water discharge and (b) spatial and temporal variability in the magnitude and location of ground-water discharge.*** The nature and extent of GW/SW interactions at a site and the specific locations of ground-water discharge areas are important in the determination of potential exposure points for ecological receptors. In this step, the hydrogeologist and ecological risk assessor delineate contaminated areas and identify areas of contaminated ground-water discharge (and associated transition zones). The focus of this step is to address the question: *Where is the contamination and where is contaminated ground-water reaching the transition zone and then discharging to the surface?* Potentially contaminated ground-water discharge areas can be identified on the basis of:

- Available chemical and hydrologic data from site wells and shoreline work in the area (e.g., ground-water chemistry, NAPL presence, aquifer extent, preferential pathways, hydraulic conductivity, hydraulic gradients and flow directions [vertical and horizontal], water table elevation, and seasonal precipitation patterns);
- Physical features indicative of a ground-water discharge area may be identified during a site visit including seeps, pools in streams, and plant species that prefer ground-water discharge;
- Direct investigations during the site visit to locate and delineate ground-water discharges (e.g., using simple measurement techniques such as temperature or conductivity probes, minipiezometers with manometers or differential pressure gauges, or seepage meters; observations of certain plant species, areas of mineral precipitation, or areas with sheens; geophysics to map and track plumes);
- Direct investigations of contamination in the transition zone (e.g., sampling interstitial water using minipiezometers, miniprofilers, passive diffusion samplers), including temporal variability.

Step 3 ***Identify ecological resources in areas of ground-water discharge, including associated transition zones.*** As areas of ground-water discharge are identified, the ecological risk assessors will evaluate the conditions at these locations and in the overlying surface-water to identify the types of ecological resources that occur (or could occur) and be exposed to the ground-water-associated contaminants. The focus of this step is to address the question: *What are the ecological resources at risk from exposure to ground-water contamination at this location?* The risk assessors will make this determination on the basis of observations made during a site visit and through a review of available ecological data for the site. Ecological resources may include habitats, species, populations, and communities that occur at or utilize the ground-water discharge areas, the associated transition zones and sediments, and the surrounding surface-waters. These resources may be exposed directly or indirectly through the food web.

Step 4 ***Identify ecological endpoints and surrogate receptors***. The habitats that will be associated with areas of ground-water discharge may support a wide variety and diversity of biota that could be exposed to contaminants in the ground-water. However, it is not feasible or practicable to directly evaluate all of these biota. Instead, a few assessment endpoints (Text Box 2) are selected to represent risks to all of the individual components of the ecosystem (U.S. EPA 1992; 1997). In this step, the ecological risk assessors will identify appropriate assessment endpoints on the basis of:

- Contaminants and their concentrations,
- Potentially complete exposure pathways linking the contaminants with the endpoints,
- Mechanisms of toxicity of the contaminants and knowledge of the potential susceptibility of the endpoints to the contaminants, and
- Ecological relevance of the endpoint.

Detailed guidance on selecting assessment endpoints and linking them to risk determinations may be found in U.S. EPA (1997).

Text Box 2: Endpoints and Surrogate Receptors

Assessment Endpoint: an explicit expression of the environmental value(s) to be protected. Individual assessment endpoints typically encompass a group of species or populations with some common characteristic, such as a specific exposure route or contaminant sensitivity, or the typical structure and function of biological communities or ecosystems associated with the site (U.S. EPA 1992, 1997).

Measurement Endpoint: a measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint. The measurement endpoint provides measures of exposure and/or effects (U.S. EPA 1992, 1997).

Surrogate Species: a species that is considered to be representative of the assessment endpoint and for which measurement endpoints may be selected and on which the risk characterization will focus.

Assessment endpoints for the transition zone will focus on the protection of (1) the biota that live within or utilize the transition zone or the ground-water discharge area (including interstitial water, sediment, and surface-water), (2) other biota that may be exposed to the ground-water contaminants either through direct contact or indirectly through ingestion of food or sediment contaminated by the ground-water, and (3) the ecological functions of these biota (e.g., productivity, benthic respiration, biodegradation). For example, transition zone assessment endpoints may include the maintenance and sustainability of the infaunal community of the transition zone, maintenance and sustainability of conditions that support fish and other surface-water species that seek out ground-water discharge zones as habitat or refugia, or maintenance of the epifaunal community inhabiting the ground-water discharge areas. For such assessment endpoints, surrogate receptors (Text Box 2) for the transition zone may include microbial functions; infaunal organisms or communities (e.g., meiofauna, or macrobenthic invertebrates). Other surrogates may include epifaunal organisms such as plants and bottom fish, as well as life stages of various organisms such as incubating fish eggs.

In the case of a baseline ERA, one or more measurement endpoints (Text Box 2) will be selected to evaluate each assessment endpoint. These measurement endpoints could include benthic macroinvertebrate abundance and diversity; the survival, growth, or reproduction of the surrogate receptors as measured by laboratory and *in situ* toxicity tests or microcosms; the concentration of contaminants in the tissues of surrogate species (as a result of bioaccumulation or bioconcentration); sediment or ground-water concentrations; or concentrations in diffusion samplers. Because there are currently no methods available to risk assessors that allow for decision-based interpretations of changes in transition zone-associated organisms (especially with regard to the microbial community), the choice of surrogate receptors and associated measurement endpoints used to address the assessment endpoints for the transition zone may be limited to species and measurement endpoints for which methods are available.

Step 5 ***Develop a CSM and associated risk hypotheses and questions***. In this step, the information and results of the preceding steps will be used to develop a CSM that identifies the known or assumed relationships among the contaminant source, the environmental fate and transport of the contaminants in the ground-water, and the assessment endpoints that may be exposed to the contaminants (Figure 3). The CSM should also identify the potential effects that the assessment endpoints may incur from the exposure. These relationships represent working hypotheses of how the ground-water contaminants are moving or will move through the environment (i.e., moving through the transition zone discharging to overlying surface-waters) and affecting the assessment endpoints (associated with the transition zone and overlying sediments and surface-waters). The CSM thus helps to conceptualize the relationships between contaminants and assessment endpoints, frames the questions that need to be addressed by the risk assessment, and aids in identifying data gaps for which the collection of environmental data may be necessary.

Risk questions about the relationships between the assessment endpoints and their predicted responses when exposed to contaminated ground-water discharges can be developed along with the CSM. These risk questions provide additional bases for the selection of appropriate measurement endpoints and study designs. Some examples of risk questions for the transition zone include (1) Does contaminant exposure exist at ground-water discharge points, and, if so, do the exposure concentrations exceed levels considered “safe” for the assessment endpoints? (2) Are exposures to contaminants at ground-water discharge points associated with deleterious effects to the assessment endpoints? (3) Does the exposure to contaminated ground-water pose unacceptable risks to transition zone, benthic, and/or surface-water assessment endpoints?

2.2.2 Hydrologic Regime and Contaminant Fate and Transport Considerations during Problem Formulation

As in any ground-water setting, the transport and fate of contaminants will be a function of the characteristics of the geologic materials through which ground-water is passing, the chemical and physical characteristics of the native ground-water, and the physical and chemical characteristics of the contaminants. In the transition zone, the mixing of surface- and ground-waters can create steep gradients (large changes over relatively short distances) in water quality parameters such as DO concentration, salinity/conductivity, oxidation-reduction potential (ORP), pH or temperature which can be measured in the field, and hardness, solids, and Acid Volatile Sulfides which can be measured in the lab. The characteristics of the substrate (especially sediments) such as mineral content, grain size, porosity, and TOC in the transition zone may also change abruptly over relatively short distances. Each of these characteristics can strongly influence contaminant mobility. Contaminants that have traveled considerable distances in ground-water with little alteration may, upon entering and passing through a transition zone, show rapid attenuation in this zone due to the dynamic physical and chemical characteristics of the zone. These changing conditions, as contaminants move from the ground-water environment to the transition zone, can facilitate attenuation processes such as adsorption, microbial degradation of chlorinated solvents, and precipitation of some dissolved metals.

On the basis of these characteristics of the transition zone, two key hydrogeologic questions to consider in problem formulation are (1) How close to the ecological resources are the contaminants or their degradation or oxidation/reduction products? and (2) What are the transport and attenuation processes controlling the mobilization, movement, flux, mass loading, and observed distribution of contaminants? In considering these questions in problem formulation it may be beneficial to understand the role of smaller scale changes in permeability, mobilization (such as ground-water moving through contaminated sediment, etc.), movement of contaminants in whatever form they are found (such as dissolved, NAPL, colloid-bound, etc.), and where the contaminants ultimately come to reside.

Various GW/SW exchange conditions are possible at the bed of any surface-water body (Figure 2) (Conant 2001, 2004). There may be situations where no ground-water discharges into surface-water because the hydraulic gradient is horizontal (Figure 2, No. 4), the hydraulic gradient is away from the surface-water body (e.g., downward vertical gradient; Figure 2, No. 5), or a geologic barrier is present that prevents discharge (Figure 2, No. 4). Alternatively, ground-water discharge may occur at a low rate due to a low hydraulic gradient and/or the presence of low to moderate permeability materials that act to slow the ground-water flow (Figure 2, No. 3).

In contrast to the above exchange conditions, the presence of a strong hydraulic gradient and/or highly permeable substrate may result in a condition where the ground-water is able to rapidly discharge with little opportunity for attenuation. In this instance, contaminants come in contact with organisms that not only live within the sediment but also live on or use the sediment surface or overlying surface-water or even preferentially seek out these areas for spawning or as thermal refugia (Figure 2, No. 2). Ground-water discharge areas exhibiting this last exchange condition may be viewed either as geologic windows that are easily detected (Figure 2, No. 2) or as small "short circuits" in otherwise no- or low-inflow zones (Figure 2, No. 1) (Conant 2004). The overall density and distribution of such short circuits may be key factors in determining whether or not they drive a significant ecological risk. It is important to remember that in any setting, ground-water flow rate and direction are controlled by hydrologic conditions. These conditions can be highly variable, and multiple sampling events conducted over time, or other tools that integrate exposure or effects over time, may be needed to characterize the transition zone.

3. Tools for Characterizing the Hydrogeology and Ecology of the Transition Zone

A variety of tools are available that can be used to help locate and characterize areas of contaminated ground-water discharge and associated transition zones (EPA 2000; see Table 1 for some site-specific examples). Similarly, there are a number of tools and approaches available for characterizing the ecological resources of the transition zone and for evaluating the exposure of, and effects on, those resources exposed to contaminated ground-water. The choice of tools will depend on the environment, the selected assessment and measurement endpoints, and use of the Data Quality Objectives Process will help the site team avoid sampling method bias. While Tables 2 and 3 highlight commonly used tools for characterizing the hydrogeology and ecology of the transition zone, additional tools are identified in *A Compendium of Chemical, Physical and Biological Methods for Assessing and Monitoring the Remediation of Contaminated Sediment Sites* (U.S. EPA, 2003).

3.1 Hydrogeological Characterization

The identification and characterization of contaminated ground-water may occur during the screening ERA (Steps 1 and 2 of the 5-step transition zone framework) and continue during the baseline ERA. During the screening ERA, this hydrological characterization may be based, in part, on

- Examination of existing maps of surficial and bedrock geology and the local hydrology;
- Examination of water chemistry data from existing wells, piezometers, and surface-water;
- Examination of boring logs and other geologic data;
- Evaluation of ground-water migration and preferential pathways;
- Collection and examination of remotely sensed thermal data;

TABLE 1 Examples of Case Studies Where Ground-Water and Surface-Water Investigations Were Employed to Answer Site-Specific Questions Regarding Ground-Water Contaminant Exposure, Risks, and Management

Site	Environmental Setting/Issue	Ground-Water Contaminant Concern/Question	Nature of Ground-Water/Surface-Water Investigation
ASARCO Tacoma Smelter, Tacoma, WA	Metal smelting with arsenic in ground-water adjacent to Puget Sound.	Is the arsenic, in parts per thousand, in ground-water discharges to the shoreline and subtidal zones likely to cause an adverse impact.	Arsenic speciation and electron probe analysis show pH and redox increase when ground-water goes through the transition zone results in precipitation and the arsenic does not enter the marine environment
Eagle Harbor, WA	Marine habitat, Puget Sound.	Identify zones of discharge to harbor floor.	Towed temperature and conductivity probe linked ground-water in the uplands with discharges to harbor sediment.
Eastland Woolen Mill, East Sebasticook River, ME	River system impacted by chlorinated solvents from former woolen mill.	Is contaminated ground-water contributing to sediment toxicity?	*In situ* and laboratory toxicity tests, nested multilevel minipiezometers demonstrated spatial pattern of chlorobenzene transport and toxicity (Greenberg et al.,2002). Microbial and meiofaunal analyses documented changes in those communities.
Leviathan Mine, CA	Open-pit sulfur mine at 7,000 ft in Sierra Nevada Mountains, with acidic discharge into Leviathan Creek.	In highly mineralized geologic setting, what is relative contribution of acid mine drainage and natural acidic discharge to water quality of the watershed?	Investigation of Leviathan Creek using a hand-held combined conductivity, pH, and temperature meter revealed a single small natural seep, compared to large inputs from the mine.
McCormick & Baxter Creosoting Co., Portland, OR http://www.deq.state.or.us/nwr/mccormick.htm	Site adjacent to Willamette River. Site used creosote, pentachlorophenol, and metals for wood treatment.	Is there seepage of creosote or other contaminants to the river via ground-water?	Working with divers collecting sediment samples and installing minipiezometers and seepage meters within river, documented non-aqueous phase liquid (NAPL) discharges from just below sediment surface and ground-water discharge at the shoreline and deeper in the river.
St. Joseph, MI	Chlorinated solvent ground-water plume migrating toward Lake Michigan.	Is natural attenuation sufficient to keep contaminants from reaching the lake?	Geoprobes with slotted screens were used to identify an offshore solvent plume discharge zone, demonstrating that natural attenuation was not completely effective at this site (Lendvay et al. 1998). In 1999, pore water sampling of the near shore sediments identified the main plume discharge (MDEQ 2005).
Treasure Island Naval Station, San Francisco, CA	Chlorinated solvent plume migrating toward/into San Francisco Bay.	Location of ground-water control monitoring points(water column measurements or wells and location of wells, if chosen).	The Navy agreed to place monitoring wells at locations where a study of tidal mixing in the ground-water revealed a 20% influence of seawater; this made the GW/SW transition zone the remedial compliance point.
Western Processing, Kent, WA	Small stream (Mill Creek) along site boundary. Contaminated ground-water discharging to stream.	Are stream sediments contaminated with solvents and metals, and, if so, what is the source of the contamination? Could a simple removal of the contaminated sediments address the ecological risks?	Standpipes in the creek indicated artesian flow. Solvent contamination was found to originate from surface input, while the metals contamination was due to the discharge of contaminated ground-water.
Chevron Mining Inc. (CMI) (formerly Molycorp, Inc.), Questa, NM	Molybdenum mine near the Red River which is a tributary to the Rio Grande. Metal and low pH loads to the river system from ground-water upwelling.	Do the concentrations of COPCs in discharging ground-water, surface water, and/or sediments in upwelling exposure areas pose unacceptable risks to aquatic life?	Laboratory and *in situ* toxicity tests, multilevel minipiezometers, exposure chemistry, benthic and fish community analyses were used to identify two specific discharge points along the study area as requiring evaluation during the Feasibility Study.

- Site walkovers for visible signs of discharge (such as areas of differing sediment grain size and structure or obvious seeps observable under the low-river stage or tide conditions); and
- Site walkovers using portable (hand-held) monitoring instruments such as salinity/conductivity, pH, DO meters, and/or temperature probes;
- Geophysical survey to characterize the underlying geology and directly or indirectly detect contaminated ground-water.

The use of "standard" monitoring wells and piezometers to characterize conditions within the transition zone may not be feasible, as these tools will typically be too large to use in a transition zone environment. A number of relatively inexpensive and simple portable instruments are available that may be used to locate areas of contaminated ground-water discharge. These instruments include:

- Passive Diffusion Samplers
- Peepers,
- Miniprofilers,
- Pushpoint pore-water samplers,
- Minipoint samplers,
- Sippers,
- Hydraulic potentiomanometers
- Seepage meters.

For the baseline ERA, additional hydrogeological characterization data may be needed to evaluate the assessment and measurement endpoints and address the risk hypotheses and questions (see Step 4 of the transition zone CSM framework). Portable instruments can be used to (1) rapidly and inexpensively identify and characterize ground-water discharge areas, (2) support a screening-level risk assessment, and (3) yield quantitative contaminant data of sufficient quality to support the needs of a baseline ERA. The instruments that could be implemented at a specific site will be based on the CSM and the capabilities and metrics of the individual tools. Because different tools may have quite different metrics, site characterization will benefit greatly from early consideration of how the data will be evaluated, interpreted, and integrated. When tools cannot effectively sample the zone of primary interest, consideration can be given to sampling in adjacent zones, provided agreements are reached how the data will be interpreted in the ERA. Brief descriptions of tools for hydrological characterization are presented in Table 2. Additional information regarding the sampling of ground-water and interstitial water can be found at:

- http://clu-in.org/techdrct/,
- http://www.epa.gov/tio/tsp/issue.htm
- http://www.ert.org/.

3.2 Characterization of Ecological Resources, Their Exposures, and Resulting Effects

Numerous tools and approaches are available for characterizing the ecological resources of a transition zone and for evaluating the effects of exposure to ground-water contamination (Williams 1999). These include survey protocols using a variety of devices to sample and/or analyze periphyton, benthic invertebrates, and fish (e.g., Barbour et al. 1999) and the microbial community (e.g., Adamus 1995; Hendricks et al. 1996; Williams 1999) (Table 3). These tools may be used to identify the types and abundances of species, characterize the structure of the ecological communities, and evaluate microbial processes of the transition zone and associated ground-water discharge areas.

Exposure of transition zone biota may be inferred from survey data by spatially linking survey habitats with the presence of contaminated ground-water (as determined using the previously described hydrogeological characterization tools). Uptake of ground-water contamination by biota may be estimated, and exposures characterized, using *in situ* approaches such as the direct analysis of ground-water-associated contaminants in biota that inhabit the transition zone and associated areas, or through the chemical analysis of test organisms following controlled exposure in areas of contaminated ground-water. Exposure of transition zone biota may be estimated using semipermeable membrane devices (SPMDs) to estimate potential uptake of ground-water contamination by exposed biota (limitations can be minimized by field calibration at the site of interest—see Section 4.2). Exposure levels may also be inferred through the use of contaminant uptake factors (such as bioconcentration factors [BCFs]) that are available in the scientific literature for many chemicals. Effects can be inferred from traditional tools applied to the transition zone (e.g., in-situ toxicity tests, comparison with criteria or risk-based concentrations for various media).

4. Evaluating Ecological Risks in the Transition Zone and Associated Ground-water Discharge Areas

Ecological risks to most biota in the transition zone and discharge area from exposure to contaminated ground-water can be effectively predicted by (1) evaluating ground-water chemistry at the transition zone and (2) estimating the resulting direct and indirect ecological effects from that exposure. Other approaches can be very useful when needed to reduce uncertainty regarding effects on the selected assessment endpoints. These evaluations may be directly incorporated into the 8-step process for designing and conducting ERAs (U.S. EPA 1997; see Section 2.1). Decisions regarding risk acceptability and subsequent risk-management decisions can be made based on the outcomes of these evaluations. Figure 4 presents an example of a decision tree for assessing ecological risks associated with the discharge of contaminated ground-water through the transition zone. If unacceptable risks are identified and remediation is appropriate, the ERA should ultimately provide risk-based preliminary remediation goals (PRGs) and will assist in the identification and evaluation of remedial alternatives and in the evaluation of remedial success (U.S. EPA 1994a, 1997).

4.1 Evaluation of Ground-water and Transition Zone Water Chemistry

The concentrations of chemicals in the ground-water and transition zone waters can be evaluated in the screening and baseline ERAs (Figure 4). These evaluations compare measured chemical concentrations to benchmark values that represent water concentrations considered protective of exposed aquatic biota. Chemicals present at concentrations below the benchmark values are assumed to pose acceptable risks to the transition zone biota. The baseline ERA may also employ evaluations of exposure and effects to support a risk characterization.

4.1.1 Evaluating Ground-Water Chemistry in the Screening-Level Risk Assessment

In the screening-level ERA, the maximum chemical concentration detected in ground-water is compared to applicable benchmark values (Step 2 of the Superfund ERA process [U.S. EPA 1997]). Use of maximum detected concentrations of the contaminants is consistent with the use of conservative assumptions in the screening-level ERA. The benchmark values used in the screening ERA are the Ambient Water Quality Criteria (AWQC) (U.S. EPA 2002a), which identify concentrations of selected chemicals that are considered protective of aquatic biota under chronic exposures in fresh and marine waters (see Text Box 3). Because the AWQC are considered protective of benthic organisms, they are suitable for evaluating transition zone organisms. When an AWQC is not available for a specific chemical (e.g., many volatile organic compounds), an alternative screening value may be selected (U.S. EPA 1997), or the chemical is carried forward into the baseline ERA for further analysis by another approach. The ground-water concentrations should be compared with the lowest appropriate chronic criteria. In brackish systems, both freshwater and marine chronic criteria should be considered. The assumptions regarding the applicability of AWQC or other benchmarks for evaluating potential ecological risks to transition zone biota should be discussed in the uncertainty analysis that is part of the risk assessment (U.S. EPA 1997).

Chemicals with maximum ground-water concentrations below the AWQC are assumed to pose negligible ecological risk and that chemical-specific ground-water pathway can be removed from further consideration in the ERA (Figure 4), while those with concentrations exceeding benchmark levels are further evaluated in the baseline ERA. Depending on the potentially complete exposure pathways identified in the CSM, chemicals may need to be evaluated in other media such as sediment or tissue.

TABLE 2 Tools That May Aid in the Identification and Characterization of Areas of Contaminated Ground-Water Discharge

Tool	Description
Direct Push Technology	Vibracores and Geoprobes are examples of direct push sampling tools that can be used in the sediments to obtain sediment cores and samples, and, with adaptations, to obtain water samples at depth below the sediment surface.
Geologic and topographic maps	Surficial and, in some settings, bedrock geologic maps of the stream and near-stream environment may indicate which zones are most likely to have significant interchange between ground-water and surface-water.
Hydraulic potentiomanometer	Winter et al. (1988) present a device that consists of a stainless steel probe with a screened section near the tip that is connected by a tube to a manometer whose other tube can be placed within a surface-water to measure the head difference between ground and surface-water at a sampling station. The device can also be used to obtain ground-water samples by detaching the probe from the manometer and withdrawing a sample with a hand pump.
Minipoint sampler	Duff et al. (1998) present a sampler that has six small-diameter stainless steel tubes set in a 10-cm-diameter array preset to drive depths of 2.5, 5.0. 7.5, 10.0, 12.5, and 15.0 cm. Ground-water samples from all depths are withdrawn simultaneously by a peristaltic pump.
"Mini" Profiler	Conanat et al. (2004) modified a soil vapor probe by Hughes et al. (1992), creating a miniature hand-driven version of a profiler that can be used to recover interstitial water samples from multiple depths in the same hole to a depth of 1.5m. The mini Profiler is a thin-walled tube (0.64 mm OD) with a drive point that contains small-screened ports. Pumping distilled water down the device and through the ports during driving keeps the ports free of material. In sampling mode, a pump purges the device of distilled water and draws a formation water sample up to the surface. The full-size Waterloo Profiler can be used to depths of 10s of meters (Pitkin et al., 1999).
Passive diffusion sampler (PDS)	Vroblesky and Hyde (1997) and Vroblesky et al. (1996, 1999) present development of an inexpensive sampler that collects volatile organic compounds (VOCs) by diffusion and has been successfully used at a number of sites to detect where VOC plumes are discharging to surface-water. Results provide an estimate of average concentration in the sampled water. Independent data are needed to determine flow direction past the sampler (i.e., if the sampler is collecting ground-water or surface-water). For additional information, see: http://ma.water.usgs.gov/publications/wrir/ wri024186/report.htm. PDSs have been developed for other contaminants (e.g. metals).
Peepers	Hesslein (1976) and Mayer (1976) first developed diffusive equilibration samplers in which the sampler consists of a vertical array of deionized water-filled chambers separated from interstitial water by a dialysis membrane. A number of modifications to this basic sampler now exist (USEPA 2001b; Burton et al. 2005). Results and limitations are similar to those encountered with PDSs above.
PushPoint interstitial water sampler	MDEQ (2006, in review) presents a sampler that consists of a thin-walled metal tube with a chisel-pointed tip and a 4-cm screened interval above this tip. A retractable stainless-steel plug prevents clogging of the screen during driving into the sediment. At the desired depth, an interstitial water sample can be removed by a syringe or peristaltic pump attached to the top of the device. For additional information on push-point sampling, see Zimmerman et al. (2005).
Radiologic analyses	Krest and Harvey (2003) describe a method using radioactive tracers (which can be quantified much more precisely than most organic chemicals), best used in areas with very low hydraulic gradient without the potential confounding factors such as salinity change.
Remotely sensed thermal data	Airborne forward-looking infrared radiometry (FLIR) thermal-imagery equipment. Helicopter-mounted FLIR equipment takes infrared photographs of the rivers to provide visual images of surface-water temperatures. Areas of ground-water discharge may be indicated if there is sufficient temperature contrast between the discharging ground-water and surrounding surface-water temperatures. For additional information, go to: http://geopubs.wr.usgs.gov/open-file/ of02-367/of02-367.pdf and http://www.ecy.wa.gov/pubs/0110041.pdf.
Sediment probe	Lee (1985) developed a sediment probe that is towed in contact with bottom sediments and detects zones of plume discharge by detection of conductivity anomalies. Other researchers have also used conductivity or resistivity measurements successfully but with more traditional, labor-intensive devices
Seepage meter	Unlike the devices discussed above, the seepage meter can give a discharge rate and flow direction through a stream bed. The basic seepage meter design originally presented by Lee (1977) and Lee and Cherry (1978), consists of the top section of a steel drum with a plastic bag attached as a sample collector. A variation on this design is the UltraSeep, system which is instrumented to monitor conductivity, temperature and fluid seepage rate (http://clu-in.org/programs/21m2/navytools/gsw/). A basic seepage device is driven into the sediment, and natural seepage is allowed to fill the sample bag. The volume obtained during deployment can be sampled for analysis as well as used to calculate a seepage rate. If it is known that seepage is into the streambed, the bag can be pre-filled with a known volume of water to allow seepage into the sediment and calculation of the seepage rate. While there are a number of uncertainties associated with the use of seepage meters, these meters can provide a measure of what is coming through the sediment and into surface-water that no other device can provide.
Sippers	Zimmerman et al. (1978) and Montgomery et al. (1979) present a sampler that consists of a hollow PVC stake with a porous Teflon® collar. The device has a sampling tube that runs its full length and a gas port at the top. The device is driven into the sediment and evacuated with a hand pump. Interstitial water then seeps into the device. The sample is removed by displacement with argon gas pumped in through the gas port. The initial filling of the device through application of a vacuum may limit its utility in sampling VOCs.
Site walkovers with handheld meters	Wading a shallow site with appropriate field sampling devices (e.g., temperature, pH, or conductivity meters) may be useful to preliminarily delineate some contaminant plumes. This may be especially useful in settings with ground-water discharge through discrete seeps where the measured parameters have steep gradients.

TABLE 3 Tools That May Aid in the Characterization of Ecological Resources of the Transition Zone and in the Evaluation of the Effects of Exposure of Those Resources to Contaminated Ground-Water

Tool	Description
Invertebrate community survey protocols	These protocols may include sampling devices such as sediment cores and colonization samplers (e.g., rock baskets, trays of sediment) to collect invertebrates of the infaunal communities at the ground-water discharge area. The transition zone community can be considered a simple extension of the infaunal communities. Sediment core samples are taken from the biologically active zone, which may be fairly deep (ca. 1 m) or fairly shallow (a few cm), or targeted to reach specific macroinvertebrates such as burrowing shrimp or bivalves (perhaps >1 m). Colonization samplers can be placed on the bottom of a water body as a means of collecting macroinvertebrate fauna. Following sampling, the collected biota can be analyzed using well-established bioassessment methods (e.g., as described in Barbour et al. 1999). The use of invertebrate surveys has proven effective in evaluating contaminated ground-water (Malard et al. 1996). When compared to uncontaminated sites, the results can reveal whether the invertebrate community has been affected by the exposure.
Laboratory interstitial water and sediment toxicity tests	These are traditional toxicity tests (U.S. EPA 1994b,e) that can be conducted on samples obtained from various locations in the transition zone. However, care must be taken to maintain the chemistry (redox, pH) and physical structure of the sample, and to prevent volatilization of contaminants.
Microbial community survey protocols	There are well-established methods for investigating microbial communities at the GW/SW transition zone (e.g., Hendricks 1996). The results of the survey may be useful to show whether there are differences between the microbial communities in contaminated and uncontaminated ground-water discharge zones.
Tissue analysis of resident biota (bioaccumulation measures)	Biota are collected from the transition zone and/or areas of ground-water discharge and associated surface-waters and analyzed for the ground-water contaminants.

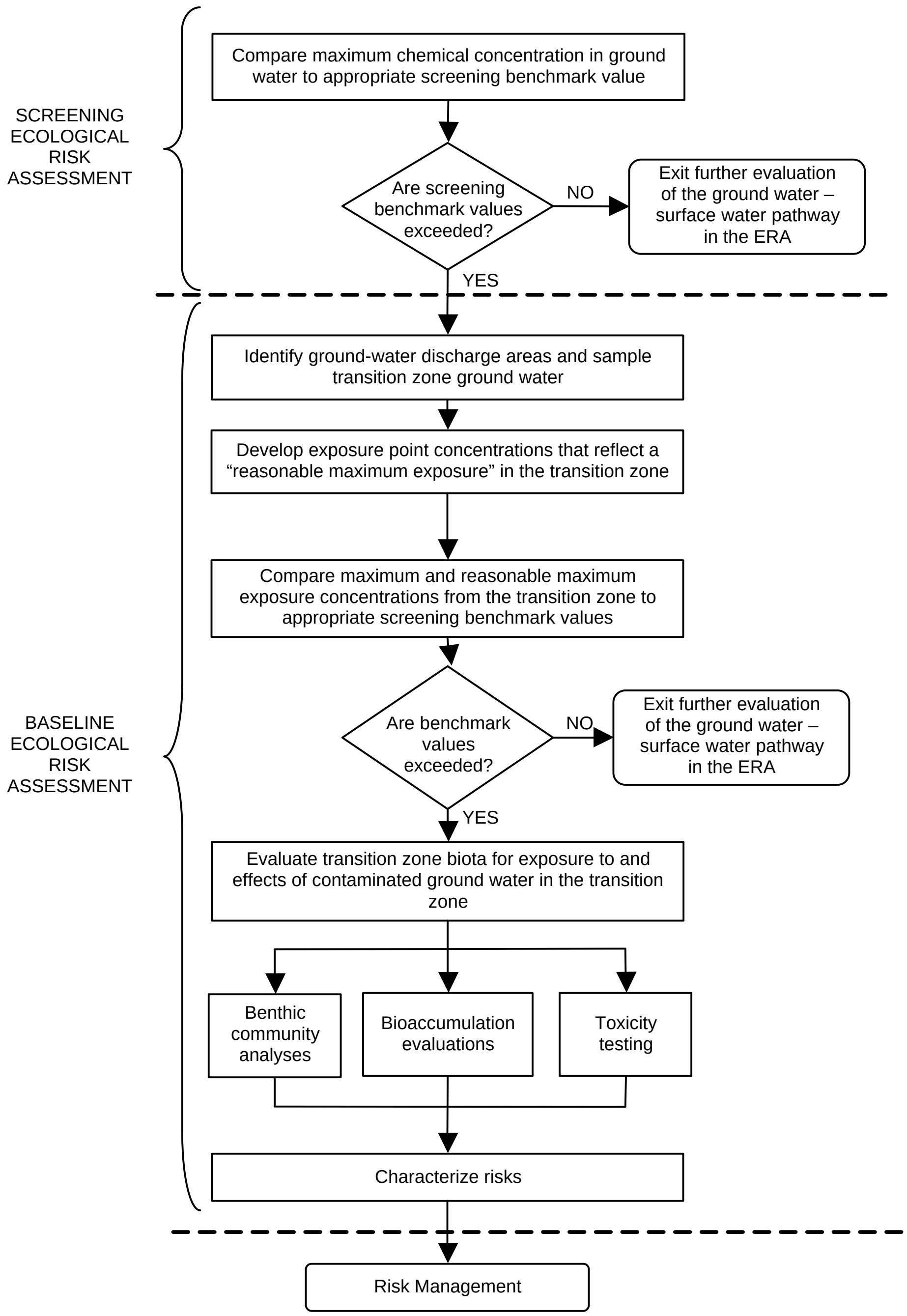

FIGURE 4 An Example Decision Tree for Evaluating Ecological Risks Associated with the Discharge of Contaminated Ground-Water through the Transition Zone.

Text Box 3: Using AWQC in GW/SW ERAs

As done for any ecological risk assessment, the assessor should determine whether the specific AWQC are appropriately protective of benthic infaunal and epifaunal organisms exposed to discharging contaminants. This determination, although difficult if AWQC are not available for certain contaminants, may be important where volatile contaminants are discharged. In these cases, reviewing the derivation of the AWQC may help determine an appropriate site-specific screening level, help select investigatory tools in the baseline ERA, or help with the uncertainty analysis.

Typically, screening-level ERAs rely on previously available data. Thus, the equipment and methods used to provide the ground-water data (see Table 2) may have been selected and implemented prior to the involvement of the ecological risk assessor. In some cases, the available ground-water data may be from wells screened below the aquifer that is discharging to surface-water. Therefore, the risk assessor should confirm that the ground-water data are acceptable and that the samples are appropriately representative for their intended use in the screening-level risk assessment. Additional information on ground-water sampling is presented in a Ground Water Forum Issue Paper (U.S. EPA 2002b). The ecological risk assessor should also determine whether the detection limits for the ground-water data will support a meaningful comparison to the benchmark values (e.g., whether the detection limits are at or below the screening values). If the ground-water data are not appropriate with regard to sampling issues and detection limits, they may have reduced value for the screening ERA.

4.1.2 Evaluating Transition Zone Water Chemistry in the Baseline Risk Assessment

In the baseline ERA (U.S. EPA 1997), chemical concentrations in ground-water at the transition zone are compared to AWQC (U.S. EPA 2002a) or other benchmark values for protection of aquatic life, but using more realistic exposure-point concentrations than those evaluated in the screening ERA. These new comparisons will not use maximum detected ground-water concentrations as in the screening ERA, but rather use exposure-point concentrations that are reasonably anticipated or expected to exist or occur at a site (the reasonable maximum exposure). Reasonable exposure point concentrations can be determined, in consultation with the site hydrogeologist, from a particular well or set of wells along the flow path(s) from the source to the discharge zone in the surface-water. However, it may be preferable to determine this more realistic exposure-point concentration from available or new data from transition zone samples. When new data are to be collected, the risk assessment team should jointly develop the sampling design. Similarly, if there are concerns for human health impacts, usually from foodweb magnification, then the sampling design should also be coordinated with the appropriate human health risk assessors.

Sampling-design considerations for the baseline ERA should include both hydrogeologic and ecological factors. Hydrogeologic factors may include ground-water and surface-water dynamics and seasonal variability, water table elevation, surface-water level and flow rates, bed material, locations of paleochannels, preferential ground-water flow paths, and contaminant concentrations in interstitial water from the transition zone. Ecological factors may include the types and distributions of biota associated with the transition zone and ground-water discharge areas, their contribution to the food web, and life history aspects of the biota such as seasonal occurrence and the vertical distribution and movement of the biota within the sediment. The collection of new ground-water data for use in the ERA may utilize one or more of the sampling tools identified in Table 2 for characterizing hydrologic conditions. Generally, these sampling tools fall into two broad categories: (1) tools that actively collect a sample at a specific time period (e.g., piezometers, pushpoint samplers) for instantaneous concentrations and (2) tools that passively collect samples over time (e.g., peepers, seepage meters, and PDSs) for more integrated concentrations or contaminant mass.

4.2 Evaluating Biota Exposure and Effects

Baseline ERAs of other ecosystems typically employ evaluations of exposure and effects to provide multiple lines of evidence for characterizing risks. The methods typically employed in evaluating exposure and effects to benthic biota can be readily extended to transition zone biota exposed to contaminated ground-water discharges. These methods include benthic community analyses, toxicity testing, and bioaccumulation evaluations. In selecting these methods to evaluate exposure and effects to transition zone biota, the risk assessor must consider the same issues that are typically addressed during benthic ecosystem risk assessments. These issues include, but may not be limited to, the use of reference sites to address natural variability and background conditions (U.S. EPA 1994d), confounding factors that could affect toxicity results, toxicity testing using media collected along contamination gradients in order to develop dose-response relationships, and uncertainties associated with many of the input parameters of uptake models. These issues are typically addressed during the problem formulation and study design portions of ERA development (Steps 3 and 4, respectively, of the Superfund ERA process).

Community analysis of transition zone organisms can be used to identify differences in community structure, biomass, species richness and density, relative abundance, and other parameters (U.S. EPA 1994c), and a variety of methods are available for sampling and evaluating transition zone biota (i.e., Hendricks 1996; Williams 1999). However, evaluating alterations in transition zone communities is challenging, and shares exactly the same issues and considerations as benthic community analyses or other field studies. These issues include natural variability (e.g., associated with ground-water discharge/recharge), the need for concurrent community analyses at appropriate reference sites (see Barbour et al. 1999), and the overarching need for synoptic sampling of exposures and effects.

Toxicity testing and bioaccumulation evaluations have been used at several sites to evaluate the effects of ground-water contamination on transition zone biota. Toxicity testing, which involves the exposure of organisms to contaminated media, provides direct evidence of contaminant effects on transition zone biota (U.S. EPA 1994e). A wide variety of toxicity tests have been developed for use in ecological risk assessments (U.S. EPA 1994b), and many of these may be directly applicable to evaluating contaminant effects on transition zone biota. While these types of studies are often conducted in the laboratory using media collected from the site, *in situ* studies have also been used and may be preferable because they provide more realistic exposures than do laboratory studies (U.S. EPA 1994e; Greenberg et al. 2002; Burton et al. 2005).

Bioaccumulation evaluations examine the uptake of contaminants by exposed biota and can be used to infer potential effects to transition zone biota when concentrations exceed tissue levels considered adverse to the organisms or their predators. Bioaccumulation may be measured by (1) tissue analysis of indigenous biota, (2) analysis of cultured test organisms (e.g., fish, macroinvertebrates) exposed *in situ* (US EPA 2004), (3) the use of SPMDs, and (4) the use of contaminant-uptake models. Tissue analysis provides a direct estimate of contaminant uptake and bioaccumulation under site-specific conditions. Semipermeable membrane devices may also provide a site-specific estimate of passive uptake and bioaccumulation. However, because SPMDs serve as surrogates for biota and involve no sampling or analysis of biota, their use for estimating bioaccumulation should be approached with caution. Unless a quantitative relationship has been established between the bioaccumulation estimated by the SPMD and that measured in biota exposed at the site, the use of SPMDs is not recommended for evaluating bioaccumulation. These devices may, however, be useful for delineating areas of contaminated ground-water discharge (as in Step 2 of the transition zone problem formulation framework) or monitoring these areas (Huckins et al. 1993). Because contaminants partition among water, sediment, and organisms (recall that partitioning will have been evaluated during problem formulation and CSM development), sediment analysis may be necessary to interpret bioaccumulation results for decision-making.

While there currently are no examples of quantitative contaminant uptake models for transition zone biota, existing approaches used to estimate contaminant uptake by aquatic biota may be applicable for use in transition zone ecosystems. For aquatic biota, contaminant uptake models employing laboratory-derived BCFs or field-derived bioaccumulation factors (BAFs) are commonly used to estimate biota tissue concentrations from contaminant concentrations measured in aquatic media (e.g., see Suter et al. 2000). While such models may be used for estimating tissue concentrations in transition zone biota, the risk assessor should address many of the typical modeling issues (such as nonlinearity between BCFs and ambient contaminant concentrations when selecting a BCF; and the potential for deviations from equilibrium assumptions) in the interpretation of model results.

4.3 Characterizing Risks

Ecological risks to the transition zone are characterized after the collection and analysis of physical, chemical, and ecological data have been completed (Figure 4). The risks can be characterized using the lines-of-evidence approach commonly used in ecological risk assessments (U.S. EPA 1997, 1998). The characterization includes uncertainty analysis to assist in risk management. Incorporating the transition zone leads to improved decision-making in the overall ERA by reducing uncertainty in the conclusions of which receptors/assessment endpoints are significantly impacted, determining which stressors dominate, and from which compartments (e.g., surface-water, bedded sediments, upwelling ground-water) those stressors originate.

5. Summary

The transition zone represents a unique and important ecosystem that exists between surface-water and the underlying ground-water, receiving water from both of these sources. Biota inhabiting, or otherwise dependent on, the transition zone may be adversely impacted by contaminated ground-water discharging through the transition zone into overlying surface-waters. ERAs addressing contaminated ground-water discharge to surface-waters typically have not evaluated potential contaminant effects to biota in the transition zone. However, numerous hydrogeological and ecological methods and tools are available for delineating ground-water discharge areas in a rapid and cost-effective manner, and for evaluating the effects of contaminant exposure on transition zone biota. These tools and approaches, which are commonly used in hydrogeological and ecological investigations, can be readily employed within the existing EPA framework for conducting screening- and baseline-level ERAs in Superfund (U.S. EPA 1997) and satisfy the requirement to identify and characterize the current and potential threats to the environment from a hazardous substance release.

6. Glossary

Abiotic: Characterized by absence of life; abiotic materials include the nonliving portions of environmental media (e.g., water, air, soil, sediment), including light, temperature, pH, humidity, current velocity, and other physical and chemical parameters. Abiotic chemical reactions are not biologically mediated (i.e., do not involve microbes).

Acute: Having a sudden onset or lasting a short time. An acute stimulus to a contaminant is severe enough to induce a rapid response. With regard to ground-water contamination, the term acute can be used to define either exposure to a chemical (short term) or the response to such an exposure (effect).

Aquifer: A body of geological materials such as sand and gravel or sandstone, that is sufficiently permeable to transmit ground-water and yield economically significant quantities of water to wells or springs

Assessment Endpoint: An explicit expression of the environmental value that is to be protected, such as specific ecological processes, or populations/communities of organisms to be protected (e.g., a sustainable population of insect larvae important as fish food)

Baseline Ecological Risk Assessment: An ecological risk assessment that evaluates the exposure and effects of a contaminant to ecological resources under site-specific exposure scenarios and using site-specific physical, chemical, and biological data.

Benchmark Value: In ecological risk assessment, a media-specific environmental concentration or a receptor-specific dose concentration that represents a threshold for adverse ecological effects (a maximum "safe" chemical concentration or dose). Media or dose concentrations at or below a benchmark value are considered unlikely to cause adverse ecological effects.

Benthos: The community of organisms (plants, invertebrates, and vertebrates) dwelling on the bottom of a body of surface-water (e.g., pond, lake, stream, river, wetland, estuary, ocean).

Bioaccumulation: The process by which chemicals are taken up and incorporated by an organism either directly from exposure to a contaminated medium or by consumption of food or water containing the contaminant.

Bioaccumulation Factor (BAF): The ratio of the concentration of a contaminant in an organism to the concentration in the ambient environment at steady state, where the organisms can take in the contaminant through ingestion with its food and water as well as through direct contact.

Bioconcentration: The process by which there is net accumulation of a chemical directly from an exposure medium into an organism.

Bioconcentration Factor (BCF): The ratio of the concentration of a contaminant in an organism to the concentration in the exposure medium, where the organisms can take in the contaminant through direct contact with the medium.

Biodegradation: The process by which chemical compounds are degraded into more elementary compounds by the action of living organisms; usually refers to microorganisms such as bacteria.

Biomass: Any quantitative estimate of the total mass of organisms comprising all or part of a population or any other specified unit, or within a given area at a given time; typically measured as a volume or mass (weight).

Biome: A biogeographical region or formation; a major regional ecological community characterized by distinctive life forms and principal plant or animal species.

Biotic: The living portion of the environment; pertaining to life or living organisms; caused by, produced by, or comprising living organisms.

Chronic: Involving a stimulus that is lingering or continues for a long time; often signifies periods of time associated with the reproductive life cycle of a species. Can be used to define either exposure to a chemical or the response to such an exposure (effect). Chronic exposures to chemicals typically induce a biological response of relatively slow progress and long duration.

Community: Any group of organisms comprising a number of different species that co-occur in the same habitat or area and interact through trophic and spatial relationships.

Community Analysis: An analysis of a community within a specified location and time. Community analyses may focus on the number of different species present, the types of species present, or the relative abundance of the species that are present in the community.

Community Structure: Refers to the species composition and abundance and the relationships between species in a community.

Conceptual Site Model: Describes a series of working hypotheses of how a stressor (chemical contaminant) might reach and affect a biological assessment endpoint; describes the assessment endpoint potentially at risk from exposure to a chemical, the exposure scenario for the receptor, and the relationship between the assessment and measurement endpoints and the exposure scenarios.

Diffusion: The process by which both ionic and molecular species dissolved in water move from areas of higher concentration to areas of lower concentration.

DNAPL: dissolved non-aqueous phase liquid

Downwelling: The movement of surface-water down into or through the underlying porous media (e.g., recharge to ground-water).

Ecohydrology: An emerging discipline linking ecology with hydrology through the entire water cycle over scales ranging from plant community relationships with ground-water to watershed-level processes.

Ecological Risk Assessment: The process that evaluates the likelihood that adverse ecological effects may occur as a result of exposure to one or more stressors.

Ecosystem: The biotic and abiotic environment within a specified location and time, including the physical, chemical, and biological relationships among the biotic and abiotic components.

Ecotone: The boundary or transition zone between adjacent communities or biomes.

Electrical Conductivity: A measure of the ability of a solution to carry an electrical current. Conductivity is dependent on the total concentration of ions dissolved in the water

Environmental Value: (See Assessment Endpoint). Environmental values include specific ecological processes or populations/communities of organisms to be protected (e.g., a sustainable population of insect larvae important as fish food).

Epifauna: Biota that live on the surface of sediment, as distinguished from infauna, which live in the sediment.

Exposure Pathway: The course a chemical or physical agent takes from a source to an exposed organism. Each exposure pathway includes a source or release from a source, an exposure point, and an exposure route (including respiration [e.g. via gills], ingestion, etc.). If the exposure point location differs from the source, transport/exposure media (i.e., air, water) are also included.

Exposure Point Concentration: The concentration of a contaminant at an exposure point.

Food Web: The pattern of interconnected energy (food) transport among plants and animals in an ecosystem, where energy is transferred from plants to herbivores and then to carnivores by feeding.

Ground-Water Discharge Zone: An area where ground-water exits the subsurface as a spring or a seep, as baseflow into a stream, or directly into an overlying surface-water body (pond, lake, ocean).

Ground-Water/Surface-Water Interface: The boundary between ground-water and surface-water that occurs in the substrate beneath the surface-water body. It is usually defined by examining and mapping interstitial water quality to determine the origin of the water. It may be very diffuse and dynamic and difficult to define (compare with: Transition Zone).

Habitat: The local environment occupied by an organism with characteristics beneficial to the organism. The habitat may be used only during a certain life stage or season

Hydraulic Conductivity: The capacity of a rock to transmit water. It is expressed as the volume of water at the existing kinematic viscosity that will move in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow.

Hydraulic Gradient: The change of hydraulic head per unit of distance in a given direction.

Hydraulic head: The height of the free surface of a body of water above a given point beneath the surface.

Hypolentic Zone: The zone of ground-water and surface-water mixing that occurs in the sediments beneath a lake or wetlands (not beneath moving waters, see Hyporheic Zone).

Hyporheic Zone: Latticework of underground habitats through the sediments associated with the interstitial waters in the substrate beneath and adjacent to moving surface-waters. The hyporheos is the community of organisms adapted to living in this zone. The zone is defined based on biological, hydrological, and chemical characteristics.

Infauna: Biota that live within or burrow through the substrate (sediment), as distinguished from epifauna, which live upon the substrate

Infiltration: Process by which water moves from the earth's surface or from surface-water down into the ground-water system.

***In Situ*:** Refers to a condition or investigation (such as a toxicity test) in the environment (in the field at a site).

Interstitial Water: The water filling the spaces between grains of sediment. Often used interchangeably with "pore water." The term indicates only the presence of water, not its origin.

Macroinvertebrate: An invertebrate animal large enough to be seen without magnification and retained by a 0.595-mm (U.S. #30) screen.

Measurement Endpoint: A measurable ecological characteristic that is related to the valued characteristic chosen as the assessment endpoint; often expressed as the statistical or arithmetic summaries of observations that make up the measurement.

Meiofauna: The small biota (<1 mm diameter) that inhabit the interstitial spaces in sediment.

Natural Attenuation: The natural dilution, dispersion, (bio)degradation, irreversible sorption, and/or radioactive decay of contaminants in soils and ground-water.

Periphyton: Attached microflora growing on the bottom of a water body, or on other submerged substrates, including higher plants.

Permeability: The capacity of a rock for transmitting a fluid; a measure of the relative ease with which a porous medium can transmit a liquid.

Piezometer: A small-diameter, nonpumping tube, pipe, or well used to measure the elevation of the water table or potentiometric surface. A piezometer may also be used to collect ground-water samples.

Pore Water: The water filling the spaces between grains of sediment. Often used interchangeably with "interstitial water."

Potentiometric Surface: A surface that represents the level to which water will rise in tightly cased wells. The water table is the potentiometric surface of an unconfined, or the uppermost, aquifer.

Problem Formulation: Problem formulation establishes the goals, breadth, and focus for an assessment. In a baseline ecological risk assessment, problem formulation establishes the assessment endpoints, identifies exposure pathways and routes, and develops a conceptual site model with working hypotheses and questions that the site investigation will address.

Productivity: (1) The rate of formation of new tissue or organisms, or energy use, by one or more organisms. (2) Capacity or ability of an environmental unit to produce organic material.
(3) Recruitment ability of a population from natural reproduction.

Refuge (refugia): An area to which an organism may escape to avoid a physical (e.g., temperature, water current), chemical (e.g., low dissolved oxygen, a high contaminant concentration), or biologic stressor (e.g., a predator).

Risk: The expected frequency or probability of undesirable effects resulting from known or expected exposure to a contaminant.

Risk Characterization: A phase of an ecological risk assessment in which the results of the assessment are integrated to evaluate the likelihood of adverse ecological effects associated with exposure to a contaminant.

Risk Question: Questions developed during the problem formulation phase of a baseline risk assessment, about the relationships among the assessment endpoints, exposure pathways, and potential effects of the exposure. These questions provide the basis for developing the risk assessment study design and the subsequent evaluation of the results.

Screening Ecological Risk Assessment: An ecological risk assessment that evaluates the potential for adverse ecological effects to ecological resources under very conservative site-specific exposure scenarios (e.g., maximum documented exposure concentrations) and using screening benchmark values.

Species Richness: The absolute number of species in a community.

Stressor: Any physical, chemical, or biological entity that can induce an adverse ecological response (e.g., reduced reproduction, increased mortality, habitat avoidance).

Surrogate Species: A species selected to be representative of an assessment endpoint and on which a risk characterization will focus.

Total Organic Carbon (TOC): Estimated concentration of the sum of all organic carbon compounds in a water or sediment sample by various methods. It can influence bioavailability because some contaminants adsorb to organic carbon.

Toxicity Test: An evaluation of the toxicity of a chemical or other test material (environmental media) conducted by exposing a test organism to a specific level of the chemical or environmental media and measuring the degree of response (mortality, reduced growth, reduced egg production) associated with the specific exposure level.

Transition Zone: The zone of transition from a ground-water dominated system to a surface-water dominated system. It includes, but is not limited to the zone where the ground-water and surface-water mix as well as any Ground-Water/Surface-Water Interface that may be present.

Unconfined Aquifer: An aquifer in which there are no confining beds between the zone of saturation and the surface.

Upwelling: The movement of water in an underlying porous medium up into the surface-water (e.g., ground-water discharge).

Water table: The elevation of the water surface in a well screened in the uppermost zone of saturation (ground-water), i.e., in an unconfined aquifer.

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