Tools and Techniques for Evaluating Coal Combustion Product Constituents in the Groundwater-Surface Water Transition Zone

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Abstract

Chemical and physical changes that occur over short distances in the groundwater-surface water transition zone (TZ) can attenuate and reduce the mobility of constituents of interest associated with coal combustion products (CCP). Because most CCP management facilities are located near water bodies, the behavior of constituents as groundwater discharges to surface water may be an important consideration in the assessment of risk and corrective measures in those settings.

The Electric Power Research Institute (EPRI) examined the processes in the TZ and evaluated tools and techniques to characterize the TZ with respect to CCP constituents (EPRI 2018). The work included an evaluation of field techniques for sampling sediment and porewater, in situ instrumentation, laboratory analytical techniques for aqueous and solid phase samples, methods to evaluate data, and groundwater-surface water interaction modeling. This paper focuses on methods to identify seepage zones and to determine mass flux of water and chemical constituents across the TZ, and groundwater-to-surface water modeling.

Keywords: Coal Combustion Product, Groundwater-Surface Water Transition Zone, Natural Attenuation, Seepage Meters, Groundwater-Surface Water Modeling
Introduction and Regulatory Guidance

Most CCP landfills and impoundments in the United States are located adjacent to surface water bodies such as rivers, lakes, and estuaries. Groundwater flows through the groundwater-surface water transition zone (TZ) before discharge to surface water bodies (Figure 1). Physical, chemical, and biological changes that affect water quality can occur over relatively short distances in the TZ, i.e., over a few centimeters to a few meters (USEPA 2000).

Figure 1.
Example Processes in the Groundwater-Surface Water TZ

Source: Winter et al. 1999

No U.S. Environmental Protection Agency (USEPA) regulatory documents specific to the TZ were identified in the EPRI study. Since the TZ often occurs within sediments, portions of the USEPA (2005) document Contaminated Sediment Remediation Guidance for Hazardous Sites may apply to TZ investigations and corrective action. State guidance documents specific to the TZ from New Jersey, Michigan, and Washington State were also identified in the EPRI study (NJDEP 2016; MDEQ 2014;
WDOE 2017). In the absence of other regulatory guidance, these documents may provide useful information to guide evaluation of the TZ.

A typical TZ evaluation could include the following components:

- Identify zones of groundwater-to-surface water discharge (seepage zones).
- Determine flux of water across the TZ.
- Collect groundwater, porewater, and/or surface water samples for chemical analysis.
- Determine important processes in the TZ such as natural attenuation.
- Perform either analytical or numerical groundwater-surface water modeling to determine flux of constituents across the TZ.
- Perform biological risk assessment based on the chemical analysis and modeling results.

The following sections provide techniques on how to identify seepage zones, measure seepage, determine the flux of water and constituents across the TZ, and model groundwater-surface water interaction.
Methods to Identify Seepage Zones

To determine the mass flux of chemical constituents from groundwater-to-surface water, the first step is to identify and characterize seepage zones. Mapping of groundwater discharge areas helps target specific locations along the bottom of surface water bodies for seepage measurements, sediment sampling, water quality testing, and biological sampling.

Some qualitative methods to determine groundwater-to-surface water discharge include visual observation (e.g., seeps, springs, discoloration of sediment, concentrated subaqueous plant growth, and others), and studies of aerial photography.

Reconnaissance techniques include thermal methods, stream gauging, geophysical methods, and electrical conductivity, temperature and pH probes that can be deployed relatively rapidly along the bottom of the surface water body. These techniques may be used to identify optimum locations for point measurement methods such as seepage meters, piezometers, and sample collection.

The use of heat as a groundwater tracer is well-documented in the scientific literature (e.g., Selker et al., 2006, 2014; Lowry et al., 2007). Temperature data can be used to identify groundwater discharge into surface water bodies due to the natural temperature contrast that may exist between groundwater and surface water. Thermal methods that have been used successfully in recent years include the following:

- Infrared imagery
- Distributed temperature sensing (DTS)
- High-resolution thermometers

Glenn et al. (2013) used aerial infrared imaging to determine where warmer wastewater injected inland was discharging into the Pacific Ocean off the island of Maui, Hawaii. The thermal work was augmented by dye tracer and isotope studies.

Selker et al. (2006, 2014) describe a thermal technique for identifying seepage zones known as DTS. In this technique, a fiber-optic cable is placed at or immediately below the sediment-water interface along the bottom of a surface water body (Figure 2). In DTS, a few of the photons of a laser pulse sent into a fiber optic cable are scattered when they interact with the glass fiber. Because the frequency of scattered light is affected by the temperature of the glass fiber, the temperature can be measured and mapped. In Figure 3, the yellow and red areas are warmer than the surrounding areas, which indicate zones of groundwater discharge if the DTS survey is performed in the
cooler months of the year when groundwater is typically warmer than surface water in temperate climates.

Figure 2.
Placing DTS Fiber-Optic Cable in a Canal

Source: Courtesy of SelkerMetrics
If the substrate is too irregular to emplace a fiber-optic cable, high resolution thermometers may be used (Selker and Huff 2015).

**Probes, Seepage Meters, and Sampling Devices**

Trident Probe (Figure 4) is the commercial name for a sampling probe that includes a temperature sensor, conductivity probe, and a porewater sampling device (USEPA 2008). Consultants and contractors have constructed instruments that perform similar functions. The Trident Probe is used to survey large areas relatively rapidly and can identify areas for additional investigations such as seepage measurements and sample collection.
The electromagnetic seepage meter (ESM; Figure 5) is commonly used to measure flux of water across the sediment-water interface. The instrument typically consists of a seepage dome, electromagnetic flow meter, and control panel, and contains no moving parts. The ESM provides a continuous series of measurements, over a range of about three orders of magnitude, thereby automating flux measurements (Rosenberry and Morin 2004; Swarzenski et al. 2004).
The UltraSeep System is a commercially available integrated seepage meter and water sampling device (Figures 6 and 7). The device combines continuous flow detection with automated sample collection, where up to 10 seepage water samples can be collected in 1-liter bags. Temperature and conductivity are measured by on-board sensors and stored in the data logger that also controls water sampling events. A flow meter is used to continuously measure the specific discharge or recharge (seepage) in the range of about 1 to 1000 centimeters/day (USEPA 2008).
Figure 6.  
UltraSeep System

Figure 7.  
Deployment of the UltraSeep System
The Henry sampler (Henry 2002) is a commercially available device for shallow, nearshore porewater sample collection that has been successfully used at utility settings (Figure 8). The Henry sampler enables porewater sample collection suitable for on-site and off-site laboratory analysis; measurement of static water levels to determine areas of groundwater discharge or recharge; and introduction of tracers or amendments to sediments (MHE Products 2018).

**Figure 8**
Henry Sampler Insertion into Sediments (Top) and Porewater Sample Extraction (Bottom)

Source: MHE Products 2018.
Vrana et al. (2005) and the USEPA (2012) provide an overview of several passive sampling technologies. Generally, passive sampling is based on flow (diffusion) of analyte molecules from the sampled medium (e.g., sediments) to a receiving phase in a sampling device, resulting from a difference in chemical potentials. Analytes are trapped or retained in a suitable medium within the passive sampler (Vrana et al. 2005). Since passive samplers operate by chemical diffusion, the collected water sample is equivalent to a filtered sample (dissolved parameters).

One type of passive sampler contains multi-chambered plates, with small chambers that have membrane walls containing distilled deionized water and are informally referred to as “peepers” (Figure 9). Peepers are placed in the sediments either from a boat in shallow water, or in deeper water by divers pushing the peepers vertically into the sediment until the target depth for monitoring is reached. After placement, the dissolved constituents in pore water diffuse through the, membrane into the peeper because of chemical gradients, and the contained water eventually reaches equilibrium with the ambient porewater (Hesslein 1976). The period of equilibration is typically on the order of typically 4 to 6 weeks. After retrieval, water from the peeper sample chambers is extracted (e.g., using a clean needle and syringe), preserved, and sent to the laboratory for chemical analysis (EPRI 2018).
Passive diffusion bags and bottles operate on diffusion principles similar to peepers. Figure 10 shows polyethylene diffusion bags in a custom-built polycarbonate housing with flow through cells.
After groundwater-to-surface water flux and chemical concentrations have been measured, chemical (constituent) flux from the TZ into surface water may be determined by multiplying the water flux by the chemical concentration.

**Groundwater-to-Surface Water Modeling**

Groundwater-to-surface water modeling can be performed for several reasons, including:

- Evaluation of the potential for impacted groundwater to discharge to surface water.
- Determining if natural attenuation is occurring.
- Predicting concentrations of constituents in surface water from groundwater.
- Evaluating corrective action options, including beneficial effects of corrective action.

The governing equations for TZ modeling include Darcy’s Law and the advective-dispersive-reactive (ADR) equation. The ADR equation usually includes a retardation factor to represent the effects of sorption to solid-phase media. Similar equations used for modeling surface water bodies incorporate hydrodynamics (flow and movement of water) and constituent fate and transport, through use of the ADR equation (EPRI 2018).
Figure 11 shows key processes that should be considered for groundwater-to-surface-water modeling.

**Figure 11.**
**Key Processes for Modeling in the TZ**

As shown in Figure 12, the following types of models may be linked into an integrated framework:

- Groundwater fate and transport
- Hydrodynamic
- Sediment fate and transport
- Contaminant bioaccumulation
In summary, several proven techniques are available to identify seepage zones, to determine mass flux of water and chemical constituents across the TZ, and to model the groundwater-surface water interface. EPRI (2018) provides additional information on characterizing the TZ, including geochemical processes, laboratory and data analytical techniques, and evaluation of natural attenuation.
References


Surface Water with Fiber Optic Temperature Measurement” *Environmental Science Processes & Impacts* 16:1772.


