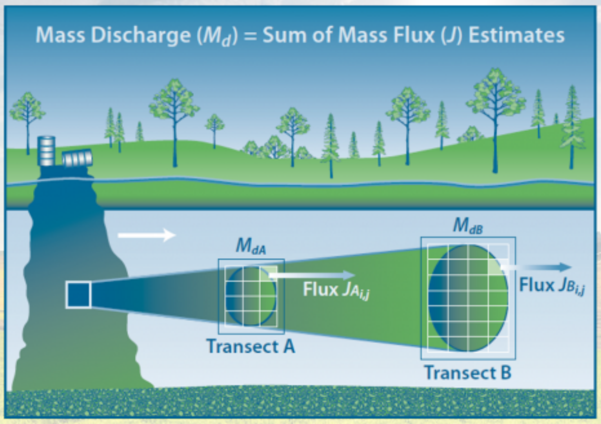
Welcome

Use and Measurement of Mass Flux and Mass Discharge



EXECUTIVE SUMMARY

Most decisions regarding contaminated groundwater sites are driven by contaminant concentrations. These decisions can be improved by also considering contaminant ***mass discharge*** and ***mass flux.*** Mass discharge and flux estimates quantify source or plume strength at a given time and location. Consideration of the strength of a source or solute plume (i.e., the contaminant mass moving in the groundwater per unit of time) improves evaluation of natural attenuation and assessment of risks posed by contamination to downgradient receptors, such as supply wells or surface water bodies.

It is important to distinguish between these two terms. *Mass flux* is a rate measurement specific to a defined area, which is usually a subset of a plume cross section. Mass flux is thus expressed as mass/time/area (e.g., $g•d^{-1}•m^{-2}$). *Mass discharge* is an integrated mass flux estimate (i.e., the sum of all mass flux measures across an entire plume) and thus represents the total mass of any solute conveyed by groundwater through a defined plane. Mass discharge is therefore expressed as mass/time (e.g., g/d). In addition to defining the source strength and plume attenuation rate, mass flux estimates can identify areas of a plane through which the majority of the contaminant mass is moving. This information is valuable in virtually all aspects of contaminated site management (Figure ES-1).

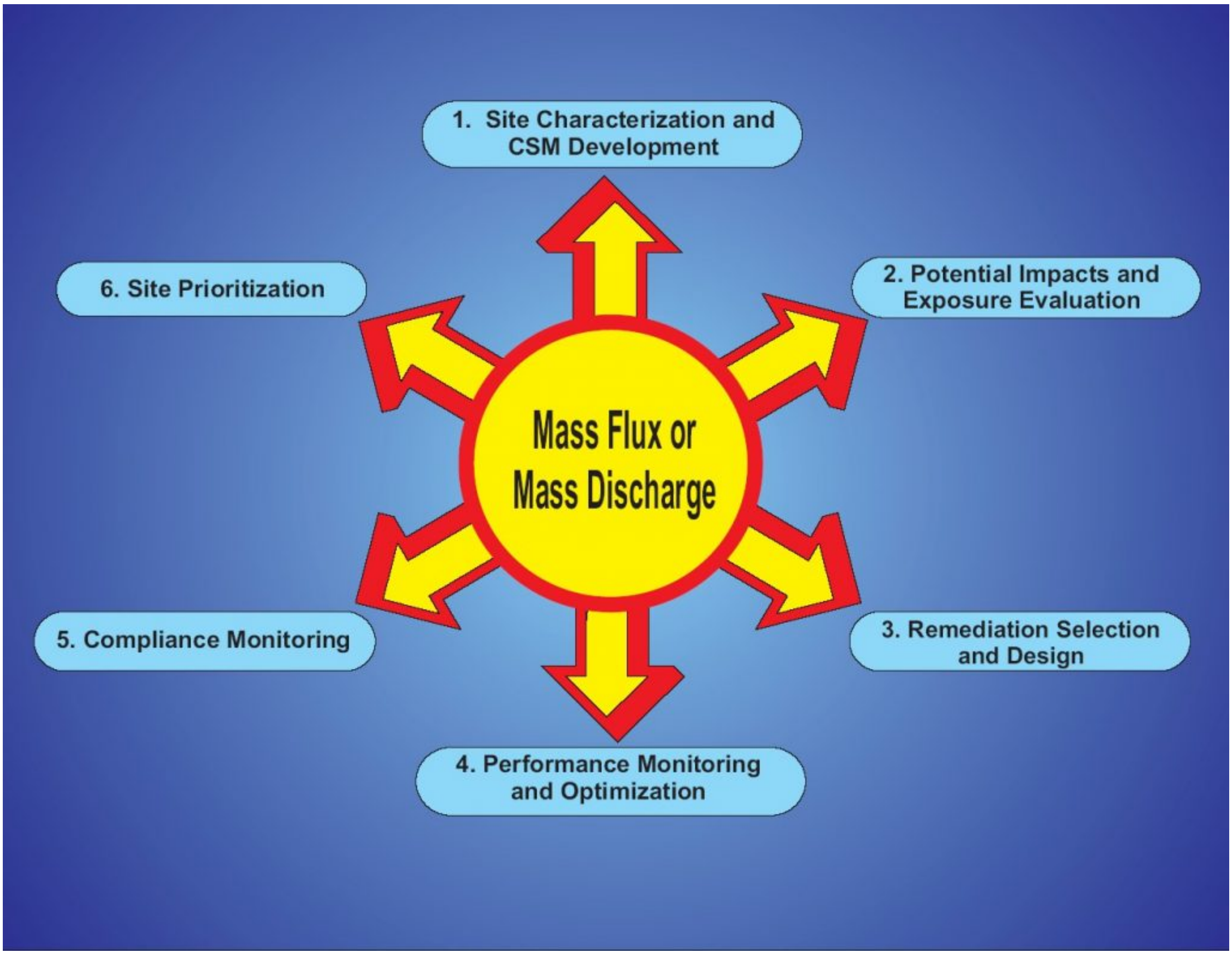


Figure ES-1. Potential applications of mass discharge and mass flux data for contaminated groundwater management.

Mass discharge is calculated by combining concentration data with the Darcy velocity of groundwater. By evaluating mass discharge at a site and thereby accounting for the combined effects of concentration and groundwater velocity on contaminant movement, managers will have a more complete understanding of the site, which will improve management decisions regarding site prioritization or remedial design and operations. For example, contaminant concentrations alone cannot provide a complete picture of the processes governing plume behavior because groundwater velocity (which varies across a site) is an integral component of plume behavior. However, incorporating mass discharge information into the conceptual site model (CSM) improves remediation efficiency and shortens cleanup times, particularly at sites with multiple source areas or where plumes cross multiple stratigraphic units.

Figure ES-2 provides an example of the benefits of mass flux information for a site with multiple stratigraphic units. In this case, the three stratigraphic layers have identical contaminant concentrations and hydraulic gradients but varying hydraulic conductivities and, therefore, varying groundwater velocities. Considering concentration data suggests only that cleanup of all three layers is equally important. But the mass flux estimates clearly identify the layer that poses the greatest downgradient risk and justify remediation of the gravelly sand first.

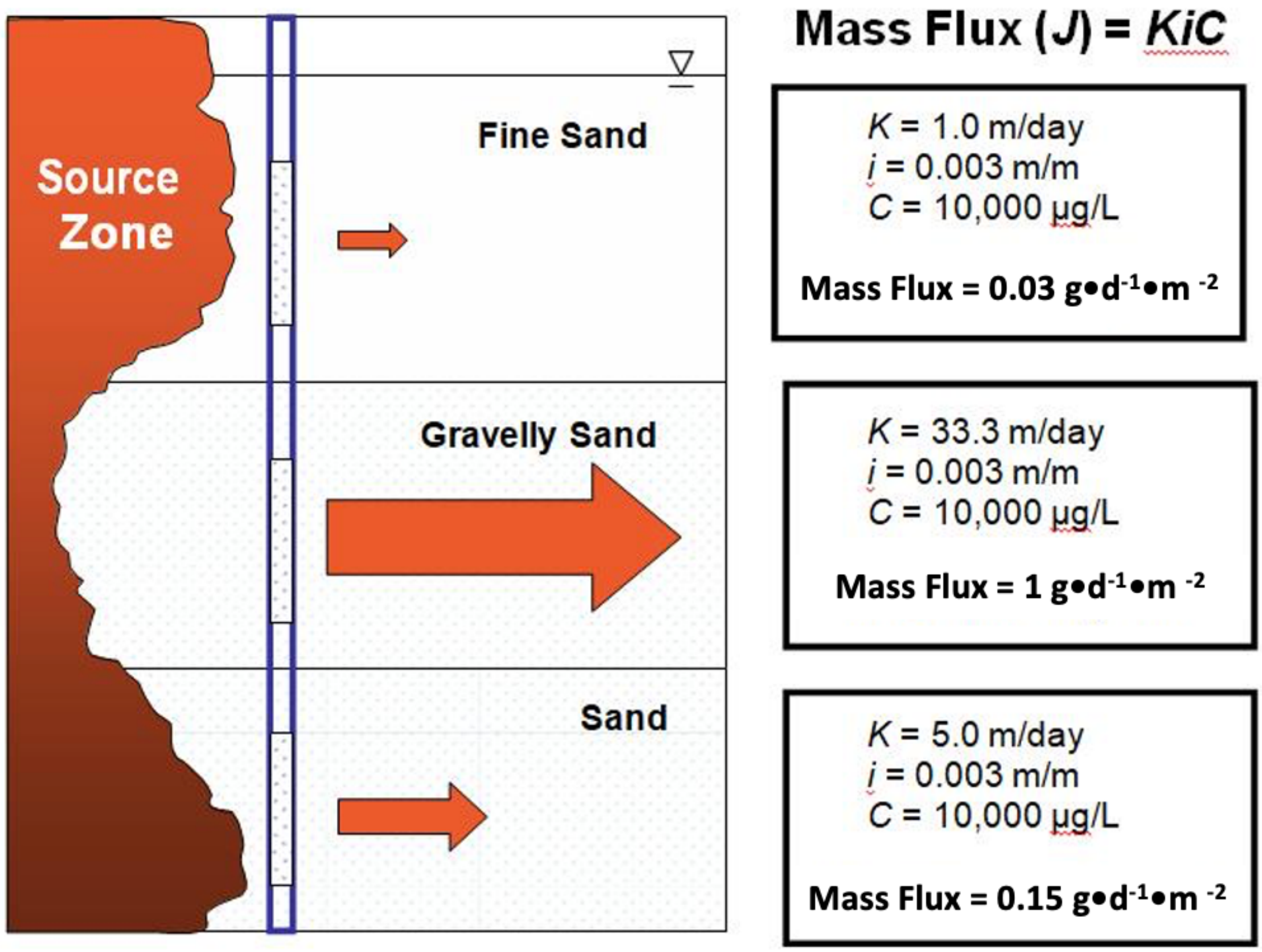


Figure ES-2. Benefit of mass flux assessments for prioritizing treatment zones. Although the concentrations and groundwater gradient (*i*) are identical, the fluxes and, therefore, the risks differ significantly because of variations in the hydraulic conductivity (*K*). Similar variations in *K* are common in most aquifers.

Mass flux and mass discharge estimates can help managers more accurately answer several key questions:

- Is the contaminant plume stable, expanding or contracting?
- How will a proposed remedial action affect the future distribution, transport, and/or fate of the contaminants?
- What will be the risks and exposures at various points in the foreseeable future?
- How much source removal will be needed before transitioning to other technologies, such as in situ bioremediation or allowing monitored natural attenuation to complete the site remediation?

In most cases, mass flux and mass discharge data will not be the only information needed to address these questions. Explicitly considering the mass information can augment the time concentration data (e.g., when evaluating plume stability). A common experience is that measuring mass flux and discharge at a site improves the overall CSM, leading to a better understanding of the potential risks and helping managers identify the highest-priority portions of the site.

Mass flux and mass discharge estimates do have limitations. Collecting the data necessary to calculate either will increase total project cost. The costs may be relatively low for estimates based on models or mathematical analyses of existing data, but they can be significant for so- called high-resolution mapping (measuring fluxes at relatively close-spaced points along one or more transects, sampling at multiple depth intervals at each sampling point). The uncertainty involved in mass flux and mass discharge estimates can be significant, and it should be quantified where possible. However, it also should be evaluated relative to the concentration data, which may be at least as uncertain. Reliable mass flux and mass discharge estimates often require more detailed characterization of hydraulic conductivity and groundwater flow field than is typically available at most sites. Ultimately, the degree of accuracy required for mass flux or discharge estimates should be determined based on the planned uses of the estimates. In some cases an initial approximation may be sufficient, and higher-resolution measurements can be collected later if necessary.

There are three basic methods to measure mass flux and/or mass discharge:

- **transect methods**, in which individual monitoring points are used to integrate concentration and flow data (Figure ES-3)
- **well capture/pump test methods**, which rely on extracting groundwater and measuring the flow and mass discharge from the wells
- **passive flux meters**, which are recently developed devices to estimate mass flux directly in wells

Mass discharge and flux also may be estimated by analyzing existing site data. Such estimates can be obtained by analyzing flow rates and concentrations (a) along transects oriented perpendicular to isocontours (or along transects using existing monitoring wells) or (b) by using solute transport models that require flow and concentration data as input parameters. Mass discharge data have been determined historically at many sites where soil vapor extraction or groundwater pump-and-treat systems have been implemented. These data are typically used to evaluate the rate of source depletion, and in some cases asymptotic and mass discharge trends have been used to determine the time to transition to a new technology or management strategy.

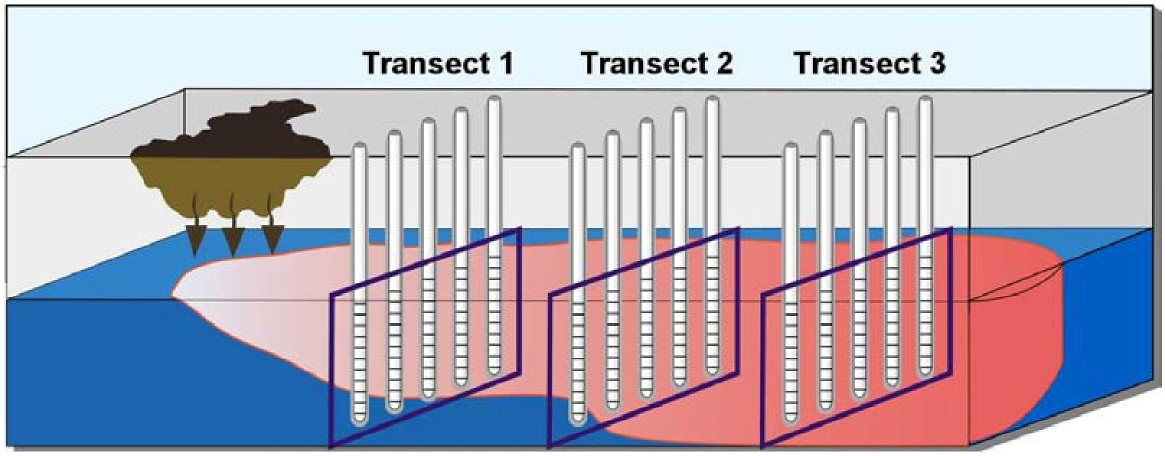


Figure ES-3. Use of multiple well transects to measure mass discharge and mass flux.*(Adapted from Einarson and Mackay 2001.)*

This technology overview summarizes the concepts underlying mass discharge and flux, their potential applications, and case studies of the uses of these metrics. Review of the case studies showed that mass discharge and flux estimates have been useful for several site management objectives and that evaluating mass discharge and flux can improve CSMs and lead to more efficient remediation. Specific findings from the case study review include the following:

- **Mass discharge and flux data have improved decision making.** For example, they have been used to trigger transition between technologies.

- **Mass discharge and flux data have reduced remediation costs.** For example, mass flux estimates have been used to identify high-priority layers in stratified aquifers, leading to more cost-effective cleanup.

- **Mass discharge and flux data have been used to prioritize sites.** For example, responsible parties have used mass discharge estimates to identify the sites needing further characterization and remediation within regional flow systems impacted by multiple sources.

- **Mass discharge and flux data have been used to predict remediation performance.** Mass discharge, high-resolution mapping, and available analytical tools have provided the basis for estimation of natural attenuation rates, plume responses to source treatment, and remediation time frames.

- **Transect testing has been by far the most common method used, and transects have proven useful**

for site management. Use of well transects has provided more credible estimates of natural attenuation rates than the more typical practice of relying on a line of wells along a flow path because transect data are less susceptible to temporal variations in flow direction and strength.

Other uses of mass flux and mass discharge data include risk assessment, particularly when evaluating risks to potential downgradient receptors or when assessing the risks of vapor intrusion into buildings located above contaminated groundwaters. In many cases, this information is used in the underlying models, but its importance is not recognized and the estimates may be highly uncertain.

Key conclusions from this overview of mass flux and mass discharge include the following:

- Mass flux and discharge estimates have proven valuable for contaminated site management and should be used more frequently.
- Use will increase rapidly as the benefits of mass flux and discharge information are more widely recognized.
- A specific estimation method may be better suited to specific site conditions and objectives, so it is important to consider the advantages and limitations of the methods available.
- Useful mass discharge and flux estimates often can be developed from existing site data and/or limited site sampling, often for relatively little cost.
- All methods of mass flux and discharge estimation involve uncertainty that should be recognized and quantified, to the extent practicable, when considering use of the parameters. However, concentration-only data may have similar, or greater, uncertainty.
- Strategies to manage uncertainty include precharacterization and sampling in stages.
- Mass discharge can also have an important role in regulatory decisions and may have advantages over concentration data for some purposes. Examples include deciding when to shift from aggressive treatments to natural attenuation; evaluating dense, nonaqueous-phase liquid (DNAPL) source remediation efforts; or even determining when no further action is required at a site.

This document is intended to foster understanding of mass discharge and mass flux estimates through description of their development and use. In the interest of brevity, this technology overview assumes the reader has a general understanding of hydrogeology, the movement of chemicals in porous media, remediation technologies, and the overall remedial process. Additionally, nothing in this technology overview modifies any existing regulatory requirement of a state or federal agency.

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