Risk Evaluation: Ground Water

9.1 Introduction

Contamination often reaches **ground water**. Ground water flows, and as it does, it can carry certain contaminants with it, sometimes over long distances. It can also desorb contamination from soils. Because many people in Indiana rely on ground water for drinking water and other uses, it is important to evaluate risks arising from existing and potential ground water contamination.

Exposure to ground water contamination occurs via three absorption routes – volatilization from water to air (inhalation route), ingestion, and dermal contact. The Indiana Department of Environmental Management (IDEM)'s residential ground water screening levels assume water ingestion, dermal contact/absorption, and inhalation of volatiles by persons of all ages. IDEM does not calculate commercial/industrial screening levels for ground water or migration to ground water, because consumption of ground water above residential screening levels is not considered health protective.

Evaluation of ground water exposure risk requires ground water sampling. In addition, contaminated soils that overlie ground water may leach contamination into ground water, thereby serving as an ongoing contaminant source. Therefore, adequate evaluation of ground water contamination risk will often require sampling vadose zone soils.

Sampling both ground water and vadose zone soil allows evaluation of current and potential ground water exposure. This section includes guidance on the evaluation of both media as part of an integrated approach to assessing risks of potential ground water exposure, present and future.[52]

9.2 Applicability

Evaluation of potential risk to ground water receptors is appropriate whenever development of the conceptual site model (CSM) involves collection and analysis of ground water and/or soil samples that can potentially impact ground water. The evaluation process may be as simple as comparison of sampling results against screening levels. In other instances, it may involve development of site-specific levels, risk characterization, or lead to investigation of potential vapor intrusion.

9.3 Ground Water: Exposure Point Concentrations (EPCs)

There are two basic approaches to calculating ground water EPCs, though IDEM will consider other proposals on their merits. The first approach defines each ground water analytical result for each potential contaminant as an EPC. The second approach calculates an appropriate upper confidence limit of the mean (UCL) for each analyte in each monitoring well[53] and defines those

[52] Ground water sampling results are also important when assessing the need for vapor intrusion investigations (Section 5).

[53] Software applications exist that can perform the necessary calculations and recommend an appropriate UCL. For example, *ProUCL* is available for free download at the United States Environmental Protection Agency (U.S. EPA) website. Whatever the approach, IDEM review of UCL calculations will require submission of algorithm inputs and outputs.

UCLs as EPCs. The second approach typically requires at least eight quarters of ground water data.[54]

Sometimes it is necessary to resample an area and derive new EPCs. For example, resampling is appropriate following removal or treatment of contamination.

9.4 Ground Water Direct Contact: Screening Levels

As a first step when evaluating potential ground water direct contact exposure risk, IDEM recommends comparing ground water direct contact EPCs derived from site analytical data against the ground water direct contact screening levels. IDEM's ground water screening levels appear in Table A-6 of Appendix A.

9.5 Ground Water Direct Contact: Site-specific Levels

Unlike the soil direct contact and migration to ground water screening level equations, the ground water direct contact equations offer few opportunities for site-specific evaluation of chemical and physical parameters. Therefore, most ground water direct contact risk evaluations employ ground water direct contact screening levels as remediation objectives, rather than site-specific levels. Exceptions include background and off-site source demonstrations (Section 6) and site-specific risk characterizations for non-MCL contaminants that employ different target risk levels or exposure assumptions than those used to calculate screening levels.

9.6 Ground Water: Closure

Closure at sites where ground water is affected will depend on site-specific circumstances and program requirements. Residential remediation objectives usually apply to all plume areas that lie outside the exposure control area.

The plume behavior component of the CSM (Section 4) should be well developed for any site prior to examining ground water contaminant EPCs and remediation objectives.

Two standard options exist when plumes lie fully within the exposure control area.

1. Ground water closure is possible when sample results show that potential ground water contaminant concentrations are less than remediation objectives throughout the plume. There are two ways to do this.
   a. Show that potential contaminant concentrations in ground water are less than remediation objectives over an appropriate time horizon.
   b. Show that the 95% UCL of the mean for eight quarters of sampling data from each well within the ground water plume is less than remediation objectives. If statistical evaluation shows that potential contaminant concentrations within the ground water plume are less than remediation objectives, the site is eligible for ground water closure.
2. Alternatively, if appropriate exposure controls are in place and the CSM sufficiently demonstrates that the plume will not extend beyond those controls, ground water closure is possible even when ground water contamination exceeds remediation objectives.

[54] At sites with many quarters of ground water data, UCLs calculated using the most recent eight quarters of data provide a better indicator of current conditions than UCLs calculated using the entire data set.

9.6.1 Wellhead Protection Areas

Wellhead protection areas (WHPAs) are susceptible areas delineated by the ground water five-year time of travel distance to municipal well(s). Alternatively, some WHPAs are delineated by a 3,000 foot radius originating at the well(s).

Contamination within a WHPA poses a high probability of human exposure. Remedy selection for ground water contamination within a WHPA will be a site-specific decision that should be made in conjunction with IDEM and local stakeholders such as drinking water providers. Appropriate remedies will address risk to residential receptors and risks to the ground water resource.

9.6.2 Ground Water Monitoring Duration

As noted earlier, evaluation of potential risk from ground water contamination requires ground water sampling. The duration of that sampling is determined by the level of confidence in the plume behavior developed in the CSM, as described in Section 4. In general, confidence in the plume behavior depends on the severity of the contamination and the predictability of its behavior in the ground water. Increasing levels of contamination and/or complexity of ground water migration require additional lines of evidence (LOEs) and/or additional monitoring to achieve a sufficient level of confidence in the plume behavior to assess the potential risk.

For releases that exhibit ground water contamination above remediation objectives, IDEM will expect (1) a well-developed plume behavior component of the CSM, and (2) a **remedy** that addresses potential risks. Note that effective ground water remedies may require addressing issues in other media. Active ground water remediation activities should be followed by a period of re-equilibration (typically one year), followed by a reassessment of the CSM plume behavior component. Post-remedial monitoring should continue until the plume behavior component of the CSM is well understood.

For recent releases with no current evidence of ground water exceedances of remediation objectives, but evidence of a potential contaminant source in vadose zone soil, IDEM will generally expect an evaluation of chemicals in vadose zone soil as a potential source of ground water impacts. If any remedial activities are undertaken, IDEM may generally expect up to four consecutive quarters of precautionary ground water monitoring.

Where investigative work fails to show contamination greater than remediation objectives in any media, the site is generally eligible for closure using investigative data. Ground water closure may require additional monitoring where site-specific characteristics warrant.

9.7 Migration to Ground Water: EPCs

Migration to ground water EPCs apply only to vadose zone soils. Typically, individual results from judgmental samples are EPCs, suitable for direct comparison to the relevant remediation objective. However, where judgmental samples are of sufficient density and spacing, it may be appropriate to estimate the UCL to represent the EPC for most contaminants. If the sampling locations are judgmentally guided through field instruments (e.g., photoionization detector) the results are likely to be biased high. However, the UCL approach can be used at many sites to provide a conservative EPC where a few individual sample results exceed screening levels.

When analyzing more than one vadose zone soil sample in a single boring, the recommended migration to ground water EPC for the sample location is the length-weighted average of the individual sample results from within the boring, using:

$$EPC = \frac{\sum_{i}^{n} C_i L_i}{\sum_{i}^{n} L_i}$$

Where C_i = concentration in sample i;

L_i = length of the soil column represented by sample i; and
n = number of samples

For samples collected using a systematic approach, the EPC is an appropriate UCL, calculated using results from a sample array that corresponds to the area under evaluation[55]. The resulting UCL is the EPC.

Sometimes it is necessary to resample an area and derive new EPCs. For example, resampling is appropriate following removal or treatment of contamination.

9.8 Migration to Ground Water: Screening Levels

As a first step when evaluating the potential risk from migration of soil contaminants to ground water, IDEM recommends comparison of vadose zone soil EPCs derived from site analytical data against the appropriate migration to ground water screening levels. IDEM's migration to ground water screening levels appear in Table A-6 of Appendix A.

9.9 Migration to Ground Water: Site-specific Levels

If the assumptions underlying IDEM's migration to ground water screening levels do not accurately reflect the physical and chemical conditions at a particular site, IDEM recommends calculating **site-specific levels**. Suitable parameters for site-specific evaluations include fraction of organic carbon (f_{oc}, Section 9.9.1), pH (Section 9.9.2), and source size (Section 9.9.3). When properly derived, site-specific levels are appropriate for use in evaluating vadose zone soils for their potential to affect ground water.

It is also possible to determine site-specific migration to ground water levels based on background concentrations. Suitably applied, any of these remediation objectives are acceptable for closure purposes. Karst terrain and geologic areas where fractures control ground water flow require site-specific approaches when evaluating the migration to ground water pathway.

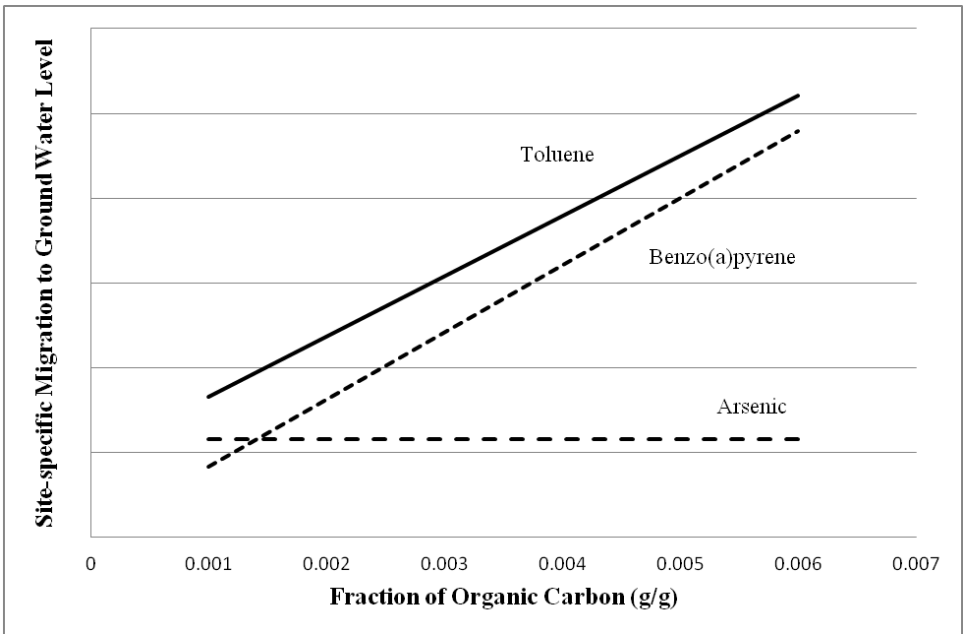
9.9.1 Fraction of Organic Carbon (f_{oc})

IDEM's migration to ground water screening levels use a single set of parameter values intended to apply statewide. Collecting site-specific values for certain parameters can result in migration to ground water screening levels better suited to the characteristics of the site.

The f_{oc} in vadose zone soil may have a significant effect on migration to ground water levels for certain kinds of chemicals. Figure 9-A depicts the effect of varying f_{oc} on migration to ground water levels for three potential contaminants.

[55] Software applications exist that can perform the necessary calculations and recommend an appropriate UCL. For example, *ProUCL* is available for free download at the U.S. EPA website. Whatever the approach, IDEM review of UCL calculations will require submission of algorithm inputs and outputs.

Figure 9-A: Effect of f_{oc} on Migration to Ground Water Levels



Changes in f_{oc} have no effect on the migration to ground water levels of metals. However, potential contaminants with higher organic carbon-water partition coefficients (e.g., many organic chemicals) can exhibit marked effects.

Background procedures (Section 6) are useful when evaluating vadose zone soil f_{oc} values. Soil samples collected for f_{oc} should be from areas not affected by organic soil contaminants, yet similar in nature, depth, and composition to potentially contaminated areas. Each soil sample submitted for f_{oc} analysis should include a duplicate sample analyzed for those organic potential contaminants present in the migration to ground water source area. Use the results of this parallel analysis to verify that the area sampled for foc is unaffected by organic contamination. IDEM (2007) and the Office of Land Quality Chemistry Services Section web page[56] contain additional guidance on f_{oc} evaluation.

9.9.2 Metals and Ionizable Organics

Soil-water partition coefficients (K_d) values for these chemicals vary with soil pH, sometimes dramatically. Therefore, changes in soil pH can significantly affect leachability of certain metals and ionizable organic chemicals (e.g., phenols, amines, and carboxylic acids). For beryllium, cadmium, mercury, nickel, and silver, the effect is especially pronounced (see Table 9-A).

[56] http://www.in.gov/idem/files/Foc_Guidance_070925_Final.pdf

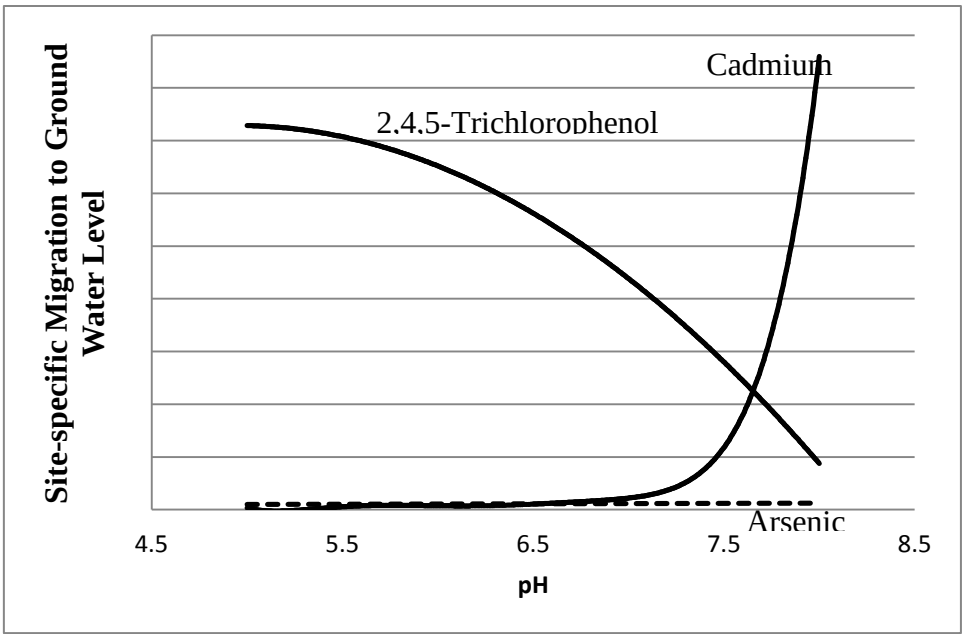
Table 9-A. K_d Values for Selected Metals at Soil pH values of 6.0, 7.0, and 8.0

Metal	K_d at pH=6.0	K_d at pH=7.0	K_d at pH=8.0
Beryllium	82	1,700	100,000
Cadmium	37	110	4,300
Mercury	3.5	82	200
Nickel	38	88	1,900
Silver	1.3	13	110

IDEM's migration to ground water screening levels assume nearly neutral (pH = 6.8) soils, and the migration to ground water screening levels are acceptable whenever soil pH falls within a range of 6.0 to 8.0. Calculation of site-specific migration to ground water levels is appropriate whenever soil pH falls outside that range. For beryllium, cadmium, mercury, nickel, and silver, calculating site-specific migration to ground water levels whenever soil pH is *greater* than 6.0 will often result in site-specific levels higher than screening levels. Always calculate a site-specific migration to ground water level for beryllium, cadmium, mercury, nickel, or silver if soil pH falls *below* 6.0.

Figure 9-B depicts the impact of soil pH on migration to ground water levels for two metals and one ionizable organic chemical. As shown in this figure, soil pH has a significant impact on the migration to ground water levels for some potential contaminants and a minimal impact on others.

Figure 9-B: Effect of pH on Migration to Ground Water Levels

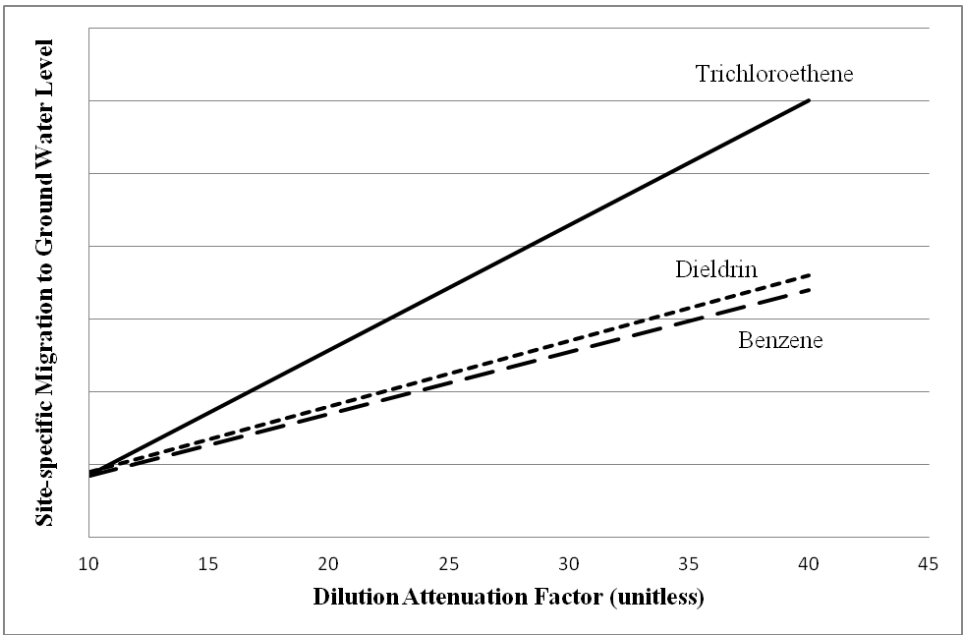


U.S. EPA (1996b, Tables C-2 and C-4) contains K_d and K_{oc} values for various metals and ionizable organics under a range of different soil pH values. IDEM recommends using these tables in conjunction with site-specific soil pH data and the equations in U.S. EPA (2011) to derive site-specific migration to ground water levels.

9.9.3 Large Migration to Ground Water Sources

Dilution and attenuation may decrease the concentration of chemicals in ground water. Dilution occurs as the dissolved chemical disperses and mixes with less concentrated ground water. Attenuation occurs as dissolved chemicals sorb to soil or degrade through a variety of processes. To account for these phenomena, the soil-to-ground water partitioning model incorporates a **dilution attenuation factor** (DAF). Changing the DAF has a direct effect on the migration to ground water levels for all potential contaminants. Figure 9-C depicts this relationship for three potential contaminants.

Figure 9-C: Effect of Varying DAF on Migration to Ground Water Levels



When calculating migration to ground water screening levels, IDEM sets the DAF parameter in the partitioning model to 20. However, appropriate DAF values vary in part as function of the size of the migration to ground water source (Table 9-B).

Table 9-B: Dilution Attenuation Factors

Source Size[57]	DAF
Source ≤ ¼ acre	30
¼ acre < Source ≤ ½ acre	20
½ acre < Source ≤ 30 acres	10
Source > 30 acres	1

Users may propose alternative approaches, although IDEM does not anticipate approving DAF values greater than 30 when those proposals base adjustments solely on source size. U.S. EPA (1996a) describes both the rationale for selection of specific DAF values and additional options for evaluation of the migration to ground water pathway.

[57] One quarter-acre is approximately the same size as a square with 100 foot sides. One half-acre is approximately the same size as a square with 150 foot sides. 30 acres is approximately the same size as a square with 1,140 foot sides.

9.10 Synthetic Precipitation Leaching Procedure (SPLP)

One alternative to calculating site-specific migration to ground water levels is to evaluate leaching of potential contaminants from soil to ground water using the synthetic precipitation leaching procedure (SPLP, SW-846 Method 1312). SPLP simulates acid rain and its effects on chemicals in soil. SPLP may prove especially useful at sites where lead and/or arsenic are a concern.

SPLP produces a leachate solution, and the laboratory reports the concentrations of chemicals in that solution. Ground water impacts above ground water remediation objectives from future leaching are unlikely when leachate concentrations are less than ground water remediation objectives. An exceedance suggests the need for additional evaluation or a remedy.

One potentially cost-saving variation on this method for VOCs avoids the expense of initial SPLP testing. Instead, the variant approach estimates a worst case SPLP leachate concentration by assuming that one hundred percent of the potential contaminant mass will leach from the soil. Divide the soil sample results in units of milligrams per kilogram by 20 (to account for the 20:1 dilution factor in the SPLP method), then, compare the resulting concentration to the ground water remediation objective, expressed in milligrams per liter. An exceedance indicates the need for further evaluation (e.g., SPLP) or a remedy. Another method for calculating an alternative soil migration to ground water screening level is to convert the tap water screening level to milligrams per liter, multiply it by twenty, and compare the resulting number against soil sample results (expressed in milligrams per kilogram).

When using any SPLP approach, collect a minimum of three soil samples from the area of highest potential contaminant concentration and analyze them using SPLP or the variant approach. Existing analytical information, knowledge of site stratigraphy, and professional judgment should guide the location and appropriate number of samples. It is acceptable to calculate an EPC for each potential contaminant.

9.11 Migration to Ground Water: Closure

Vadose zone soils sampled using judgmental methods are eligible for closure of the migration to ground water pathway when vadose zone soil EPCs are less than relevant migration to ground water remediation objectives. Options for sites where vadose zone soil EPCs exceed migration to ground water remediation objectives include:

- Removal or treatment of contamination
- Institutional controls and/or engineering controls that reduce risk to an acceptable level
- Demonstration of acceptable plume behavior
- Demonstration of acceptable leaching behavior using SPLP
- Other appropriate lines of evidence that demonstrate a remedy is not necessary

Figure 7-A (Section 7.7) presents a generic decision tree for comparing EPCs and remediation objectives.

The ultimate criterion for ground water closure is ground water data. While remediation of saturated soils can minimize or eliminate the need for long-term controls, IDEM does not anticipate requesting remediation of saturated soils, except insofar as necessary to meet soil direct contact remediation objectives (where relevant), address vapor intrusion risk, or drive ground water concentrations below remediation objectives.