

Remediation Closure Guide

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Office of Land Quality

Indiana Department of Environmental Management

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Introduction

1.1 Purpose

The *Remediation Closure Guide* (RCG) describes selected approaches to investigation and risk-based closure¹ of contaminated or potentially contaminated sites. Its purpose is to provide for consistent application of Indiana Code (IC) 13-12-3-2 and IC 13-25-5-8.5, which form the statutory basis for risk-based cleanup in Indiana.

A companion manual, the *Remediation Program Guide*, provides guidance related to specific regulatory programs. Together, the *Remediation Program Guide* and the RCG provide a framework for investigating sites and moving them toward closure.

The procedures in the RCG are technically sound and, when used appropriately, are applicable to a broad range of sites. However, the Indiana Department of Environmental Management (IDEM) recognizes that there are many possible approaches to investigation and closure of sites, and that other procedures may be more appropriate at some sites.

IDEM will evaluate alternative approaches on their merits.

The RCG is a substantial revision of the 2001 *Risk Integrated System of Closure (RISC) Technical Resource Guidance Document*. The RCG builds on the earlier guidance, eliminating some things that proved less useful than anticipated, and introducing new material or expanding sections.

The RCG follows a broad outline, beginning with an introduction that explains the statutory basis and use of several key concepts, and sketches out an overall process. Sections 2 through 6 describe various aspects of developing a **conceptual site model** – essentially, a detailed description of the investigative area that demonstrates an understanding of present and likely future contaminant type(s), concentrations, and distribution. Sections 7 through 11 build on the conceptual site model, using the information it contains to evaluate potential risks to exposed or potentially exposed populations. In some cases, that evaluation will indicate the need for selection and implementation of a remedy of some kind – the topic of Section 12. Supporting materials comprise the last sections of the RCG.

IDEM will update or revise the procedures described herein as necessary. Updates will appear on the [Risk-based closure web page](#).² In addition, IDEM staff can provide clarification regarding updates on the contents of this volume.

¹ Closure is IDEM's written recognition that a party has demonstrated attainment of specific investigative or remediation objectives for contaminants in a particular area.

² <http://www.in.gov/idem/4153.htm>

1.2 Applicability

As directed by IC 13-12-3-2, the RCG applies to the following IDEM remediation programs:

- Leaking Underground Storage Tank (LUST) Program
- Voluntary Remediation Program (VRP)
- Resource Conservation and Recovery Act (RCRA) Subtitle C Programs, including RCRA Treatment Storage and Disposal (TSD) facility closures, interim status TSD closures and RCRA Corrective Action projects³
- State Cleanup Program (SCP)
- Indiana Brownfields Program (IBP)

Cleanups completed under these programs may use risk-based remediation objectives established by IC 13-25-5-8.5. The RCG and risk-based remediation objectives may also be applied to the closure of certain RCRA Subtitle D surface impoundments as management practices that are protective of human health and the environment.³

As a non-rule policy, the RCG does not have the effect of law. *If a conflict exists between the RCG and state or federal rules and statutes, the rules and statutes will prevail.*

Some conditions require quick response action to mitigate any potential imminent and substantial threat to human health or the environment. Examples include:

- Releases covered under the Spill Rule⁴
- Acute exposures to contamination
- Presence of corrosive, explosive, flammable, or toxic vapors
- Actual or imminent contamination of a drinking water supply well

The RCG does not specifically address these situations. However, where appropriate, RCG activities may proceed concurrently with emergency mitigation measures.

IDEM did not develop the RCG for use in obtaining information specific to real estate transfers. Other resources (e.g., ASTM 2002, 2005) contain guidance suited for this purpose.

³ While RCRA Subtitle C and D facilities may take advantage of some of the closure options afforded by the RCG, program-specific statutes and rules may require the removal of contamination. Where there are conflicts with such requirements, removal of contamination to land use specific concentrations may be required.

⁴ 327 IAC 2-6.1

1.3 Remediation Objectives

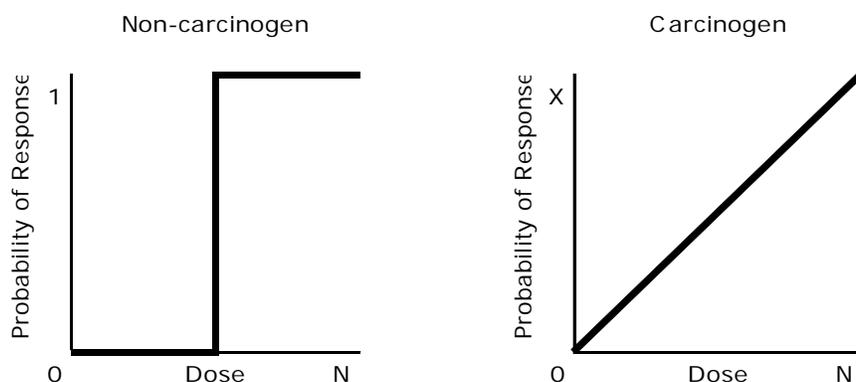
IC 13-25-5-8.5 directs responsible parties to specify **remediation objectives** for sites where releases occur. The statute describes two fundamental types of remediation objectives.

The first type bases remediation objectives on the background levels of substances that occur naturally on the site. Background demonstrations are very useful when showing that site activities have not contributed contamination to the environment above naturally occurring levels.⁵ When a release *has* occurred, remediating the released chemical to background levels is often difficult and unnecessarily stringent.

The second type of remediation objective uses a risk-based approach. Risk-based methods recognize that there is a relationship - the **dose-response relationship** - between the concentration of a chemical to which a population is exposed and the likelihood that members of that population will suffer adverse effects.

Dose-response relationships differ by chemical and by *type* of chemical. For example, IDEM follows the United States Environmental Protection Agency (U.S. EPA) in assuming that the dose-response relationship of non-carcinogens is different from that of carcinogens (Figure 1-A).

Figure 1-A: Dose-Response Relationships



For non-carcinogens, IDEM assumes that there is a **threshold dose** below which adverse effects are unlikely. For most carcinogens, IDEM assumes that the probability of an adverse effect is proportional to the dose, and that there is no non-zero threshold below which the probability of an adverse effect is zero. Threshold doses and the slopes of the carcinogenic response lines (**slope factors**) are estimates, and they differ from chemical to chemical. All are subject to change as new data become available.

Adverse effects are unlikely when exposure to a non-carcinogen is lower than its threshold dose. Calculating acceptable environmental concentrations for carcinogens is more complicated. For carcinogens, IDEM assumes that any exposure carries some risk. IDEM follows U.S. EPA in considering an incremental carcinogenic risk of 10^{-4} to 10^{-6} as acceptable, with 10^{-5} as the usual target.

About 40 percent of Americans develop cancer at some point in their lifetimes (American Cancer Society, 2010). Therefore, cancer will probably occur in about 40,000 persons in an area of 100,000 residents. An incremental risk of 10^{-5} to that population should, on average, add one additional cancer case.

⁵ Section 6 includes procedures for determining background concentrations at sites.

The objective of a risk-based approach is to define an environmental concentration that corresponds to an acceptable level of risk to persons⁶ who may undergo exposure to a particular chemical. Risk-based approaches do this by using equations and assumptions that mathematically relate environmental concentrations to the risk of adverse effects, structured so that the result is a set of environmental concentrations considered acceptable, *subject to the underlying assumptions*. As the underlying assumptions change, the calculated acceptable environmental concentrations also change.

Many regulatory agencies employ this general approach to generate tables of acceptable concentrations for chemicals in various media under specific exposure scenarios. Indiana statute directs the agency to calculate such numbers. IDEM calls them **screening levels**.⁷

For ease of presentation in this document, IDEM has chosen to define a **contaminant** as a chemical present at a concentration above the chemical's remediation objective. This definition is consistent with the definition contained in previous guidance, but reflects a shift in terminology away from the use of contaminant of concern. However, IDEM's authority, and a responsible person's⁸ obligation, to undertake a response action is specific to the applicable remedial statute.⁹ In general, IDEM's authority, or a person's obligation, is triggered by a release (regardless of concentration or quantity) of hazardous substances, regulated substances, hazardous waste, or petroleum.¹⁰ IDEM has chosen to refer collectively to such releases as releases of **potential contaminants**. Any unintentional reference in this guidance to a contaminant (as opposed to a potential contaminant) does not alter IDEM's authority or a responsible person's obligation to perform response actions.

⁶ Or non-human receptors, where applicable.

⁷ Formerly *default closure levels*.

⁸ IDEM is using the terms responsible person, responsible party, owner, operator, and applicant interchangeably for purposes of this document. However, Title 13 contains specific definitions for the various terms.

⁹ See IC 13-22-13, IC 13-23-13, IC 13-24-1, and IC 13-25-4; also IC 13-25-5, the Voluntary Remediation Program, applies to releases of hazardous substances and petroleum.

¹⁰ Some of these terms overlap.

1.3.1 Screening Levels

IC 13-25-5-8.5(d)(1) – Levels of hazardous substances and petroleum calculated by the department using standard equations and default values for particular hazardous substances or petroleum.

As directed by statute, IDEM periodically calculates **screening levels**. IDEM relies on the values found in the regional screening level (RSL) tables (U.S. EPA, 2011b and updates) and guidance from the [Regional Screening Levels User's Guide](#)¹¹ (U.S. EPA, 2011) when deriving screening levels. Appendix A describes the methods that the agency uses to calculate screening levels. Links to current and archived screening levels appear on the [Risk-based closure web page](#).¹²

IDEM calculates screening levels for several different exposure scenarios:¹³

- Direct (surface soil) contact for residential and commercial/industrial users
- Direct (subsurface soil) contact for excavation workers
- Ground water exposure for residential users, including migration to ground water screening levels designed to predict future ground water concentrations arising from chemicals in soil
- Vapor exposure for both residential and commercial/industrial users

Each of these exposure scenarios differs from the others in types and/or durations of exposures to chemicals.

Screening levels *applied under appropriate land use scenarios* are suitable for use at any site. In practice, the protective assumptions built into the screening levels make the probable additional carcinogenic risk of using those levels under appropriate land use scenarios substantially lower than 10^{-5} . Non-carcinogenic effects at screening levels are also unlikely, for the same reason.

Screening levels are like “first cut” values – if chemical concentrations at a site do not exceed screening levels, the site is generally eligible for closure, though conditions may apply.¹⁴ An exceedance of screening levels indicates the need for additional evaluation.

1.3.2 Site-specific Levels

Sometimes the assumptions that underlie IDEM’s screening levels may not accurately reflect the physical reality of a particular site. This can have the effect of over-estimating the risk at the site. In some cases, it may even suggest the need for mitigation when none is necessary. Where this seems likely, it may prove worthwhile to collect additional data to calculate **site-specific levels** that more accurately characterize risk.

IC 13-25-5-8.5(d)(2) – Levels of hazardous substances and petroleum calculated using site specific data for the default values in the department’s standard equations.

For example, IDEM’s migration to ground water screening levels incorporate an assumption that the fraction of organic carbon (f_{oc}) in subsurface soil is 0.002 gram/gram (g/g). This value, while reasonable for sand, is toward the low end of the range found in Indiana subsurface soils. Many Indiana subsurface soils have organic carbon fractions higher than 0.002 g/g, and are therefore less likely to leach organic chemicals than a soil with an f_{oc} of 0.002 g/g.

¹¹ http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm

¹² <http://www.in.gov/idem/4153.htm>

¹³ Other agencies may have authority in regulating exposures to commercial/industrial populations.

¹⁴ Ground water and vapor closure typically require more than one sampling event.

By collecting and analyzing subsurface soil samples for f_{oc} , it may be possible to show that subsurface soil f_{oc} exceeds 0.002 g/g at a particular site, and use that information to derive site-specific migration to ground water levels that are simultaneously higher and more appropriate than the screening level. See Section 9.9.1 for more information on the derivation of site-specific levels using f_{oc} analysis.

Because of the protective assumptions incorporated into screening levels, IDEM expects that site-specific levels will nearly always exceed screening levels.

Many physical and chemical parameter values appear in the equations used to derive screening levels, and it may be worthwhile to collect site-specific data on those parameter values to calculate site-specific levels. Additional details appear in Sections 7 through 10.

As with screening levels, exceedance of a site-specific level means that further action is necessary. Such action might include remediation, risk management, and/or a demonstration utilizing appropriate lines of evidence that the risk characterization overstates the actual risk.

1.3.3 Risk Characterization

Screening level and site-specific level calculations begin with a predetermined level of acceptable risk and use standard equations, toxicity criteria, and exposure assumptions to solve for acceptable environmental concentrations of chemicals. In contrast, risk characterization begins with observed chemical concentrations and uses the same equations, criteria, and assumptions to solve for the resulting risk. In other words, the risk characterization and the screening level/site-specific level approaches solve for different things.

<u>Approach</u>	<u>Begin with</u>	<u>Solve for</u>
Screening level/ Site-specific level	Target risk level Standard equations Exposure assumptions Toxicity criteria	Screening level/Site-specific level
Risk Characterization	Observed chemical concentrations Standard equations Exposure assumptions Toxicity criteria	Risk level

Risk characterization also includes a qualitative component that identifies key assumptions and bias, and states the limitations and uncertainties associated with the risk assessment. A complete risk characterization then integrates the quantitative and qualitative assessments. While the screening level/site-specific level approach determines only whether or not observed chemical concentrations exceed screening levels or site-specific levels, the risk characterization approach estimates the actual risk level and conveys the range of information considered and used in developing the assessment. In short, risk characterization clarifies the scientific basis for decisions, while screening levels or site-specific levels do not, by themselves, give a true picture of the assessment. Risk characterization is a powerful approach that allows comparison of the risk estimate to the target risk range (10^{-4} to 10^{-6}). U.S. EPA uses risk characterization to evaluate risks and the necessity of remedial action at Superfund and RCRA sites. There is more clarity in a risk characterization because the magnitude of any risk exceedance is both quantified and qualified.

For example, if soil arsenic is present for residential direct contact at a representative concentration of 10 milligrams per kilogram (mg/kg), it clearly exceeds the screening level of 5.5 (mg/kg). However, it is not apparent whether the observed concentration results in an exceedance of the target risk range. A risk characterization using the same screening level exposure assumptions reveals that the soil arsenic poses a potential 2.6×10^{-5} cancer risk. It is then possible to compare this numeric risk estimate to the IDEM screening level target risk of 10^{-5} and the 10^{-4} to 10^{-6} target risk range. Although the numerical comparisons are important, the limitations and uncertainties identified in the risk characterization (e.g., low confidence due to use of average exposure parameters at an elementary school yard, versus high confidence due to use of screening level exposure parameters at an industrial facility) should also inform decisions about the site.

Non-carcinogenic risk assessments where the target hazard quotient is 1 may employ a similar analysis, although a hazard risk range is not suitable. Section 7 provides more information on the components of risk assessment. Section 7.5 provides more information on the target risk range.

1.3.4 Risk Management

Indiana statute permits derivation of site-specific levels based on other site-specific factors, including remedies that incorporate various risk management strategies. Risk management strategies reduce or eliminate specific exposure pathways through **engineering controls** (ECs) or **institutional controls** (ICs).

IC 13-25-5-8.5(d)(3) – Levels of hazardous substances and petroleum developed based on site specific risk assessments that take into account site specific factors, including remedial measures, restrictive covenants, and environmental restrictive ordinances that (A) manage risk; and (B) control completed or potential exposure pathways.

ECs physically limit contaminant contact or migration. Examples include engineered caps, slurry walls, vapor mitigation systems, sheet piling, etc.

ICs include legal restrictions on the use of a property. Some examples are prohibitions on residential use, limits on the extraction or use of ground water, or restrictions on soil excavation. **Environmental restrictive covenants** (ERCs) or **environmental restrictive ordinances** (EROs) are types of ICs.

Effective ICs or ECs reduce or eliminate exposure via specific exposure pathways and remove those pathways from the risk evaluation. However, effective risk management may require an ongoing commitment to monitor, operate, and/or maintain the control. The ongoing commitment will vary with the nature of the control, and could range from periodic inspections designed to monitor compliance with the terms of an ERC, all the way up to operation and maintenance of a complex engineered system.

1.4 Process Overview

Figure 1-B is an overview of the process that IDEM anticipates most sites will follow as they move toward **closure**.¹⁵ There are two basic closure types. **Unconditional closures** are true “walk away” closures that leave the site environmentally suitable for any future use.¹⁶ All other closures are *conditional*.

Conditional closure means that IDEM’s closure approval depends on one or more *ongoing* activities or restrictions that reduce exposures to levels acceptable for a particular land use. Examples include (but are not limited to) restrictions on residential use, construction and maintenance of a physical barrier, or installation and operation of an active system.

Closures are usually conditional whenever chemical concentrations exceed residential remediation objectives.

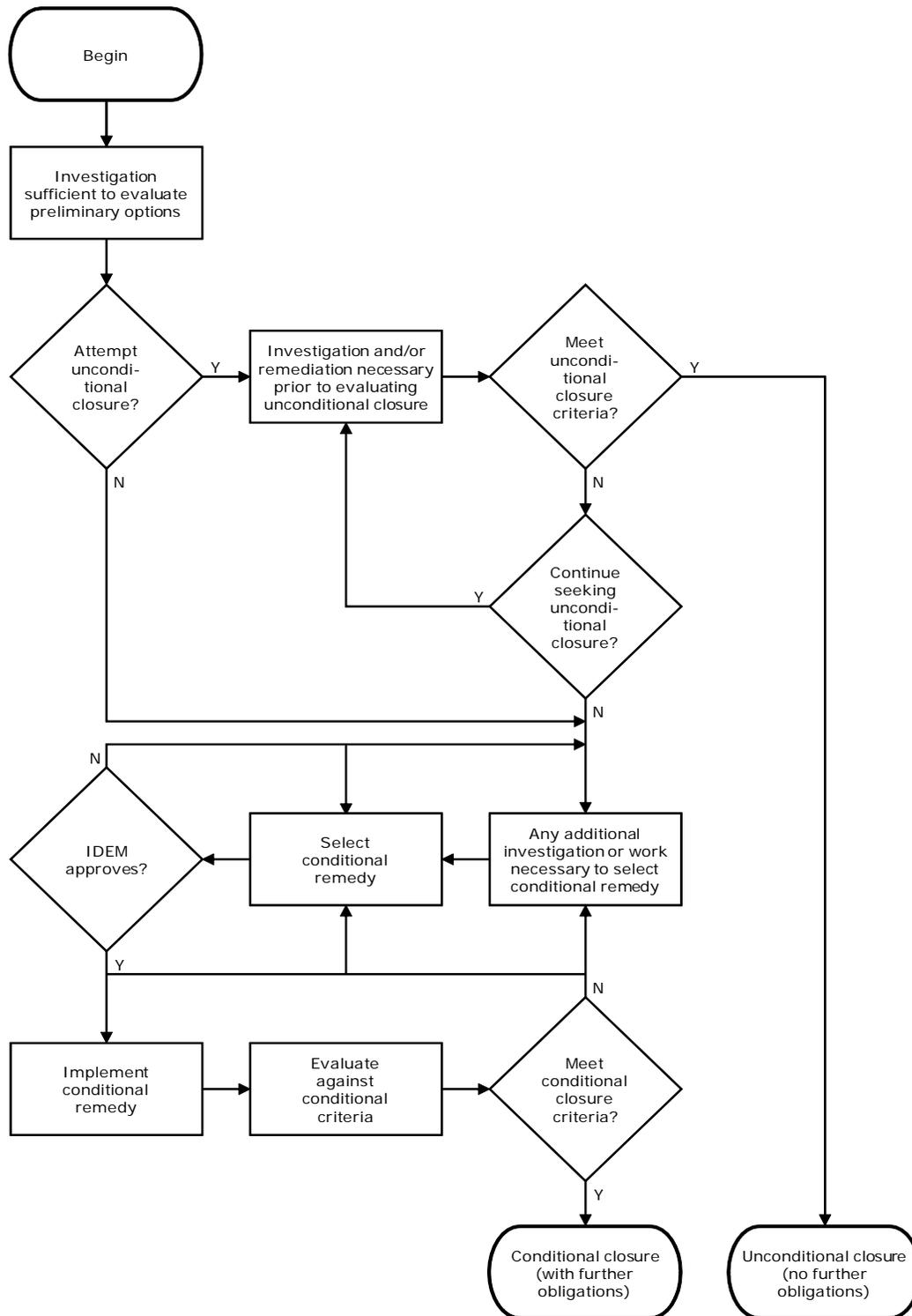
An adequate conditional closure will involve implementation of one or more measures that together prevent unacceptable exposure. Active remediation is not always necessary, though IDEM expects that active remediation will, in many cases, reduce the number and/or scale of necessary future activities or restrictions. The party implementing a remedy is free to weigh the relative costs and benefits of various options. However, closure always requires a demonstration that site-related chemical concentrations remaining from a release do not pose an unacceptable risk to human health or the environment.

Any preceding investigative work must be sufficient to support development of an adequate **conceptual site model** and allow informed decisions about the selection and implementation of potential remedies, if any. Many sites will have contamination in more than one medium. *Site* closure will require meeting closure requirements in all affected media.

¹⁵ Under RCRA, the term closure refers to a series of formal procedures required to minimize the need for maintenance and control, minimize or eliminate post-closure releases of hazardous waste, hazardous constituents, leachate, contaminated run-off, or hazardous waste decomposition products to the environment.

¹⁶ New information about the presence of contaminants at a site may require post-closure responses, and IDEM may require further action where the conditions that formed the basis for IDEM’s approval of closure have changed or not been met.

Figure 1-B: Closure Process Overview



Conceptual Site Model (CSM) Development: Presampling

2.1 CSMs

A CSM describes the characteristics of a site and the processes by which potential contaminants may move from source(s) to receptor(s). CSMs facilitate site understanding and help organize site activities. CSMs are useful at every site.

CSM complexity will vary with site complexity, and the CSM should undergo revision as understanding of the site improves. A CSM can include text, maps, diagrams, and anything else useful in understanding the site.

ASTM (2003) describes six basic components of the CSM development process:

- Chemical identification – what potential contaminants (if any) are present in the soil, ground water, air, and other media at the site.
- Source identification – where did the potential contamination originate?
- Identification of potential contaminant migration pathways – how might potential contamination move from source(s) to receptor(s)?
- Background evaluation – a comparison of on-site chemical concentrations with those found in similar, nearby areas unaffected by site activities.¹⁷
- Receptor identification – who or what might the potential contamination affect?
- System boundary delineation – across what area should the CSM apply?

This section focuses on activities important in CSM development *prior to* sample collection – records review, site visit, sampling planning, data quality objectives, etc. However, it is important not to ignore data collected during any previous sampling events, provided those data are still relevant and usable.

¹⁷ May not be applicable at all sites.

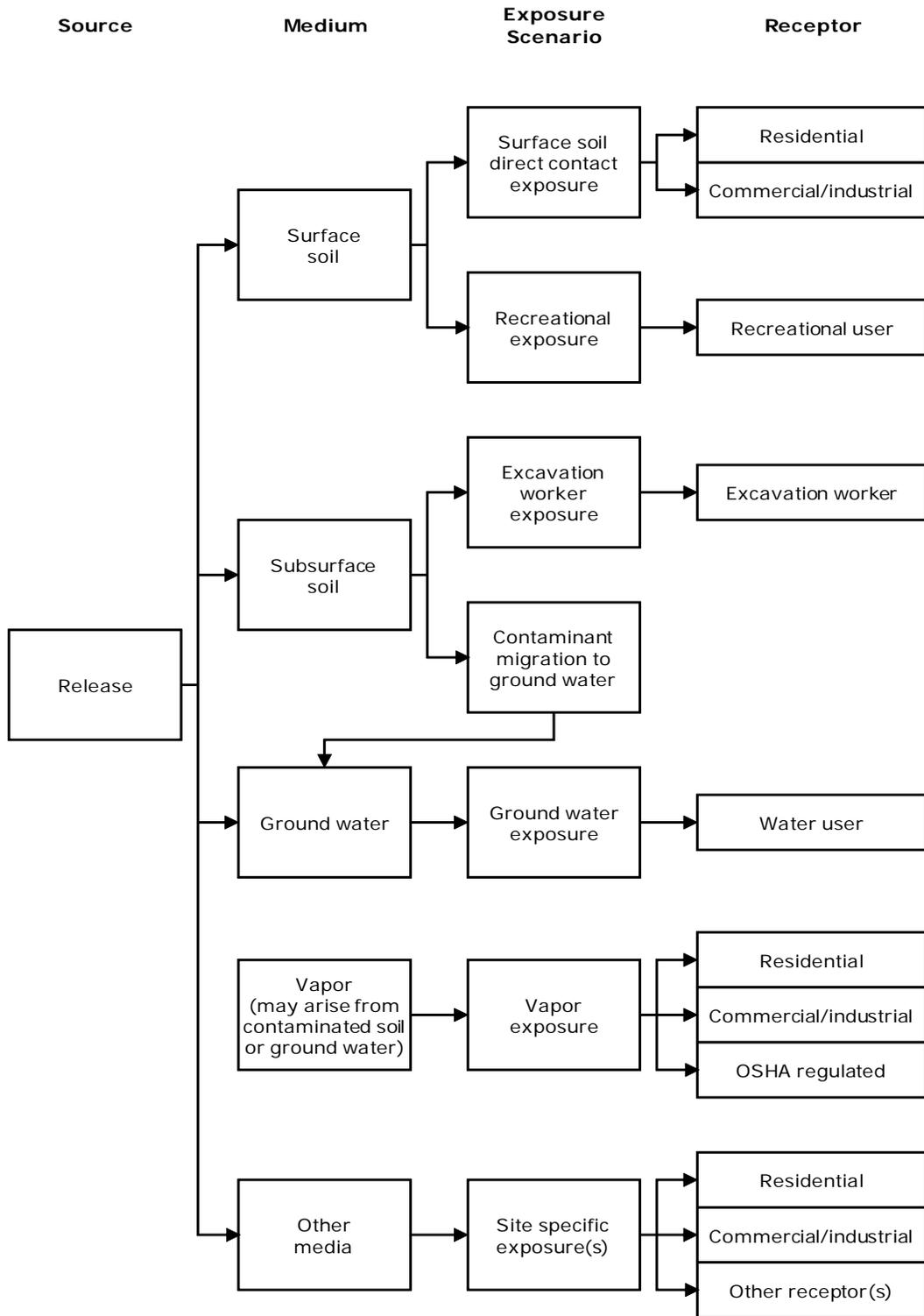
2.1.1 CSM Overview Diagram

Figure 2-A is an example of a CSM overview diagram. It traces possible pathways from source(s) through media and exposure scenarios to specific types of potential receptors.

CSM overview diagrams are a useful way of graphically depicting the CSM thought process. CSM overview diagrams can help investigators systematically plan investigations, isolate relevant exposure scenarios, evaluate potential risks to specific receptors, and guide selection of any necessary remedies. CSM diagrams also help evaluate the sufficiency of the investigation, risk evaluation, and remedy selection (if any).

There are many ways to draw CSM overview diagrams (U.S. EPA, 1996b); they need not conform to any particular format. It is entirely appropriate to tailor CSM overview diagrams to the characteristics of the site and investigation. As an investigation proceeds, modify the CSM and any accompanying CSM overview diagram to reflect newly acquired information – eliminating specific media and exposure scenarios, for example – to better focus on scenarios that are more important. Updates to the CSM should be included in the various investigative reports required by Indiana Department of Environmental Management (IDEM) remediation programs.

Figure 2-A: Example CSM Overview Diagram



2.2 Records Review

Records review includes collection and review of available site-specific information about the site and its surroundings, including local and regional conditions relevant to releases, migration, and receptors. The records review should also attempt to identify all past property uses and transfer dates. Other presampling guidance is available (ASTM, 2005). Potential information sources include, but are not limited to:

- Past investigative reports
- Site records pertaining to operational processes, chemical use, and waste storage and disposal practices
- Regulatory databases and files maintained by the United States Environmental Protection Agency (U.S. EPA), IDEM, and local health departments
- Aerial photographs, fire insurance maps, property tax or land title records, city directories, satellite imagery, and geographic information system maps
- Regional and site-specific geological information such as United States Geological Survey hydrologic and topographic maps and reports, Natural Resources Conservation Service Soil Surveys, and Indiana Geological Survey maps and reports
- Information on utilities, storm and sanitary sewers, water supply intakes, waste water treatment plants and disposal/discharge areas, and electrical transformers
- Regional ground water and surface water records from available sources, which may include Indiana Department of Natural Resources Water Well Records and logs for wells in the vicinity, and IDEM Office of Water Quality records on wellhead protection areas
- Interviews with current or past owners and employees, local fire and police departments, county health officials, and site neighbors
- Information on rare, threatened or endangered species, environmentally sensitive areas, or critical habitats near the site

2.3 Site Visit

The purpose of a site visit is to obtain information based on visual inspection of the site. Important site features include building locations and dimensions, potential contamination sources, and former or current operational or disposal areas. Potentially contaminated areas or receptors on surrounding properties and land use, particularly for nearby residential areas, are also important. Site visits should document:

- Whether the site is active or abandoned, and the general condition of site structures
- Presence, location, and identity of oils, chemicals or wastes stored on or disposed of on the property
- Whether storage tanks (including associated piping and fill or vent ports) or drums are present and, if so, whether there is evidence of leakage or releases
- Locations of potential indoor sources of contamination (e.g., chemical storage areas, maintenance areas, drains, sumps, oil/water separators, parts cleaners, etc.)
- Locations of exterior areas where contamination may occur (e.g., pits, ponds, lagoons, septic systems, etc.)
- Visible evidence of spills or leaks (e.g., stained floors or soils, stressed vegetation, etc.)
- Potential transport pathways that exist in areas where chemicals were used, treated, stored, transported, or disposed (e.g., cracked floors, drains, sumps, etc.)
- Conditions that exist at or near facility doors, bay exits, shipping docks, and pumping stations (e.g., French drains, ditches, sump pump outlets, etc.)
- Underground utilities
- Other features that may affect chemical migration
- *Specific* descriptions (retail, office, day care, residence, school, etc.) of surrounding land use and potential receptors, particularly for neighboring properties
- Whether and where on-site or off-site ecological or surface water impacts from site releases are evident or possible

2.4 Land Use

Indiana Code (IC) 13-25-5-8.5(b) specifies that: *remediation objectives... shall be based on: (1) background levels of hazardous substances and petroleum that occur naturally on the site; or (2) an assessment of the risks... taking into consideration the... (A) Expected future use of the site. (B) Measurable risks to human health, natural resources or the environment based on the: (i) activities that take place; and (ii) environmental impact; on the site.*

Exposure assumptions and remediation objectives depend critically on current and future land use. Therefore, present and future uses of potentially impacted properties weigh heavily in the risk evaluation process.

Residential remediation objectives apply to any area that does or will contain occupied residences, associated property, and other areas where children may be present on a daily basis (e.g., **playgrounds**, schools, day care facilities, and similar areas or uses). IDEM's residential screening levels assume that residents, *including children*, undergo frequent and long-term exposure to potential contaminants – an assumption that generally results in the highest potential exposures and lowest screening levels.

Commercial/industrial remediation objectives apply to factories, warehouses, office buildings, and retail businesses. IDEM's commercial/industrial screening levels assume limited, adults-only exposure. If portions of a commercial/ industrial property have different exposures (e.g., a daycare facility within an office complex), remediation objectives should reflect those exposures.

Recreational remediation objectives apply to areas and facilities where leisure time activities take place. Examples include parks, trails, walkways, sports complexes, and open areas where people gather to enjoy recreational activities. Recreational remediation objectives are appropriate for this land use. However, residential objectives may be better suited to playground areas that present an opportunity for daily high soil contact rates for pre-school children.

Probable future land uses are important when evaluating remedial and closure strategies. Remediation objectives need only be as restrictive as appropriate for the intended use. If future land use is not consistent with intended land use at the time of closure, then the basis for closure may no longer be met and IDEM may require the responsible party to take further action. Local government planning resources (e.g., plan commission, comprehensive plan, etc.) are possible sources of information about potential future land use changes. U.S. EPA (1995b) contains additional guidance on considering future land use in the remedy selection process.

2.5 Geologic Setting

The geologic setting of a site provides the fundamental framework for understanding the distribution, migration, and fate of chemicals. Geologic materials influence the movement of chemicals from source to receptor over the ground surface, through the subsurface, and by ground water flow in aquifers. However, the subsurface environment is rarely homogeneous, and a thorough understanding of the complex relationships between its composition and structure is needed to understand the factors controlling the fate and transport of chemicals. A well developed CSM will sufficiently characterize the geologic setting, and allow identification and evaluation of all potential migration pathways.

The CSM should evaluate three fundamental components of the geologic setting:

Regional Landforms – Characterization of the major landforms (rivers, lakes, topography, karst, significant water withdrawals, land use, etc.) in the vicinity of a site provides a broad understanding of the geologic framework controlling chemical distribution and migration at a site. For example, topography drives surface runoff and regional ground water typically flows towards streams and rivers. This portion of the CSM can be developed from site records, site visits, and published literature on regional geology.

Subsurface Composition and Structure – While regional landforms provide an overview, subsurface investigation (soil borings, monitoring wells, geophysical investigations, soil analysis, etc.) provides a site-specific characterization of the subsurface and insight on the relationships between materials beneath and near the site. Investigative activities should provide detailed physical descriptions of unconsolidated and consolidated materials; determination of the thickness, depth, and horizontal extent of distinct geologic features (sand lenses, confining layers, bedrock topography, etc.); identification of natural and anthropogenic preferential pathways (sand stringers, utility corridors, karst, soil fractures, etc.), and the relationship of contaminant distribution to the site-specific geology.

Ground water Flow – Ground water flow is a complex and dynamic four-dimensional process. To understand the migration of dissolved contaminants, the CSM should characterize the flow direction(s), vertical and horizontal gradients, and velocities for each identified water-bearing unit within the subsurface. The variable nature of ground water flow dynamics is often sensitive to local and/or regional natural or anthropogenic changes (e.g., precipitation, flooding, pumping), and typically requires regular monitoring to characterize the magnitude and significance of changes in flow.

The CSM should relate the above components of the geologic setting to the distribution of contaminants, to provide a clear understanding of the mechanisms controlling their migration through saturated and unsaturated media, and areas where saturation levels fluctuate. Such an understanding can be used to efficiently guide further investigative efforts; identify, evaluate, and eliminate exposure pathways; and evaluate the applicability of various remediation techniques.

2.6 Susceptible Areas

Susceptible areas are places in which standard risk assessment models and screening levels may not apply. Anyone performing a site inspection and/or records review should be familiar with these classifications and determine whether contamination from a release could affect susceptible areas.

Preferential pathways may have characteristics that allow potential contaminants to enter and move rapidly through a ground water system, often in unpredictable ways. These characteristics invalidate the assumptions of the soil-to-ground water partitioning model and vapor equations used to calculate screening levels. Examples of preferential pathways include **karst terrain**, mined areas, drainage tiles, utility lines, and other areas where fractures, anthropogenic features, or conduits enlarged by solution control ground water flow. Karst systems – common in southern Indiana - may transport contaminated soil as suspended load and deposit the soil within the system or along streams that receive water from an impacted karst system¹⁸. Because several endangered and/or threatened species occur in southern Indiana cave systems, karst terrain is also ecologically susceptible.

Wellhead protection areas (WHPAs) are defined zones that supply ground water to public wells. WHPA contamination poses a high probability of human exposure. Contact IDEM's Ground Water Section (Drinking Water Branch, Office of Water Quality at 317-234-5025) to determine whether a release lies within a WHPA. See Section 9.6.1 for guidance on evaluating risk in WHPAs.

Ecologically Susceptible Areas (ESAs) are special habitats that merit consideration of potential effects on non-human receptors. Examples include karst terrain; surface waters, including wetlands and riparian areas; parks, preserves, and other protected areas; and habitats used by endangered or threatened species, or species of special concern.¹⁹

Every investigation should include a **screening level ecological risk assessment** - a desktop review and site inspection to determine if ESAs exist at or near the site, and whether a release could affect them. If there are no ESAs within or near the site, and contaminants are not likely to affect ESAs beyond the site, then further ESA evaluation is not necessary.

Additional ecological risk assessment may be necessary if contaminants from the release could affect an ESA and may include, as appropriate, sampling and analysis of soil, sediments, surface water, ground water, and/or biota in ESAs, and in areas that might serve as pathways from the release to an ESA. Section 11 contains additional guidance on ecological risk evaluation. U.S. EPA (1997b, 1998a, 1999b, and 2003c) provides additional ecological risk assessment guidance.

¹⁸ Receptor identification in karst terrain may require location of potentially impacted karst springs.

¹⁹ Potential information sources include the Indiana Department of Natural Resources and the United States Fish and Wildlife Service (National Wetlands Inventory, Endangered/Threatened Species).

2.7 Planning Sampling and Quality Assurance Project Plans (QAPPs)

Careful planning is essential in executing environmental projects, and this is especially true with respect to the sample planning phase. A QAPP documents the sample planning process. QAPPs describe the decision making process, plans for data acquisition, quality criteria, and procedures for assessing investigation results. A site-specific QAPP prepared prior to collection of samples is an important part of every environmental project.

QAPPs define and describe:

- Data users
- Project goals, objectives, questions, or issues
- Decision(s) that the data will support
- The how, when, and where of project information generation
- Potential problems and corrective measures
- Projected type, quantity, and quality of data
- Data quality necessary to support the decision(s)
- Means of analyzing, assessing, and reporting data

The scope of QAPPs will generally increase with the complexity of the projects they support. New information and/or changes in project scope may also necessitate revisions to the QAPP.

A complete description of QAPPs and their components is beyond the scope of this document. U.S. EPA (1993, 1997e, 1999d, 2000c, 2001c, 2002c, 2002e, 2004d, 2005d, and 2006b) provides guidance on many aspects of QAPP development and implementation. IDEM's Leaking Underground Storage Tank Program has a generic QAPP that may prove useful during development of a site-specific QAPP. IDEM's [Chemistry Services Section](#)²⁰ also welcomes opportunities to review QAPPs prior to initiation of field work.

²⁰ <http://www.in.gov/idem/4673.htm>

2.8 Choosing Areas to Sample

Sample areas depend on investigation objectives. Investigation objectives vary widely, and so will the sample areas necessary to pursue those objectives. Possible investigation objectives include:

- Find contaminated areas
- Evaluate exposure across a particular area
- Determine if receptor impacts exist
- Evaluate background levels
- Collect information needed for remedial system design
- Demonstrate achievement of remediation objectives in a given area

There are many other possibilities. Whatever the investigation objective(s), reports should include the rationale and supporting evidence for selection of specific sampling areas. Presampling investigations will usually provide enough information to guide initial selection of sample areas.

Note that different parts of a site may have different likely future exposures (e.g., paved parking, daycare, break area, factory floor, etc.). Separate sampling plans for each identifiable exposure area allow subsequent separate exposure evaluations in those areas, rather than using the same exposure assumptions across the entire site.

2.9 Identifying Potential Contaminants

Use information obtained during the presampling investigation to focus sampling efforts on specific **potential contaminants**.

When site-specific operating information is incomplete or unreliable, IDEM programs *may* specify pre-defined lists of potential contaminants. For example, the comprehensive list for Resource Conservation and Recovery Act Subtitle C sites may include Appendix VIII²¹ (for soil) and Appendix IX²² (for ground water). Less comprehensive lists, such as the Comprehensive Environmental Response, Compensation, and Liability Act target compound list or target analyte list may be appropriate if they include potential contaminants. See the *Remediation Program Guide* for more details on program-specific requirements. Ecological risk assessment may involve evaluation of different or additional potential contaminants than those relevant to human health risk assessment.

IDEM's Office of Land Quality [Chemistry Services Section web page](#)²³ includes lists of the most commonly encountered potential contaminants at several types of sites.

²¹ Code of Federal Regulations (CFR) Title 40, Part 261

²² CFR Title 40, Part 264

²³ <http://www.in.gov/idem/4673.htm>

2.10 Choosing Media to Sample

Appropriate sample media will depend on site characteristics and the exposure scenarios under evaluation. For example, a subsurface release may not warrant collection of surface soil samples. Conversely, a surficial release followed immediately by removal might achieve closure with only post-removal surficial soil samples. If site conditions suggest that contaminant migration through the soil column is unlikely (e.g., dense clay)²⁴, a site-specific investigation approach that minimizes or eliminates ground water sampling may be appropriate.

2.11 Sampling Design

There are many possible ways to place sample locations across a site. Although the *Remediation Closure Guide* confines discussion to two basic approaches, IDEM will evaluate alternative proposals on their merits. Whatever the approach, the number of samples necessary for an adequate investigation is site-specific.

Judgmental sampling uses professional judgment and existing site knowledge to place sample locations. Judgmental sampling works best at sites with known locations of potentially contaminated areas, receptors, or other indicators for sampling. In such cases, judgmental sampling may simplify sample placement.

Systematic sampling places samples at fixed intervals beginning from a random starting point (as along a drainage way, excavation wall, or perimeter) or according to a predefined pattern that distributes samples uniformly over an area. Systematic methods are suitable at any site, but are especially useful at sites where there is limited information about the distribution of potential contamination (e.g., fields, vacant lots, or sediment deposition zones).

It is appropriate to use the results of systematic samples to calculate exposure point concentrations (Section 7.2.3) *across* exposure areas. However, use of statistical methods to evaluate sites may require more samples than are necessary under judgmental approaches.

Sometimes it is useful to combine the two approaches. For example, judgmental sampling may identify specific areas of concern, followed by systematic sampling within those areas. The resulting exposure estimate may be more representative of on-site contamination than the original sample points.

U.S. EPA (2002d) offers information on numerous sampling designs, including: judgmental, simple random, stratified, ranked set, adaptive cluster, composite, systematic, and grid sampling methods. IDEM will consider proposals to use these sampling schemes and will evaluate such proposals on their merits.

²⁴ For example, naturally occurring homogeneous materials exhibiting low effective porosity and permeability (10^{-6} cm/sec or less), laterally continuous in extent, substantially thick (10 feet or greater), with no primary or secondary features such as fractures, joints, weathered zones, etc. that can serve as preferential pathways to ground water below.

Conceptual Site Model (CSM) Development: Sampling

3.1 Introduction

Indiana Code (IC) 13-12-3-2 and IC 13-25-5-8.5(c) provides statutory authority for characterizing the nature (Sections 2.8 and 3.9) and extent (Section 3.7) of contamination with respect to remediation objectives (Section 1.3). Sampling is vital to development of an adequate CSM. It is the only way to know whether contamination exists as the result of a release, whether receptors may be affected and the pathways by which contamination reaches receptors.

In some cases, limited sampling may qualify sites for closure without further investigation. Other sites may require elaborate multi-stage investigations that span several media. Specific objectives may vary by project and include (for example) adequate characterization of the potential risks of contamination present on or emanating from sites, information needed for remedy selection and design, or demonstration of attainment of remediation objectives.

This section includes guidance on collection of samples in various media under typical circumstances. It also includes guidance on sample handling, analysis, and reporting, as well as data evaluation. It is not a complete compendium of acceptable procedures.

Note that **preferential pathways** (e.g., drain tiles, karst features, utility conduits, sand lenses) may facilitate rapid contaminant migration, sometimes in unexpected directions. Preferential pathways merit special attention and may require different investigative and sampling methods. The most appropriate approach will ultimately depend on site-specific factors.²⁵ Alternative proposals that meet investigation and data quality objectives are certainly acceptable; the Indiana Department of Environmental Management (IDEM) will evaluate them on their merits.

Note that IDEM may conduct field audits during any sampling event. The scope of audits may vary by program and may include split sampling. For this reason, program areas and project managers may request advance notice of proposed field activities.

²⁵ Investigation procedures differ for petroleum releases regulated by Underground Storage Tank (UST) or Leaking Underground Storage Tank (LUST) rules. See the *Remediation Program Guide* for more information on LUST sites.

3.2 Sampling Soils

There are many possible reasons for sampling soil. Examples include: assessing potential for direct contact exposure, evaluating subsurface soil chemicals as a potential source of ground water contamination or vapor intrusion, or guiding remedy design, selection and implementation.

3.2.1 Sampling Surface Soil

Surface and near surface soil sample collection usually occurs whenever it is necessary to evaluate the potential for direct contact to chemicals. The *Remediation Closure Guide* (RCG) defines soil direct contact exposure as including dermal soil contact, soil ingestion, inhalation of soil particles and inhalation of vapors arising from soil. Where potential soil contamination is likely confined to the subsurface (e.g., following a release from an underground storage tank), surface soil samples may not be necessary.

The RCG does not define a specific depth interval for surface soil. Soil that is at or near the existing surface that has the potential to result in direct exposure under current or likely future land use should be evaluated for direct contact exposure. At some sites, surface soils lie underneath concrete, asphalt, or other barriers. Where future exposure to surface soil is a concern and access is feasible, sampling beneath the barrier may be necessary if surface contamination is suspected. Doing so will document the degree of potential contamination within surface soil and allow evaluation of the necessity of (for example) maintaining a cap or other cover to limit direct contact exposure.

See Section 3.2.4 for special procedures that apply when sampling soils for volatile organic compounds (VOCs).

3.2.2 Sampling Excavation Walls and Bottoms

IDEM's underground storage tank programs have specific guidance for collecting soil samples along excavation walls and across excavation bottoms. Similar procedures are usually appropriate at other sites. However, IDEM will evaluate alternative procedures on their merits.

3.2.3 Sampling Subsurface Soil

There are many reasons to collect and analyze subsurface soil samples. If it is likely that excavation activities will bring soil to the surface, or that excavation or utility work may expose workers to subsurface soil, then it is important to evaluate future direct contact with subsurface soil. Residential, commercial/industrial, or recreational direct contact remediation objectives apply when evaluating soils that are likely to remain on the surface following excavation.

If chemicals from a release are present in soil but ground water is not impacted, then it is important to assess the potential for the chemicals in the soil to leach to ground water.

Applicable lines of evidence (LOEs) when assessing this potential may include: the mass and physical characteristics of the chemicals, time since the release, chemical concentrations in the soil, soil synthetic precipitation leaching procedure (SPLP) data, soil pH, or ground water monitoring data.

When evaluating the leaching potential of subsurface soils, collect soil samples from intervals that are above the water table at the time of sampling. If ground water elevations subsequently rise, analytical results from soil samples previously collected below the new ground water elevation may no longer be appropriate for comparison against migration to ground water remediation objectives. Migration to ground water remediation objectives may be irrelevant in areas with very shallow ground water.

If ground water is already contaminated, evaluation of leaching *potential* usually becomes irrelevant. Evaluate ground water contaminant concentrations directly, using an appropriate monitoring well network. The observed presence of ground water contamination is a better indicator of whether contaminated soils are a source of ground water contamination than is a theoretical fate and transport model.

If contaminated ground water is present, then subsurface soil data may be collected for other reasons, such as:

- Evaluating direct contact risk, as described above.
- Effectively designing and monitoring performance of remediation systems.
- Developing an understanding of contaminant distribution necessary for CSM development and risk evaluation.
- Ensuring proper placement of monitoring well screens.
- Determining whether contamination extends into deeper water-bearing units.
- Meeting the requirements of program-specific rules that specify soil samples from certain locations (e.g., excavation bottoms).

The following conditions may identify one or more subsurface soil locations suitable for sampling, whatever the purpose of the sampling:

- Locations that elicit the highest field screening result.
- Stained, discolored, oily, shiny, or visibly altered soil.
- Soil in strata likely to be contaminated based on chemical characteristics and soil type. For example, potential accumulation of metals in clay or silt, accumulation on the top of clay strata or at the bottom of sand strata, or other locations *based on the expected behavior of the potential contaminant in the environment*.

Important characteristics when evaluating and describing soil cores include the following: texture, lithological description, color, soil structure, sedimentary features, consistency, moisture content (qualitative determination), boundary or contact, and zones of secondary porosity. Munsell soil charts, or a suitable alternative, are useful when evaluating and describing soil color.

In the absence of positive screening results or visual cues, the samples from borings submitted for laboratory analysis should be from a material within the core interval displaying the greatest apparent effective porosity. Other options include analyzing a sample from each **stratum**, or from each two-foot interval.²⁶

As with surface soils, special procedures apply when sampling subsurface soils for VOCs (see Section 3.2.4). See Section 8.3 for additional information about soil sampling.

3.2.4 Sampling VOCs in Soils

As their name suggests, VOCs evaporate readily. This property can lead to significant VOC losses during sample collection and handling, and result in biased analytical data. Therefore, special precautions and procedures are appropriate when sampling VOCs in soils, particularly when VOC concentrations may be below residential remediation objectives.

Use U.S. EPA SW-846 Method 5035A (as updated) to minimize VOC loss, especially when collecting soil *closure* samples for VOC analysis. Appendix A of Method 5035A describes several options for the collection, preservation, and storage of samples for VOC analysis. The use of specialized containers and preservation techniques as described in Method 5035A may be unnecessary for samples collected within areas of known or suspected contamination, as long as the sampling method meets project objectives.

SW-846 Method 5035A, Appendix A, Section 7.1 states:

“After a fresh surface of the solid material is exposed to the atmosphere, the subsample collection process should be completed in the least amount of time in order to minimize the loss of VOCs due to volatilization. Removing a subsample from a material should be done with the least amount of disruption (disaggregation) as possible. Additionally, rough trimming of the sampling location’s surface layers should be considered if the material may have already lost VOCs (been exposed for more than a couple of minutes) or if it may be contaminated by other waste, different soil strata or vegetation. Removal of surface layers can be accomplished by scraping the surface using a clean spatula, scoop, knife or shovel”.

Screening instrument results, professional judgment, and knowledge of the source area and site soils should determine which samples are sent to the laboratory. Collect subsamples from the soil core as quickly as possible, taking special care to limit exposure and disaggregation of the soil’s physical structure. This is necessary to minimize loss of VOCs (IDEM, 2008). Any samples not sent to the lab can be discarded. The field record should clearly document reasons for choosing particular samples for lab analysis.

²⁶ Section 9.7 describes procedures for calculating length-weighted subsurface soil chemical concentrations *within* borings.

Planning and careful preparation are critical for a successful sampling event. When sampling under this procedure:

- Allow sufficient time between subsurface soil core retrievals to avoid sampling backlogs
- Protect soil cores from direct sunlight, rain, wind, etc.
- Collect subsamples soon after the soil core has been removed from the borehole. It is not appropriate to collect subsamples from previously iced material, or to wait five or more minutes for a standard headspace analysis before deciding whether or not to collect subsamples from soil left in the core barrel liner (or similar device) or soil screening container.

IDEM will consider alternatives to the procedures and equipment described in Method 5035A and supplemental IDEM guidance on a site-specific basis.

Photoionization detectors (PIDs) detect most VOCs and are probably the most commonly used VOC field screening instrument. PIDs are suitable for chemicals with an ionization energy less than the PID's lamp voltage – typically 10.6 electron volts. Higher voltage PID lamps exist and can somewhat extend the range of detected chemicals. PIDs see extensive use in investigation of gasoline and chlorinated solvent releases.

A flame ionization detector (FID) may be a suitable alternative when working with unknown investigative chemicals, or when the chemicals have higher ionization potentials than the PID lamp. FIDs may prove especially useful when screening for diesel fuel, and weathered or heavy petroleum products.

All field instruments have advantages and limitations. The sampling and analysis plan should describe the field instrumentation and its use as appropriate for potential contaminants. The discussion should also include any limitations that could affect the use of an instrument (e.g., chemicals not detected, moisture, cold weather, etc.).

IDEM's Office of Land Quality [Chemistry Services Section web page](#)²⁷ contains additional information on sampling soils for VOCs.

3.3 Sampling Ground Water

Short-term ground water sampling may employ any appropriate technology; it need not involve the installation of monitoring wells. However, when collecting and comparing ground water samples over time, use properly constructed monitoring wells that meet the requirements of 312 IAC 13-8-3. IDEM (2009b) contains guidance on implementing this rule.

Appropriate ground water sampling procedures and equipment will vary depending on site-specific conditions and individual program requirements. U.S. EPA (2002b) provides general guidance on preparing for and performing ground water sampling. U.S. EPA (2005b) addresses sampling ground water from direct-push wells.

Turbidity in ground water samples can cause problems. For example, sampling-induced turbidity may result in samples that are not representative of the **aquifer** under evaluation. Turbidity in water samples can also interfere with analysis and cause inaccurate results. In many cases, low-flow, nonpurge, or passive sampling techniques can minimize induced sample turbidity.

²⁷ <http://www.in.gov/idem/4673.htm>

Low-flow (also called “micro-purge” or “minimal drawdown”) sampling procedures often improve ground water sample quality. Puls and Barcelona (1996) is the primary U.S. EPA guidance on this procedure. A nonpurge sampling option may be suitable in some very specific cases; IDEM (2009c and 2009d) contain low-flow and nonpurge sampling guidance.

Polyethylene diffusion bag samplers and other types of passive sampling devices *may* also be acceptable for long-term ground water monitoring at sites that meet a strict set of criteria (ITRC 2004, 2007a). IDEM (2005) contains a discussion of filtration and other issues related to sample turbidity.

Ground water sampling equipment should be capable of meeting the project’s data quality objectives. Bailers, peristaltic pumps, high-speed submersible pumps, and inertial lift pumps may cause excessive agitation of ground water samples, and IDEM does not recommend their use when collecting samples for VOC analysis (ASTM 2006; Nielsen 2005; U.S. EPA 2002b, 2005b). The [Federal Remediation Technologies Roundtable website](#)²⁸ includes descriptions of many types of sampling equipment and a matrix that compares the advantages and disadvantages of different types of sampling equipment. ASTM (2006) also contains guidance on selecting appropriate sampling devices.

The project quality assurance project plan (QAPP) should describe proper disposal of contaminated purge water or other investigation-derived wastes. IDEM (2002) may apply to some waste materials.

3.4 Sampling Vapor

Section 5 addresses vapor sampling.

3.5 Sampling Fill

In the context of the RCG, fill is material used to modify land topography. Fill comprised of waste deposited onto the land as a means of disposal may be subject to solid or hazardous waste regulations and requires a site-specific approach that is beyond the scope of this guidance.

Fill areas can complicate development of a CSM. Fill alters hydrogeologic conditions at a site, and may contain chemicals in common with those from a release. Sometimes it is difficult to distinguish fill from waste fill that is subject to regulation. These challenges make it especially important to have a clear understanding of sampling objectives when sampling fill or in fill areas. Sometimes the objective may be to characterize a release in a fill area. In other cases, the objective may be to characterize the fill itself as a potential source of contamination.

With sufficient knowledge of the fill material(s) and their location(s) in the study area, standard or slightly modified standard methods for sampling surface or subsurface soil may be suitable for collecting fill samples. However, it may be difficult to collect a representative sample of fill material, especially if the material is too heterogeneous, or there is little or no information on the source of the material.

U.S. EPA (2009h) contains guidance on developing a sampling plan for fill material. In some cases, adequate characterization of fill material may cost more than removing it.

3.6 Sampling Other Media

The RCG does not provide detailed guidance on sampling surface water or sediment. Investigation of those media requires site-specific approaches. USGS (2009) includes surface

²⁸ <http://www.frtr.gov/>

water sampling guidance. U.S. EPA (2001b) contains sediment sampling guidance. U.S. EPA (2003a) and Davis *et al.* (2005) provide guidance on choosing appropriate sediment sampling equipment.

3.7 Extent of Investigation

Investigations should be sufficient to allow evaluation of the risks, if any, posed by contamination, and the effectiveness of any proposed remedy. Unfortunately, it is rarely possible to know in advance how much work will be necessary to support an adequate evaluation. Any investigation may reveal the need for further investigation.

3.7.1 Delineation

Delineation is an iterative process of determining the horizontal and vertical extents of contamination. Understanding the distribution of contaminants is important for identifying receptors and evaluating potential exposure.

In most cases, IDEM expects a ground water investigation *in conjunction* with a soil investigation. Soil should be evaluated for direct contact exposure (ingestion, dermal contact, and inhalation of vapors and soil particles) and, if necessary, its potential to effect ground water. Ground water should be evaluated for direct contact (inhalation and ingestion), and its potential to act as a source for vapor intrusion.

Delineation criteria differ with media type and potential receptor. In general, IDEM expects delineation of contamination to the extent necessary to evaluate all potential exposure pathways. This typically entails defining the on-site vertical and horizontal extents of contamination to land-use specific remediation objectives (commercial/industrial, residential, and/or recreational, where applicable) based on potential exposure scenarios and migration pathways identified in the CSM, *and* a demonstration showing that contamination doesn't leave the **exposure control area**²⁹ at concentrations exceeding residential remediation objectives. There may be circumstances where defining contamination to land-use specific levels (on-site and off-site) is impractical or unnecessary, and IDEM is willing to consider demonstrations that involve sampling and/or an evaluation of various LOEs, such as:

- Distance and/or time of travel from the delineated area to the boundary of the exposure control area
- Current and likely future use of the property, including ground water
- Extent of the area in which the release(s) occurred
- Possible preferential pathways
- Contaminant characteristics (e.g., mobility, toxicity, volatility, persistence)
- Potential for changes in ground water flow direction (e.g., start up or shut down of existing or planned production wells)
- Magnitude of contaminant concentrations relative to remediation objectives
- Presence of residential and/or ecological receptors in the vicinity

²⁹ An exposure control area is an area over which a remedy reduces exposure to an acceptable level. An exposure control area can be, but often is not, the same as the area of property control; it may involve multiple properties and multiple owners.

Demonstrations based on LOEs are inherently site-specific, and will rely on the technical judgment of all involved. IDEM will evaluate such demonstrations on their merits.

If contamination at concentrations greater than residential remediation objectives extends outside the exposure control area, IDEM expects delineation to residential remediation objectives *or* a demonstration employing LOEs to show why this is not necessary.

Horizontal delineation typically begins at or near the origin of a release and expands laterally; delineation of ground water contamination most often proceeds in the direction of ground water flow. However, it is also possible to start by sampling at or near receptors or the boundary of the exposure control area and then work back toward the origin. This approach may reveal potential problems more quickly at sites with significant potential risk to receptors.

When investigating a surface release, it may be necessary to begin soil sampling at the ground surface, proceeding downward until direct contact exposure is adequately understood. This may involve collecting more than one surface or near surface sample. If contamination extends into the subsurface, additional samples may be necessary to understand the contaminated zone. In most cases, sampling below 15 feet to evaluate direct contact isn't necessary because exposure to soil below that depth is unlikely.

Horizontal delineation efforts may employ a step-out procedure, as illustrated in Figure 3-A. In this figure, each box represents a sample location, and the numbers within the boxes correspond to sampling round, so that a box containing a "1" marks the location of a sample collected during the first sampling round, and a box containing a "3" marks the location of a sample collected during the third sampling round. Shaded boxes represent sample results that significantly exceed the remediation objective.

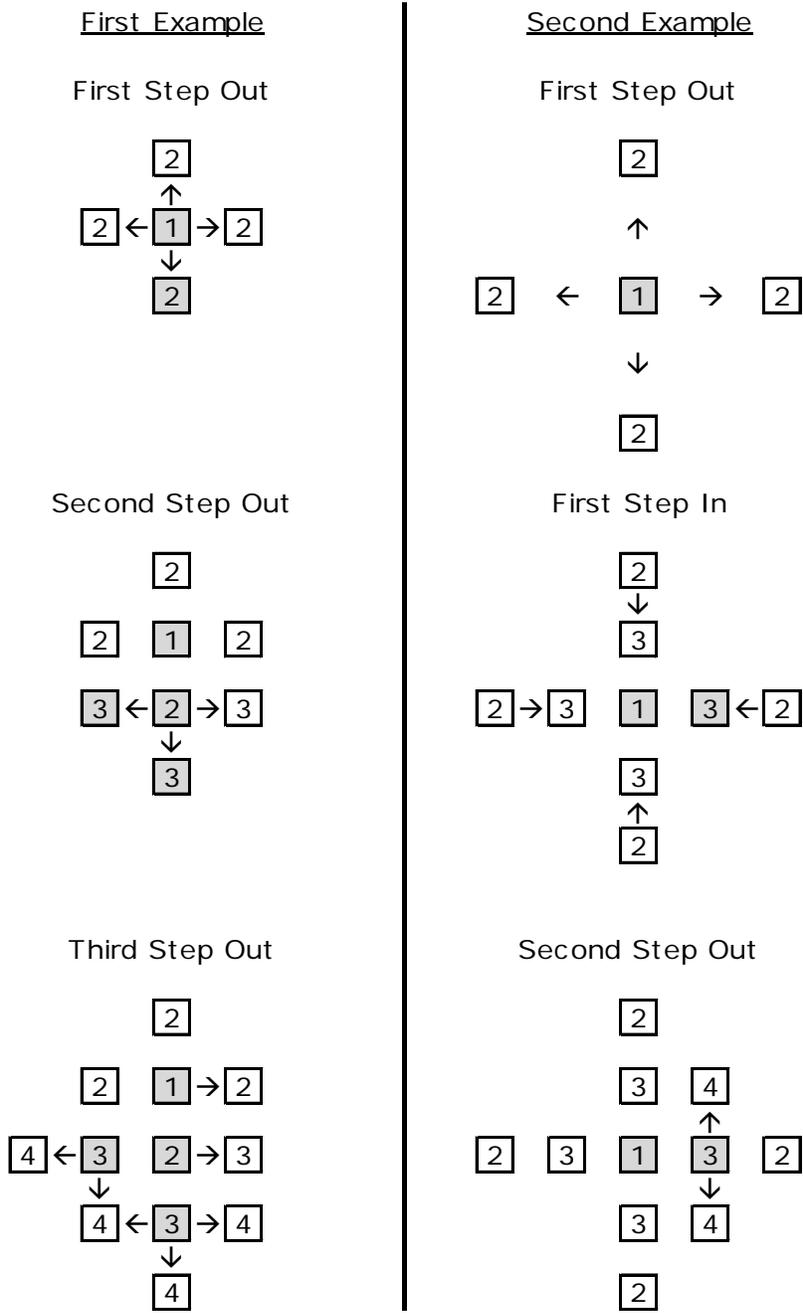
The step-out procedure investigates each significant unbounded exceedance of the remediation objectives by collecting additional samples in unsampled cardinal directions (i.e., north, east, south, and west). Step-out distances can vary as suggested by site characteristics. The process is iterative, with step-outs surrounding each successive exceedance until the horizontal extent of contamination is delineated.

In some cases, it may be advisable to employ a step-in procedure, as illustrated in the second example of Figure 3-A. In this example, a bounded exceedance is more tightly bounded using a second set of samples placed closer to the initial exceedance. Step-in procedures may be especially useful when attempting to reduce the size of an area proposed for active remediation or institutional controls (ICs).

Vertical delineation of soil should proceed as far as necessary for development of the CSM and evaluation of exposure scenarios, and to provide any information needed for other purposes, such as remedial design. Vertical delineation of ground water contamination below the first water bearing unit may or may not be necessary, depending on potential contaminant and site characteristics.³⁰ Clay units and other deposits often thought of as confining may be fractured or discontinuous, allowing contamination to migrate between water-bearing zones. *Therefore, the existence of low-permeability clay units is, by itself, insufficient evidence to demonstrate that deeper aquifers or water-bearing units are not contaminated.*

³⁰ Breaching a confining unit at the base of a water-bearing unit creates a pathway for potential contaminant migration. To minimize communication between aquifers, use dual-wall casing of wells installed in lower units; otherwise, plug the boring immediately upon completion (312 IAC 13-10).

Figure 3-A: Stepping Out (or In)



Key: Result > Remediation objective
 Result < Remediation objective
 Numbers in boxes refer to sampling round

3.8 Sample Handling

Standard procedures for handling and documenting field samples are important to ensure high-quality, representative samples. A site-specific sampling and analysis plan (SAP) or similar sampling document should describe sample handling and field documentation procedures. IDEM's Office of Land Quality (OLQ) does not currently offer a general guidance document for sample handling, and OLQ does not typically require specific field documentation forms.

IDEM OLQ staff use standard forms to document their field sampling activities. IDEM does not require outside parties to use these forms, though they may prove useful in illustrating the documentation that IDEM expects. IDEM (1999) contains copies of these forms, and describes standard field documentation and sample preservation procedures.

It is important to deliver samples to the laboratory as soon as possible after collection or within a set time frame if the method requires it (U.S. EPA, 2009h). Samplers should maintain and document custody of the samples from collection until delivery.

Some samples require physical and/or chemical preservation in order to maintain sample integrity from time of collection until delivery to the laboratory. Laboratories can provide information on appropriate sample preservation methods. U.S. EPA (2009h, Chapter 2) contains summary tables showing preservation methods and holding times for SW-846 analytical methods. A more general table appears in IDEM (1999, Part III).

3.9 Sample Analysis and Reporting

It is important to choose sample analysis methods that can meet the project's data quality objectives (DQOs). The QAPP, SAP, or other relevant project-specific sampling document should list sample analysis methods and any variations from these methods. Reference to standard published methods is typically acceptable as long as the laboratory performs the analysis exactly as stated in the method. Sources for standard analytical methods include ASTM (2009), NIOSH (2009), SMO (2009), and U.S. EPA (2009h, 2009c, 2009b, 2009a).

Some key considerations regarding sample analysis include:

- Analytical methods capable of delivering reporting limits at least as low as the relevant remediation objectives
- The laboratory's ability to provide data that meet project DQOs. Unlike some states, Indiana does not currently certify laboratories for remediation work.
- When analyzing solid samples (e.g., soils, sediments, and solid waste) for VOCs, IDEM recommends collecting and extracting them using US U.S. EPA SW-846 Method 5035A. IDEM (2008) contains additional guidance on this topic.

Analytical documentation necessary to evaluate data will depend on the intended use(s) of the data. In general, reporting limits and detection limits, along with actual sample results and associated qualifiers, are essential to data interpretation. Section 3.9.1 contains additional information on analytical documentation. See IDEM (1999, 2003, and 2009a) for additional guidance.

3.9.1 Quality Assurance/Quality Control Elements

Data quality is meaningful only as it relates to the intended use of the data (i.e., the DQOs). A quality assurance/quality control (QA/QC) program is the means of judging whether or not the data meet DQOs. QA/QC programs incorporate several elements, including information from sampling, laboratory operations, and method-specific procedures.

Table 3-A includes elements that IDEM has determined are necessary to support two types of DQOs. For example, every element in Table 3-A is, where appropriate to the particular type(s) of analysis, necessary to support DQOs for a final nature and extent investigation, closure evaluation, or stand-alone assessment of the vapor intrusion pathway. Other investigations can support DQOs using the elements indicated in the minimum data documentation requirements (MDDR) column.

In addition to the elements in Table 3-A, the following *sampling-related items* should support every investigation:

- Completed chain of custody with sample date, time, and identification
- Map or diagram of sample locations
- Sample field sheets that document sample identifiers, locations, date and time, sampling methods and equipment, samplers, calibration methods, and any notable observations (color, clarity, texture, reactions with preservatives, etc.)
- Blanks – trip, field, or equipment rinsate blanks, as appropriate
- Identity of field duplicates – typically at least one per twenty samples per matrix for each method
- Adequate sample volume

The following *laboratory-related items* should support every investigation:

- Completed chain of custody with date and time of receipt
- Condition of samples on receipt
- Sample identification – site identification and lab identification
- Sample preparation logs with extraction, cleanup or digestion details
- Certificates of analysis with method, analysis date, results, method detection limits, reporting limits, and any dilution factors
- Case narrative detailing any deviations, problems, and corrective actions

If the purpose of sampling is a stand-alone assessment of the vapor intrusion pathway, IDEM recommends U.S. EPA Methods TO-14A, TO-15, or TO-15 SIM (all canister-based methods)³¹ and use of a fixed laboratory when analyzing air, soil gas, or subslab gas samples. The following sampling-related items should support every vapor intrusion investigation:

- Field records of the initial and final canister pressures, start and stop times for canister filling, and approximate fill rates
- Field measurement records (ambient temperature and pressure, screening results)
- Records of any leak tests performed
- Documentation of canister cleaning (batch or individual certification)
- Copy of a completed [Indoor Air Building Survey Checklist](#) (as applicable)³²

³¹ Subject to a demonstration that use of an alternative sampling device or analytical procedure can provide results of comparable quality to results using summa-type canisters and Method TO-15 or similar, IDEM will consider approving the use of such devices and techniques on a site-specific basis. Due to the variety of site-specific conditions and objectives typical of vapor intrusion investigations, generic approval of a particular sampling device or analytical technique is unlikely at this time.

³² <http://www.in.gov/idem/files/la-073-gg.pdf>

Table 3-A: Elements for MDDR and Full QA/QC DQOs

<u>Element</u>	<u>Method Type</u>	<u>MDDR</u>	<u>Full QA/QC</u>
Sample introduction method (e.g., direct injection, purge-and-trap)	Specific gas chromatography (GC) detector method	✓	✓
Tuning criteria and results	Gas chromatography/mass spectroscopy (GC/MS)		✓
Initial calibration (IC) and IC verification	All		✓
Continuing calibration(s)	All		✓
Blank results (e.g., field, prep, method)	All	✓	✓
Laboratory control sample	All	✓	✓
Internal standard summary	GC/MS, GC	✓	✓
Surrogate recoveries	GC/MS, GC	✓	✓
Matrix spike/matrix spike duplicate recoveries	All (except TO-14A, TO-15, and TO-15 SIM)	✓*	✓
Interference check sample	Inductively coupled plasma (ICP) methods		✓
Serial dilutions	ICP methods		✓
Method of standard additions (if applicable)	ICP methods		✓
Raw data (instrument printouts, chromatograms, and/or mass spectra as applicable)	All		✓
Confirmation on second column (or GC/MS)	Pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene and xylenes (BTEX) and other VOCs by GC		✓

*Only necessary during initial and final sampling.

The IDEM OLQ [Chemistry Services Section web page](http://www.in.gov/idem/4673.htm)³³ contains additional information on QA/QC elements.

³³ <http://www.in.gov/idem/4673.htm>

3.10 Data Evaluation

There are three major components of the data evaluation process: verification, validation, and comparison against user requirements. The data evaluation process assesses whether the sample results fulfill project objectives. It verifies that sample collection, documentation, and delivery occurred as planned. It validates results for the end user against predetermined quality criteria. It compares those results against user requirements. Finally, it incorporates any new information into the CSM.

3.10.1 Verification

Verification assesses whether sample collection and analysis occurred as planned. Examples of deviations include sample relocation due to access issues, low soil recovery from a boring, dry wells, or analytical error. In some cases, the verification process may reveal the presence of data gaps.

3.10.2 Validation

Validation is an analyte specific and method specific process that compares data quality (i.e., accuracy and precision) against quality criteria predetermined during the planning phase (Section 2.7). Validation demonstrates whether the data are reliable enough to meet project objectives. For example, inaccurate reported concentrations close to a decision level may lead to an incorrect decision. Another example occurs when high levels of one chemical mask the presence of other, perhaps just as important, chemicals. Validation documents any effects on the results, thus allowing the end user to reach an informed conclusion. See U.S. EPA (1999d, 2001c, 2002e, 2004d, 2005d) for additional detail on the data validation process.

3.10.3 Comparison with User Requirements

The final component of the data evaluation process includes a comparison against project objectives. Ideally, the data should enable project-related decisions. However, sometimes new data do not meet project objectives, or they indicate a need for change in the original project objectives. As always, incorporate new information into the CSM and use the updated CSM to plan any necessary further activities.

3.11 CSM Documentation

Materials needed to support a CSM and aid IDEM evaluation of project reports will vary from site to site. Coordination with IDEM staff will help ensure efficient development of a CSM that is consistent with industry best practices. Supporting materials include, but are not limited to:

Land Use Documentation

- Summary of site location, size, ownership history and years of operation
- Summary of contaminant or potential contaminant types, sources, and locations
- Phase I and/or Phase II report(s)
- Previous investigative reports
- Scaled plan view map(s) showing structures, property boundaries, exposure control areas, adjacent properties and *specific* land uses, subsurface utilities, potential release origins, and other relevant site information
- Records of interviews with current or past owners and employees, local officials, and/or site neighbors
- Historic aerial photographs, where available
- Site records – current and past historical processes, chemical use, and waste storage and disposal practices
- Property tax records
- Municipal utility maps
- Identification of sampling area access restrictions
- Fire insurance maps

Geological Setting Documentation

- Scaled site map showing sample locations and descriptions
- Soil boring and monitoring well stratigraphic logs
- Geologic cross-section diagrams that include analytical results, borings, wells (with screened areas and water levels), subsurface utilities, excavated areas, tanks, and any types of piping or drains
- Potentiometric surface maps
- Indiana Department of Natural Resources Water Well Records for wells within one mile of the release, and high capacity wells within two miles
- Topographic maps and/or elevation surveys
- Soil survey maps
- Utility (water, sewer, electric, gas, etc.) location maps, including known pipe invert locations
- Hydrogeologic and geotechnical data (e.g., site-specific slug/pumping test results or other relevant local hydrologic data, test results, grain size analysis, fraction of organic carbon, mineralogy, soil chemistry)
- Monitoring well construction diagrams
- Maps showing the vertical and horizontal extents of contamination delineated to appropriate levels in each affected medium
- Narrative summarizing investigative findings discussing the inter-relationship of the identified main geologic units, aquifers, ground water flow characteristics, and preferred contaminant pathways

Susceptible Areas Documentation

- Ecologically susceptible area evaluation
- Geologically susceptible area evaluation
- Wellhead protection area evaluation
- Preferential pathway analysis (naturally occurring and anthropogenic)
- Evaluation of potential exposure scenarios

Data Analysis Documentation

- SAP
- QAPP
- Analytical results for all samples in tabular format, including comparisons to relevant remediation objectives, and appropriate supporting documentation.
- Methods employed in placing, collecting, screening, and handling samples
- Real world coordinates for each sample location based on [*IDEM Office of Land Quality Spatial Data Collection Standards*](#)³⁴ (IDEM, 2008b).
- Digital copy of all sampling results formatted according to OLQ [*Electronic Data File Submittal Guidelines*](#)³⁵
- Analysis of temporal trends
- Calculations for site-specific remediation objectives

³⁴ http://www.in.gov/idem/files/olq_spatial_data_collection_standards.pdf

³⁵ <http://www.in.gov/idem/5384.htm>

Conceptual Site Model (CSM) Development: Plume Behavior

4.1 Introduction

The saturated subsurface is a dynamic environment, in which contaminant migration can occur through a variety of pathways and processes. Understanding ground water contaminant plume behavior allows evaluation of potential *future* risk to receptors.

This section describes a variety of contaminant, site, and plume characteristics useful in understanding the nature and extent of a contaminant release. Each characteristic offers insight into contaminant plume behavior. While no single characteristic is enough to understand the overall behavior of a contaminant plume, agreement among multiple lines of evidence (LOEs) provides greater confidence in assessing plume behavior. It is not necessary to develop any particular LOE discussed in this section – only those needed to provide adequate confidence in the understanding of plume behavior.

Active remediation can be conducted at any time. However, because active remediation alters plume dynamics, the potential future risk associated with contaminated ground water cannot be evaluated during active remediation. An equilibration period is necessary between the end of active remediation and the beginning of a trend analysis monitoring program.

4.2 Applicability

Ground water contaminant plume behavior is a necessary component of the CSM. Plume behavior should be evaluated prior to closure for all sites with ground water that exceeds residential remediation objectives. However, it may be appropriate to postpone or forgo the complete assessment of plume behavior when:

- The nature and extent of contamination is still under investigation.
- Active remediation is occurring.
- The ground water remediation objective is an unconditional residential closure.
- The ground water remediation objective is closure via a background or off-site source demonstration.
- Other LOEs demonstrate that the evaluation is unnecessary.

A high level of confidence in plume behavior may not be necessary under the above conditions. Even so, it may prove worthwhile to consider plume behavior LOEs prior to investigative and remedial activities, either to meet specific program requirements, or in case a plume behavior evaluation becomes necessary in the future.

4.3 Plume Behavior

The concentration of a ground water contaminant will generally decrease as it migrates. Causes of this decrease may include dilution, adsorption to matrix materials, or physical/chemical degradation. The distance over which contaminant concentrations decrease to acceptable levels will depend on the chemical properties of the contaminant, the physical properties of the saturated zone, and the magnitude of the contamination.

Ground water plumes resulting from petroleum-related releases have been extensively documented and shown to generally migrate and degrade within reasonably predictable parameters. For instance, data indicate that 95% of benzene, toluene, ethylbenzene, and xylene (BTEX) ground water plumes will terminate within 750 feet of their origin, regardless of the physical properties of the subsurface or the nature of the release (Mace *et al.*, 1997; Newell *et al.*, 1990; Rice *et al.*, 1995; Wiedemeier *et al.*, 1999). Conversely, ground water plumes of persistent chemicals (e.g., tetrachloroethene) can extend for long distances – sometimes more than a mile.

4.3.1 Investigating Plume Behavior

Well locations are important when characterizing plume behavior. Data on contaminant levels and aquifer characteristics should come from wells and boreholes capable of providing a clear three-dimensional picture of the hydrogeologic and geochemical characteristics of the site. If the wells do not meet appropriate criteria, or if site conditions change, previously installed wells may no longer produce samples that adequately represent the plume. In such cases, new wells *may* be necessary.

CSM development may require further characterization of ground water contaminant plumes through additional ground water monitoring and assessment of data trends (e.g., plume area, contaminant concentrations, contaminant mass, and the center of mass over time). Assessment of these trends helps understand plume behavior, and the potential for contamination to migrate beyond the exposure control area.

If hydraulic conductivity, saturated thickness, flow gradients, or other important characteristics vary significantly over the evaluation area, it may prove difficult or impossible to confidently predict plume behavior. Similarly, preferential pathways (e.g., karst conditions, fracture flow, utility backfill, etc.) that control ground water flow and contaminant migration complicate assessment of plume behavior. Where this is the case, understanding plume behavior may require assessment of LOEs that do not appear in this document.

4.4 Lines of Evidence (LOEs)

As noted above, numerous factors affect the behavior of a ground water contaminant plume. While any single factor provides some insight into the behavior of the plume, examination of multiple LOEs provides the most comprehensive assessment of plume behavior. LOEs can be grouped into three categories:

- Contaminant characteristics (Section 4.5)
- Site characteristics (Section 4.6)
- Plume characteristics (Section 4.7)

The following subsections present and describe LOEs that IDEM will use to evaluate ground water contaminant plume behavior. Other LOEs may be submitted, and IDEM will evaluate them on a site-specific basis.

4.5 Lines of Evidence: Contaminant Characteristics

Some contaminants behave in reasonably predictable ways. For example, benzene readily degrades in well oxygenated subsurface conditions, while tetrachloroethene does not (Howard, 1990, 1991). Certain contaminant properties help predict how a contaminant plume is likely to behave. Appropriate LOEs based on contaminant characteristics include:

- Toxicity
- Solubility
- Persistence

4.5.1 Toxicity

Contaminant toxicity is important when evaluating the relative threat the contaminant poses to a receptor. Highly toxic contaminants require a greater level of confidence in plume behavior than do less toxic contaminants. In the context of evaluating plume behavior, IDEM bases the relative toxicity of a contaminant on its human health effect (e.g. carcinogenic, mutagenic, etc.).

4.5.2 Solubility

Contaminant solubility directly relates to mobility, which affects the level of confidence needed in plume behavior. Greater solubility implies a greater need for confidence in plume behavior. IDEM may also consider effective solubilities. See Wiedemeier *et al.* (1999) and U.S. EPA's [Effective Solubility Calculator](http://www.epa.gov/athens/learn2model/part-two/onsite/es.html)³⁶ for more information on evaluating site-specific effective solubilities.

4.5.3 Persistence

Contaminant persistence determines the relative timeframe over which confidence in the plume behavior is needed. Highly persistent contaminants require a greater degree of confidence in the plume behavior, while short-lived contaminants require less.

³⁶ <http://www.epa.gov/athens/learn2model/part-two/onsite/es.html>

4.6 Lines of Evidence: Site Characteristics

Nature and extent investigations typically generate data applicable to evaluation of plume behavior. Several site characteristics are easy to document and reproducibly measure by established methods. Appropriate site characteristic LOEs for evaluating the behavior of ground water contaminant plumes include:

- Age of the release
- Presence of non-aqueous phase liquid (NAPL)
- Maximum concentration
- Plume core size
- Hydraulic conductivity
- Ground water time of travel to exposure control area boundary
- Ground water time of travel to nearest receptor
- Variation in ground water flow direction
- Variation in ground water elevation

Exercise due diligence in identifying any receptors with a high probability of human exposure. Give special consideration to municipal well fields, wellhead protection areas, public reservoirs, rivers, or other potential receptors near contaminant plumes. IDEM recommends contacting public water utilities or other significant local water users to determine if there are any planned changes in well locations, pumping rates, or other activities that could influence ground water elevation or flow direction.

4.6.1 Age of the Release

This LOE applies only to BTEX contamination. Given the well documented behavior of petroleum releases, the age of the release is an appropriate indicator of the plume lifecycle. Regardless of the size of the release or subsurface conditions, the extent of *most* petroleum related releases will stabilize within approximately five years (Rice *et al.*, 1995). Given this relationship, IDEM will have greater confidence in the behavior of petroleum plumes that have documented historic release dates. Conversely, the behavior of recent petroleum releases merits less confidence.

4.6.2 Presence of Non-aqueous Phase Liquid

NAPL may be an ongoing source of ground water contamination. While the presence of NAPL does not preclude understanding the behavior of a ground water contaminant plume, it does complicate that understanding. In such cases, additional LOEs may bolster IDEM's confidence in the understanding of plume behavior

Examples include the NAPL, maximum concentration, and plume core size LOEs. While interdependent, each of these LOEs provides additional information about the magnitude of the ground water contamination. In some instances, however, some of these LOEs may prove redundant and unnecessary for the evaluation of plume behavior.

In general, IDEM will consider NAPL to be present if measurable light NAPL (LNAPL) thickness exceeds 0.1 feet, or if one or more dense non-aqueous phase liquid (DNAPL) forming contaminants are present at concentrations exceeding ten percent of their solubility. IDEM will consider NAPL as *potentially* present if measurable LNAPL thickness lies between 0.01 and 0.1

feet, or if one or more DNAPL-forming contaminants are present at concentrations between one and ten percent of their solubility.

4.6.3 Maximum Concentration

The maximum ground water contaminant concentration is an appropriate measure of the relative magnitude of the contamination and the confidence level needed to assess plume behavior. Ground water plumes with maximum concentrations at or near the remediation objective require less confidence in plume behavior, while higher concentrations require more confidence.

4.6.4 Plume Core Size

Plume core size is a measure of the area of the plume with the highest contaminant concentrations. It is the area where the maximum extent of the contamination exceeds a contaminant specific threshold concentration, which is often less than the absolute solubility limit. Threshold concentrations allow use of a large, more easily measured, region of the contaminant plume to represent the source of the contamination. Plume core size may be completely measured using sampling points, or partially inferred using sampling data and the nature of the release. IDEM will give more weight to plume core size measurements obtained with more sampling.

The initial threshold concentration for BTEX constituents is defined by the effective solubility of the fuel blend:

$$\text{Effective Solubility } C_w = X_0 S$$

$$C_w = \text{Effective solubility}$$

$$X_0 = \text{mole fraction (of chemical in fuel)}$$

$$S = \text{solubility}$$

$$\text{Mole Fraction } X_0 = MF_x MW_0 / MW_x$$

$$MF_x = \text{mass fraction of selected chemical in fuel}$$

$$MW_0 = \text{average molecular weight of fuel}$$

$$\text{Est. 105 g/mole for gasoline}$$

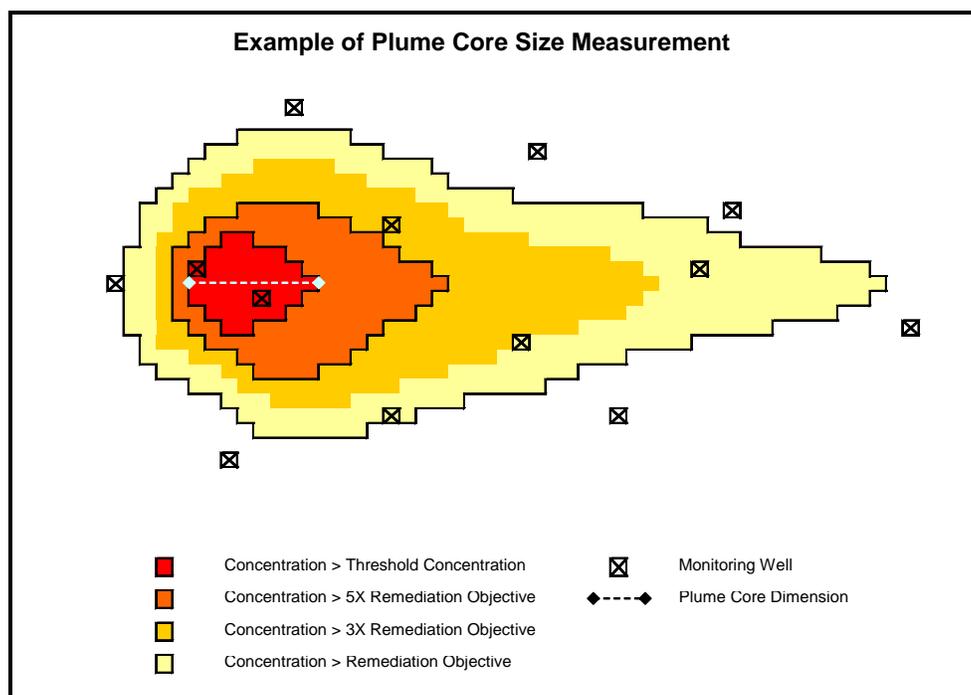
$$\text{Est. 165 g/mole for jet fuel}$$

$$\text{Est. 230 g/mole for diesel fuel}$$

$$MW_x = \text{molecular weight of selected chemical}$$

For unknown fuel blends, standard mass fractions for BTEX constituents are as follows: benzene – 0.4%; toluene – 8.6%; ethylbenzene – 1%; total xylenes – 5.3%. These mass fractions correspond to effective solubilities of 9,570 µg/l; 51,500 µg/l; 1,480 µg/l; and 8,160 µg/l, respectively. For DNAPLs, the threshold concentration is one percent of the constituent's absolute solubility. Consult IDEM technical staff for threshold concentrations of other contaminant classifications.

To measure plume core size, develop an adequate isopleth representing the contaminant specific threshold concentration. The plume core size is the longest transect across the area within the isopleth. If the threshold concentration isopleth includes more than one contiguous area, combine the lengths of the longest transect for each area. If the maximum concentration (Section 4.6.3) exceeds the threshold concentration, the plume core size will likely be large. Figure 4-A depicts an example of determining the plume core size.

Figure 4-A: Plume Core Size Measurement

Developing this LOE may require a monitoring well network of greater density than that necessary to characterize the extent of contamination. Special care should be taken when designing monitoring well networks in the presence of potential DNAPLs.

Ground water contaminant concentrations at or near their solubility limit suggest direct transmission of contamination to the ground water. The larger the area of the ground water plume approaching the solubility limit, the greater the potential for a large contaminant plume with variable behavior. Conversely, a plume with a limited extent of contamination approaching solubility is more likely to result in a limited plume with more readily assessed behavior.

4.6.5 Hydraulic Conductivity

Hydraulic conductivity affects the ability of contaminants to migrate within the subsurface. All other hydraulic factors being equal, hydraulic conductivity, and the potential for migration of contaminants dissolved in a clay-rich aquifer, will be orders of magnitude lower than in a coarse sand and gravel aquifer. Hydraulic conductivity depends in part on the density and scale of aquifer features such as grain-size distribution, fracturing, gravel lenses, or other types of bedding. Hydraulic conductivity estimates must be site-specific, documented, reproducible, and representative of conditions at a scale relevant to contaminant transport. Given the potential for greater mobility, high hydraulic conductivities require more robust demonstrations of plume behavior.

4.6.6 Ground Water Time of Travel (Exposure Control Area)

This LOE estimates the time it will take for ground water to travel from the furthest extent of concentrations exceeding the remediation objectives to the edge of the exposure control area. This LOE provides perspective on the size of the plume relative to the exposure control area. Sometimes, the exposure control area will coincide with the property boundary. In other cases, environmental restrictive covenants (ERCs) or environmental restrictive ordinances (EROs) may extend the exposure control area beyond the property boundary. Ground water chemistry and contaminant interactions with matrix materials complicate estimation of migration rates and may require site-specific data. *IDEM will not consider time of travel estimates that are contradicted by the known extent of contamination as representative.*

4.6.7 Ground Water Time of Travel (Nearest Receptor)

This LOE estimates the time it will take for ground water to travel from the furthest extent of concentrations exceeding the remediation objective to the nearest receptor. This LOE provides perspective on the size of the plume relative to the location of the receptors. In the context of this section, the receptor pathway is in direct contact with contaminated ground water. However, a thorough understanding of plume behavior is important when evaluating potential receptors via the vapor inhalation pathway. *IDEM will not consider time of travel estimates that are contradicted by the known extent of contamination as representative.*

4.6.8 Variation in Ground Water Flow Direction

Ground water flow is usually the primary driver of ground water contaminant plume migration. A thorough understanding of ground water flow is fundamental to evaluating the behavior of the plume. A consistent ground water flow direction lends confidence to the understanding of plume behavior, while highly variable or erratic ground water flow direction yields less confidence. Highly variable ground water flow also makes it difficult to determine proper locations for monitoring wells that consistently represent plume conditions. Evaluate this LOE based on changes in the calculated ground water flow direction measured using a minimum of three representative monitoring wells determined to be appropriate by the facility representative and IDEM. While this approach cannot capture all the complexities of ground water flow, it does provide a consistent measurement.

4.6.9 Variation in Ground Water Elevation

High variability in depth to ground water reduces confidence in understanding plume behavior. Significant contaminant mass can often remobilize when ground water elevations undergo large fluctuations, which introduces uncertainty in understanding contaminant plume behavior. This LOE applies only to unconfined aquifers, and should be evaluated in the area of the highest contaminant concentrations.

4.7 Lines of Evidence: Plume Characteristics

The previously listed contaminant and site characteristic LOEs are appropriate for evaluating how a plume is *likely* to behave. However, actual plume behavior is a more robust LOE. Appropriate LOEs for evaluating the actual behavior of a plume are as follows:

- Plume length
- Commingled plume
- Qualitative analysis
- Natural attenuation
- Modeled behavior
- Trend analysis

4.7.1 Plume Length

A significant body of research shows that regardless of the size of a petroleum (BTEX) release or hydrogeological conditions, benzene will stabilize to 10 parts per billion (ppb) within 750 feet of the release point (Newell and Connor, 1998). Evaluating the length of a plume of benzene against the statistical distribution of benzene plume lengths provides a reasonable indication of the plume's behavior. Longer plume lengths provide greater confidence that the petroleum related contaminant plume is nearing its maximum extent, while short plume lengths warrant additional information on the plume behavior. This LOE applies only to petroleum contamination; it does not apply to petroleum additives or special blends (e.g., E85).

4.7.2 Commingled Plumes

It is not uncommon to encounter ground water contaminant plumes that commingle with additional ground water contaminant plumes originating from the same or adjacent facilities. In these instances, it can be difficult to differentiate the behavior of one plume from the other. Thus, commingling of ground water contaminant plumes reduces confidence in plume behavior. While the presence of commingled plumes does not preclude a thorough understanding of plume behavior, it does require additional information to obtain a greater degree of confidence in the plume behavior.

4.7.3 Qualitative Analysis

Qualitative analysis of plume behavior relies on specific knowledge of site conditions rather than analytical data. While quantitative examinations of contaminant trends are powerful tools for evaluating the behavior of a contaminant plume, meaningful statistical tests require substantial monitoring timeframes to acquire sufficient data. In some situations, trends in contaminant concentrations are qualitatively discernible in shorter timeframes. IDEM will evaluate such interpretations on their merits. If sufficient data (eight or more consecutive quarters) are available for quantitative trend analysis, then it is likely that the quantitative and qualitative analyses will be redundant demonstrations. Therefore sites with eight or more consecutive quarters of data should only utilize qualitative demonstrations as contrary evidence to quantitative analytical methods. For example, statistical analysis may show no discernible trend, but a qualitative examination of the most recent sampling events may suggest decreasing concentrations.

4.7.4 Natural Attenuation

Natural attenuation of a plume involves processes such as dilution, matrix adsorption, and contaminant degradation (IDEM 2004; U.S. EPA 1999c, 2004a; API 2007). Demonstrating the occurrence of these processes can provide powerful evidence of the plume's behavior. Changes in the distribution of contaminants and geochemical parameters in and around the ground water contaminant plume over time and space can provide confirmation of natural attenuation activity. Some considerations for making this demonstration appear below.

It is possible to make general statements about the effects of various geochemical parameters on natural attenuation (e.g. high dissolved oxygen (DO) is generally good for degrading benzene). However, specific levels are relative to the contamination at the site (e.g. 1 ppm dissolved oxygen is adequate for Site A, but Site B needs 4 ppm dissolved oxygen to have the same effect on the contamination). Therefore, it is more appropriate to show that conditions are having an effect in the area of contamination. This typically involves demonstrating contrasting geochemical parameters between the areas where contamination is and is not present (e.g. high DO levels decrease in the areas of contamination, and biodegradation byproducts increase).

Degradation by-products or daughter products are also acceptable as criteria. However, degradation products may present a greater risk than the parent contaminant. Natural attenuation demonstrations should consider the following:

Contrasting conditions. As noted earlier, natural attenuation is a highly site-specific phenomenon, and IDEM has not established specific geochemical criteria. An effective demonstration will show contrasting geochemical parameters between contaminated and uncontaminated areas (e.g., decreased DO levels and high biodegradation product levels in contaminated areas). Graphical means (isoconcentration maps, box plots, etc.) are acceptable for this purpose.

Parameters. Geochemical parameters of interest should be consistent with API (2007), IDEM (2004), and U.S. EPA (1999c, 2004a) and/or other scientific literature. Parameters of interest include, but are not limited to, dissolved oxygen, nitrate, sulfate, soluble ferrous iron, oxidation-reduction potential, hydrogen sulfide, and degradation byproducts.

Timeframe. This demonstration is not necessarily of a time-dependent, statistical nature, and thus does not require at least eight quarters of data. However, demonstrations may require professional judgment to interpret seasonal fluctuations in ground water conditions, where that occurs.

Biological. IDEM will review biological assay results, but has determined that they are not the most significant metric in evaluating natural attenuation.

4.7.5 Modeled Plume Behavior

Models are useful for describing the behavior of a contaminant in ground water, as long as they adequately reproduce observations of the ground water system. It is important to choose models that are appropriate for the contaminant and conditions at the site. Most importantly, input parameters for the model should fall within realistic ranges for the hydrogeologic system defined during CSM development (ASTM, 2008). Use of literature-based parameters or undocumented site-specific parameters may invalidate model results. Some modeling demonstrations may require site-specific calibration and/or field verification to be suitable for demonstrating confidence in contaminant plume behavior.

Possible modeling approaches for demonstrating plume behavior include plume length versus time, centerline concentration versus distance, or well contaminant concentration versus time. IDEM will consider other approaches on a site-specific basis.

4.7.6 Plume Trend Analysis

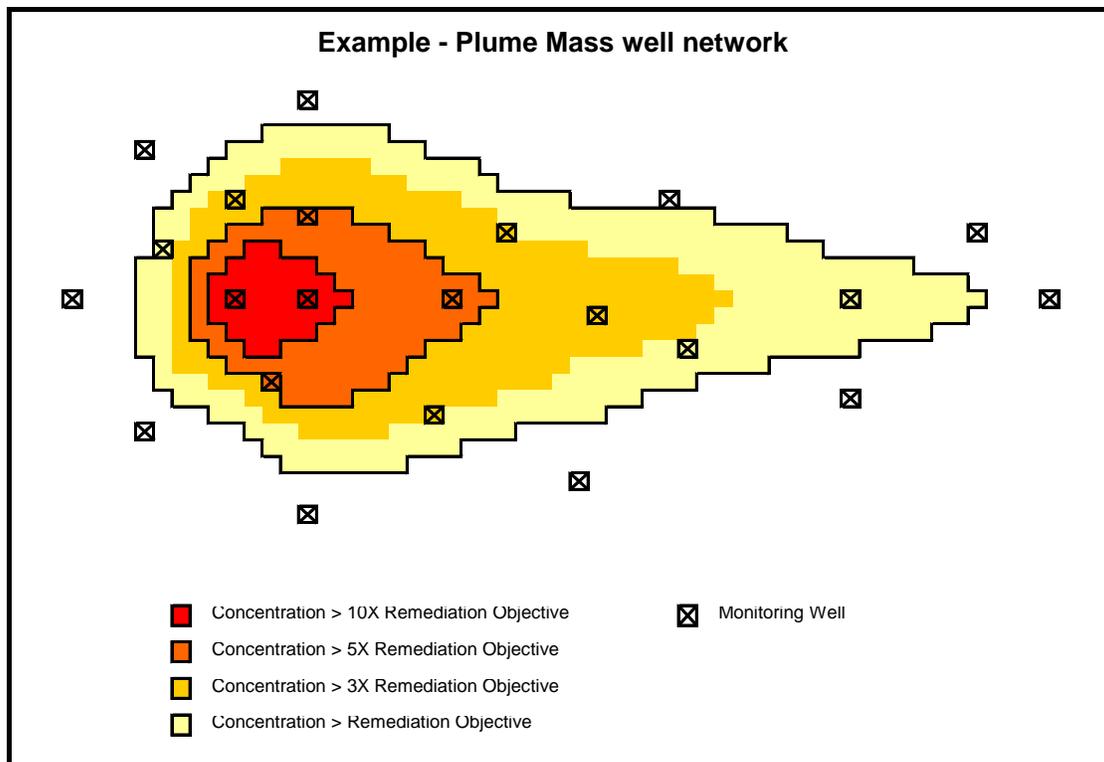
Plume trend analysis provides a statistically-based demonstration that a ground water contaminant plume is behaving in a consistent manner, both temporally and spatially. However, the usefulness of the demonstration depends heavily on the quantity of data available. Statistical trend analysis of time-series data requires a minimum of eight quarters of data. Further, it is inappropriate to assess trends in the ground water data for the purpose of defining plume behavior while active remediation measures are underway. Several possible trend analysis LOEs appear below. IDEM will evaluate other methods on a case by case basis.

4.7.6.1 Plume Trend Analysis: Plume Mass

Plume mass is defined by a three-dimensional understanding of dissolved contaminant concentrations. The quantitative vertical extent of contamination is vital to this analysis. A statistical evaluation that shows a decreasing plume mass provides a high level of confidence in the expected behavior of the plume. Fundamental to this LOE is the characterization of the plume mass with sufficient resolution to accurately represent changes in the overall plume mass. This demonstration may require an extensive ground water monitoring network that includes multiple sampling depths to accurately characterize the plume in three dimensions. The mass may be completely measured using sampling points, or partially inferred using sampling data and the nature of the subsurface. Plume mass measurements using more sampling data will increase the value of the LOE.

The extent of the necessary monitoring well network will vary on a site-by-site basis. Consultation with IDEM technical staff is recommended to ensure that the monitoring well network is appropriate for the demonstration. IDEM recommends beginning with a regression analysis and concluding with a Mann-Kendall analysis of the change in mass over time. However, IDEM will evaluate alternative statistical demonstrations on a site-specific basis.

Figure 4-B: Illustration of Plume Mass Well Network

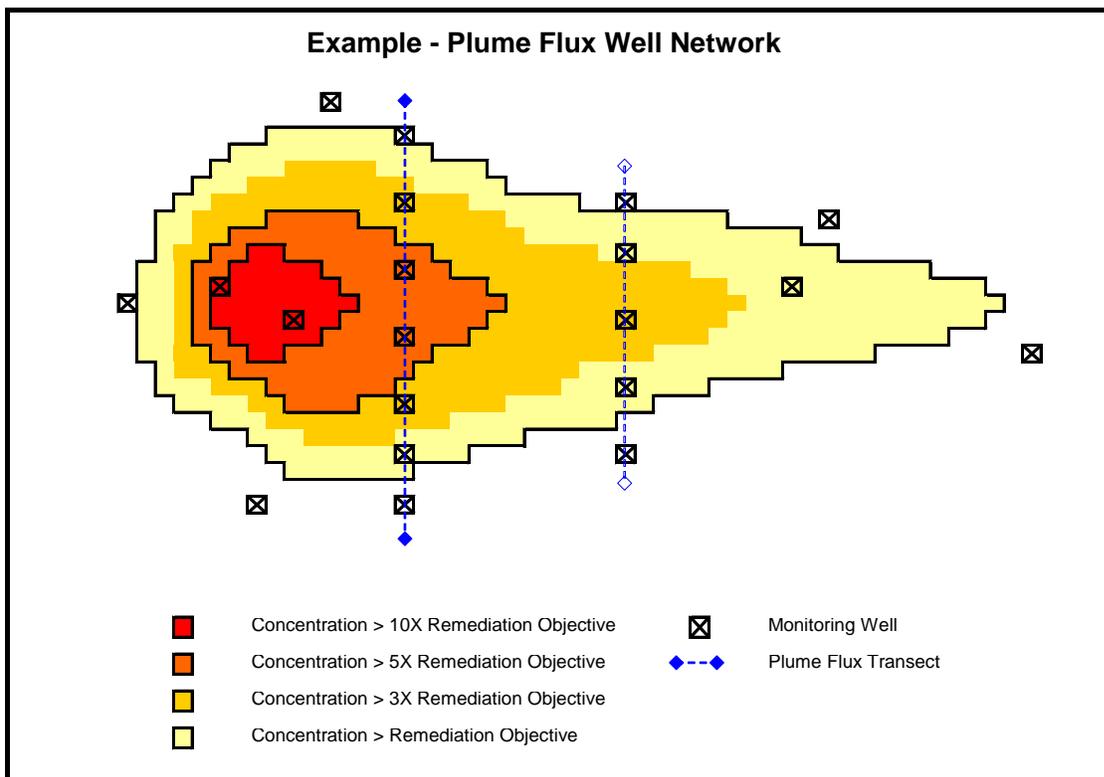


4.7.6.2 Plume Trend Analysis: Plume Flux

Plume flux is a measurement of change in contaminant concentration across a plane. Examining the trend in plume flux across one or more projected planes is a useful way to evaluate contaminant migration (Figure 4-C). However, as with plume mass, complete and accurate characterization of flux may require a substantial monitoring well network that includes multiple transects across the plume at multiple sampling depths. Plume flux may be completely measured using sampling points, or partially inferred using sampling data and the nature of the subsurface. Plume flux measurements using more sampling data will increase the weight of this LOE.

Consultation with IDEM technical staff is recommended to ensure that the monitoring well network is appropriate for the demonstration. Plume flux analysis supplements the plume mass LOE with additional statistical evaluations. IDEM recommends beginning with regression analysis for each transect, and concluding with Mann-Kendall analysis for each transect. However, IDEM will evaluate alternative statistical demonstrations on a site-specific basis.

Figure 4-C: Plume Flux Well Network

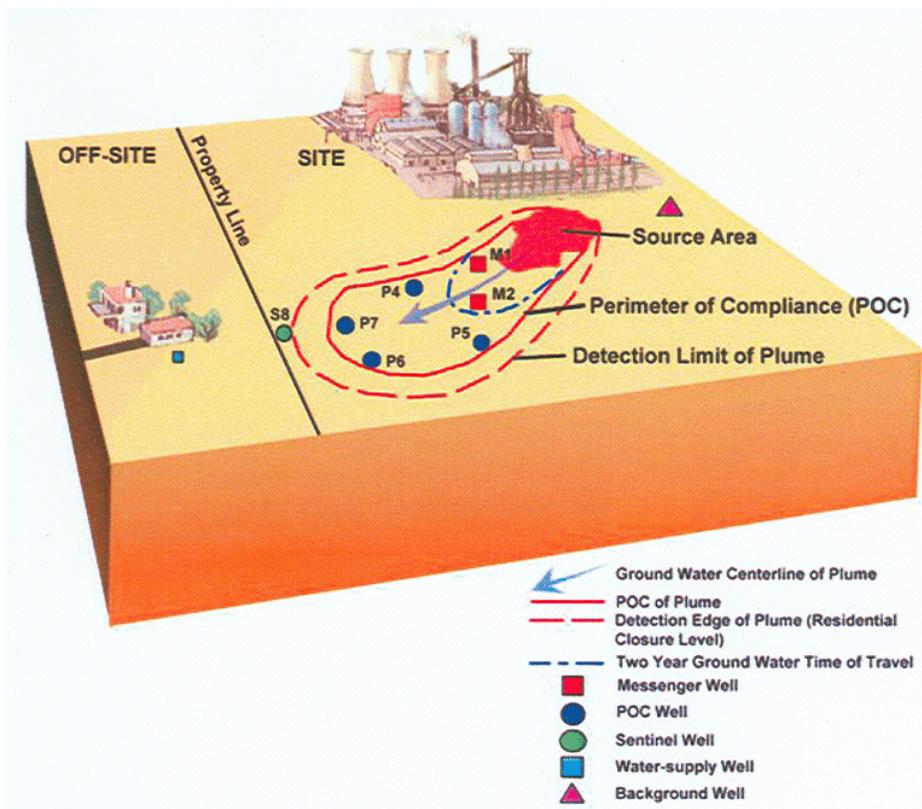


4.7.6.3 Plume Trend Analysis: Statistical Analysis

This powerful LOE combines monitoring data with regression analysis, trend analysis, and other statistical tests from a representative ground water monitoring well network to demonstrate an increasing, decreasing, or constant plume. A demonstration via this method that a plume is decreasing provides a high level of confidence that risks are decreasing. Conversely, an increasing plume warrants additional investigation and/or monitoring. Consistent characteristics across the extent of the plume provide a higher level of confidence that the potential future behavior of the plume is understood (U.S. EPA, 2006d). This involves evaluating the trend of multiple sampling locations with multiple observations; all else equal more data will increase the weight of this LOE. Confidence is lower when at least two of the plume monitoring wells exhibit different trends, or when characteristics are not consistent across relevant monitoring wells.

All monitoring methods require properly designed, located, and installed ground water monitoring wells. Figure 4-D depicts typical plume behavior demonstration well locations.

Figure 4-D: Plume Monitoring Network



Messenger wells are in the internal area of the plume, downgradient from the source, within the two-year ground water time-of-travel distance. At least one messenger well must be adjacent to the source, and a second messenger well must be between the first messenger well and the two-year ground water time-of-travel distance of the plume. Most ground water closure demonstrations use two to four messenger wells. Some large or multi-lobed plumes may require more messenger wells. Messenger wells should be (1) as near to the center flow line or flow path as possible and (2) in an area where the contaminant concentrations are likely to be highest and significantly exceed closure levels.

The network should include at least three **perimeter of compliance** (POC) wells located hydraulically downgradient from the messenger wells, where:

- Dissolved contaminant concentrations will likely exceed estimated quantitation limits (EQLs) for at least 75 percent of the monitoring events.
- Contaminant concentrations approximate remediation objectives.
- It is possible to monitor the contaminant plume after it has passed through the source and messenger well areas.

Install **sentinel wells** if there is potential risk to downgradient receptors. Locate sentinel wells hydraulically downgradient from POC wells and along a line between the source and any potential receptors. Though sentinel wells are highly useful for signaling an expanding plume, they may be unnecessary if there is no downgradient receptor.

Place **background wells** upgradient of the area of concern and out of the zone of influence of the source. Background wells are essential to understanding upgradient ground water conditions. If both upgradient and downgradient concerns exist at a site, at least one background well is necessary. However, additional background wells may be necessary, depending on conditions discussed below.

Characterization of hydrogeologic conditions may require additional wells. If the wells do not meet appropriate criteria, or if site conditions change, previously installed wells may no longer produce samples that adequately represent the plume. In such cases, new wells may be necessary, or existing wells may be redesignated to serve a different monitoring function than originally intended.

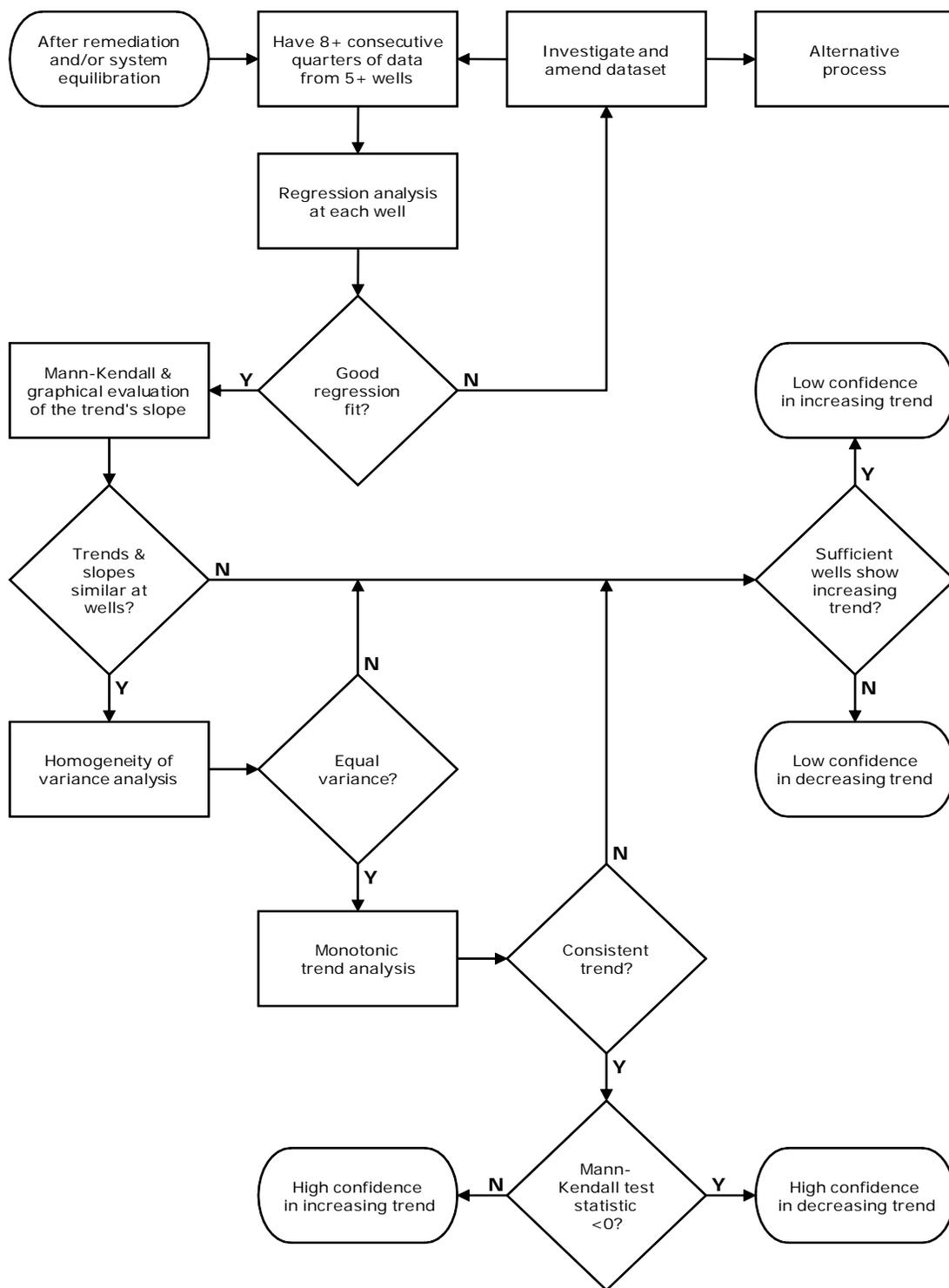
Some wells must be located within specific ground water time-of-travel distances from the source. Before installing wells, estimate the advective flow velocity of ground water at the site to ensure that the new wells will meet ground water time-of-travel requirements. This approach will allow sufficient time during monitoring to ensure that ground water from the closure area reaches key monitoring wells.

One process for evaluating plume behavior is as follows:

- Step 1: Regression analysis of data from each well
- Step 2: Mann-Kendall trend analysis of data from each well
- Step 3: Graphical demonstration that data from each well exhibit similar trends and slopes
- Step 4: Homogeneity of variance analysis
- Step 5: Monotonic trend analysis

Figure 4-E illustrates the steps in the above approach. IDEM will evaluate other plume trend analysis methods on their merits. U.S. EPA (2006d) describes various methods for evaluating trends of different combinations of spatial and temporal data.

Figure 4-E: An Example of Plume Trend Analysis



Conceptual Site Model (CSM) Development: Vapor

5.1 Introduction

Vapor intrusion (VI) refers to subsurface volatile chemicals that can move through the air-filled pores of vadose zone soils and enter the breathing space of buildings. VI can also occur when contaminated ground water infiltrates buildings and chemicals directly volatilize from the ground water into indoor air of the building. Vapors may move through permeable soils, fractures in bedrock or clay tills, man-made subsurface structures such as utility lines, basement sumps, cracks in the building foundation, or any combination of these pathways.

This section describes some procedures for evaluating VI. In addition to utilizing professional judgment and developing lines of evidence (LOEs), these procedures rely on existing CSM information, and also contribute to further CSM development. The science of VI is evolving rapidly. Other VI investigatory procedures are described in the literature, and IDEM will evaluate the implementation of those procedures consistent with principles addressed in U.S. EPA guidance and literature.

VI investigations typically begin with preliminary screening (Section 5.4), which includes an evaluation of volatile organic compounds (VOCs) in soil and ground water. Sites that meet certain qualifying conditions and have ground water VOC concentrations below applicable VI screening levels screen out of further evaluation of the VI pathway. Ground water stability is assumed during the screening process. If ground water plume stability remains undetermined, or if the ground water plume is expanding, the VI screening process may be iterative. Sites that do not meet these criteria require further evaluation, which typically involves two or more rounds of subslab soil gas (SGss), crawl space air (CSA), and/or indoor air (IA) sampling. However, certain low risk sites (Section 5.4.2) may rely on exterior soil gas (SGe) measurements during further evaluation.

5.2 Applicability

It is appropriate to evaluate both current and potential VI exposures at buildings. Current exposures exist when VI is documented in an occupied building. Potential exposures may be a concern when:

- Vapor phase chemicals exist beneath a building, even if they do not currently affect IA quality,
- Vapor phase chemicals may move into previously unaffected structures,
- A currently unoccupied building has vapor contamination, and/or
- New construction may result in exposure.

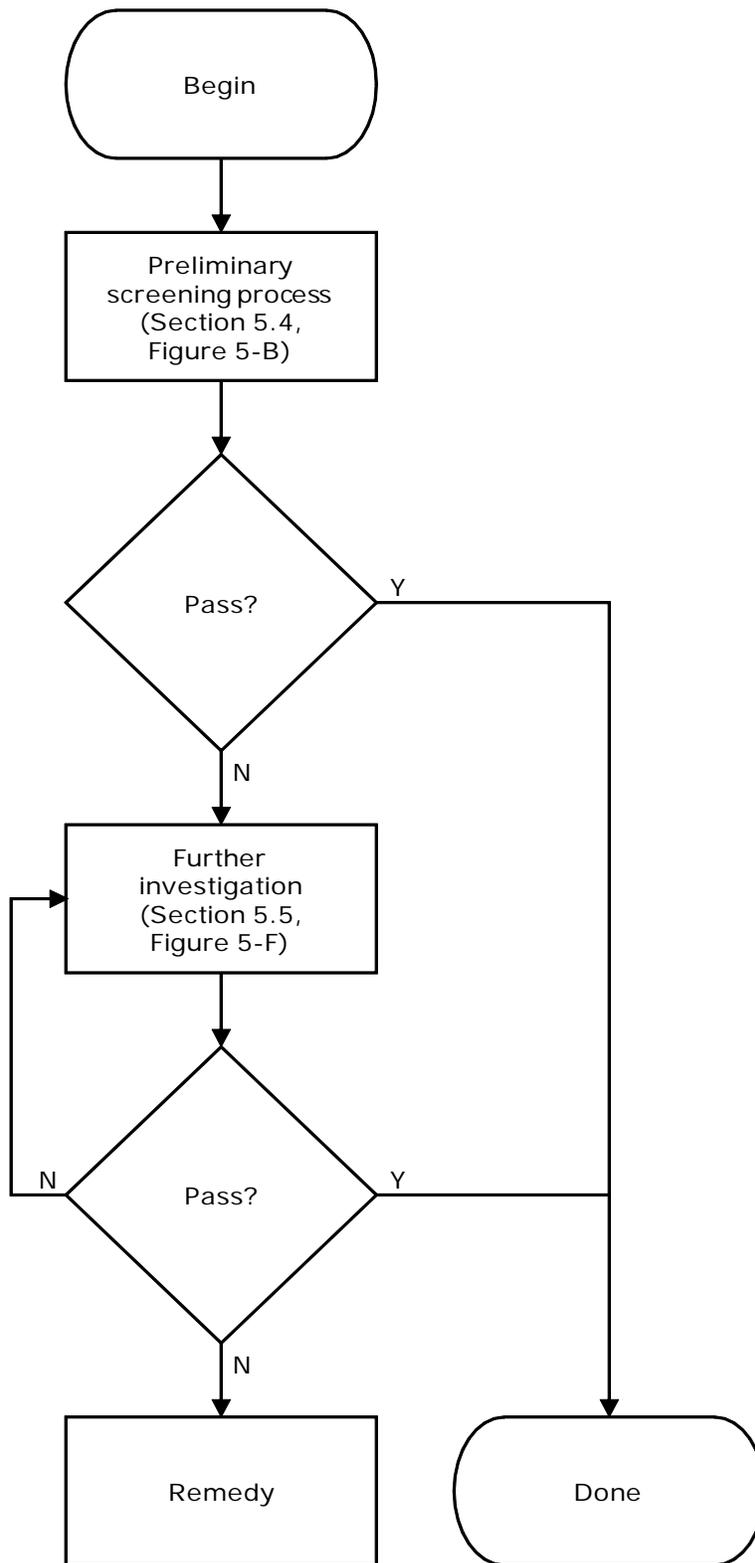
5.3 Process Overview

VI investigations are typically sequential (Figure 5-A), beginning with a preliminary screening process (Section 5.4). Preliminary screening evaluates the CSM to determine whether existing soil and/or ground water chemical concentrations may result in VI. Further investigation is appropriate where that is the case, and may show the need for additional work, or it may show that the VI pathway is incomplete and eligible for closure.

Further investigation (Section 5.5) is necessary for sites that do not screen out during the preliminary screening process. Further investigation typically begins with either SGss or CSA sampling, or paired SGss/CSA and IA sampling of potentially affected structures. SGe sampling may prove useful where interior access is not available or practical. The success of SGe sampling is dependent upon reasonable documentation of the subsurface lithology as it relates to vapor transport, particularly in heterogeneous settings.

Section 10 discusses comparison of sample results with applicable screening levels. An exceedance of the screening levels may indicate the need for further investigation or a remedy. If further investigation shows that VI does not present unacceptable present or future risk, the VI pathway is typically eligible for closure.

Figure 5-A: VI Investigation Process Overview



5.4 Preliminary Screening Process

Preliminary screening (Figure 5-B) determines whether subsurface VOCs exceed screening levels and whether preferential pathways and potentially affected buildings are present. The preliminary screening process relies on information obtained during CSM development. Conversely, the VI investigation will build LOEs useful in updating the CSM and evaluating the VI pathway.

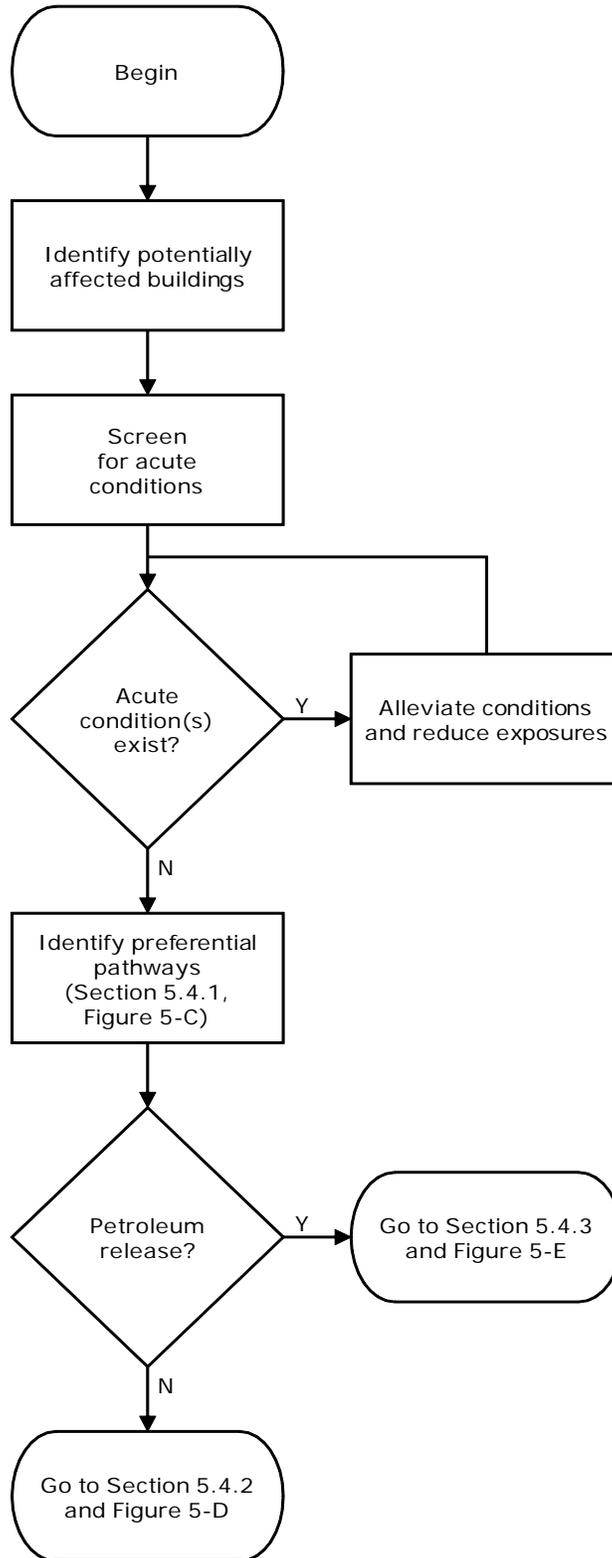
Another component of preliminary screening is the identification of structural characteristics important in vapor transport. These might include: basements (including earthen-floored basements), crawl spaces, crawl space linings, slab-on-grade construction, open sump pits or shallow ground water (less than five feet below the basement, crawl space or slab). Field instruments, such as a photoionization detector (PID) or a flame ionization detector (FID), may be useful for identifying vapor entry points and preferential pathways within a building.

Field instruments may also be useful in verifying the presence or absence of acute, explosive, or imminently dangerous conditions at a site. Where such conditions exist, the initial priority should be the immediate safety of the building occupants. This may require actions such as removal of occupants and/or immediate corrective action to reduce exposure and/or explosive hazards.

Preferential pathways are often important conduits for vapor transport. Section 5.4.1 includes additional guidance on the identification and preliminary screening of preferential pathways.

Chlorinated VOCs (CVOCs) and petroleum-related volatile chemicals generally exhibit different densities and biodegradation potential (Howard 1991; McHugh *et al.* 2010). These properties influence subsurface transport behavior in a manner that justifies preliminary screening procedures specific to each group (U.S. EPA, 2011d). Preliminary screening procedures for CVOC appear in Section 5.4.2, while Section 5.4.3 covers preliminary screening procedures for petroleum chemicals.

Figure 5-B: Preliminary Screening Process



5.4.1 Preliminary Screening Process: Preferential Pathways

In the context of VI, preferential pathways may be thought of as subsurface routes of least resistance for vapors. Vapors typically move from areas of high concentration to low concentration (diffusion), and areas of high pressure to low pressure (advection). Preferential pathways serve as a conduit that facilitates both of these processes. Examples of preferential pathways include: underground conduits and utility corridors (e.g., sewer lines, tile drains), fractured bedrock, karst geology, sump pumps, etc.

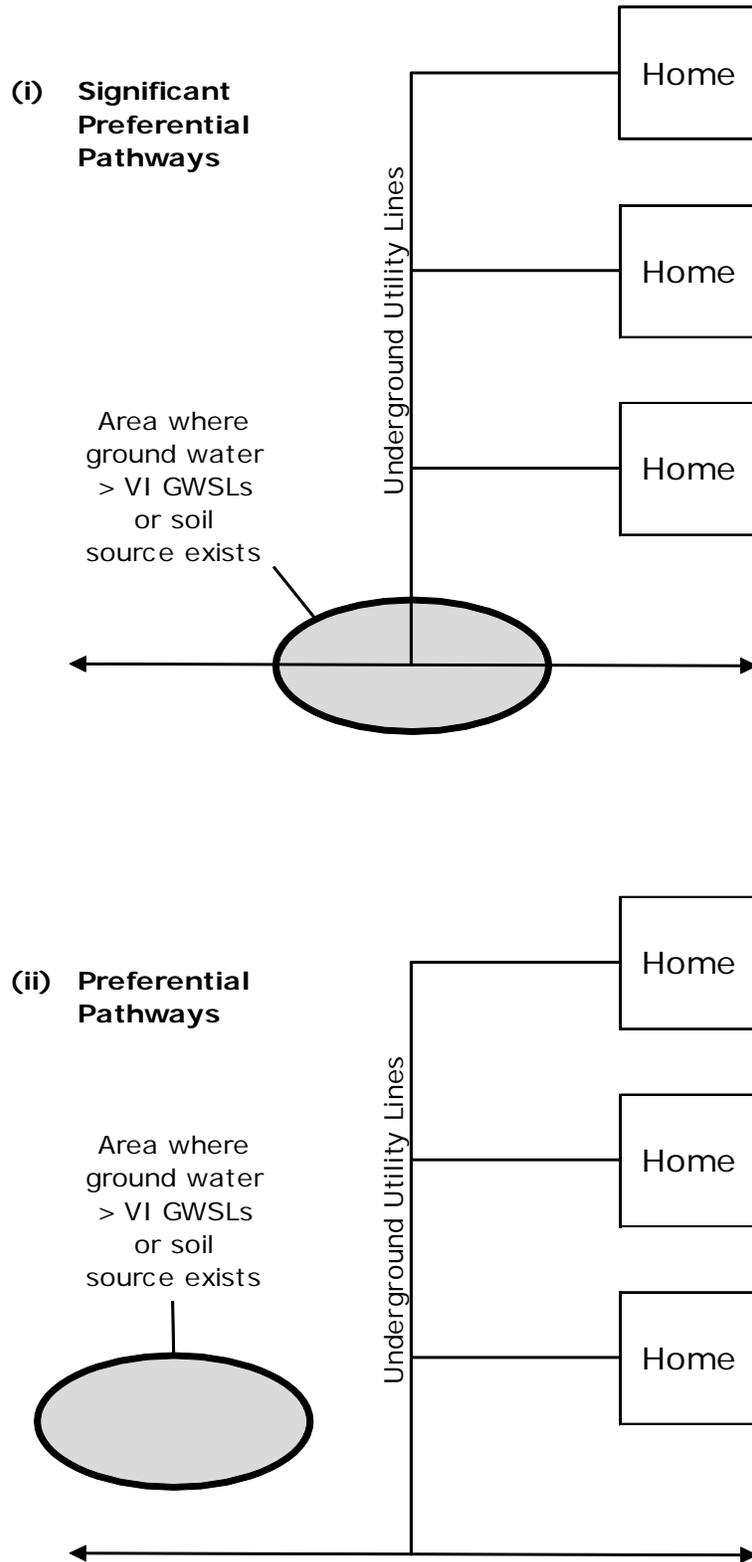
Preliminary screening should include mapping of man-made preferential pathways (e.g., utility conduits, drainage tiles, parking lots, etc.). Mapping man-made preferential pathways provides a sense of where vapors might move and whether preferential pathways may be significant.

For the purpose of VI investigations, IDEM considers a preferential pathway to be significant if it extends through *both* an area where ground water exceeds VI ground water screening levels (GWSLs) *and* a building footprint. This may include utility conduits overlying ground water that exceeds the VI GWSLs. Figure 5-C(i) illustrates a significant preferential pathway that merits further investigation (Section 5.5.1). Figure 5-C(ii) depicts a situation in which further investigation of the preferential pathway may not be necessary.

While VI investigations typically focus on the shallowest ground water interval as the VI source, soil VOC contamination may also act as a source of VI. Evaluation of soil as a vapor source requires professional judgment. LOEs relevant to evaluating the soil matrix as a potential VI source include:

- Distance of a source area from a building
- Contaminant degradation capacity
- Contaminant concentration in the soil (high, medium, low)
- Soil texture

Figure 5-C: Preferential Pathways



5.4.2 Preliminary Screening Process: Chlorinated Chemicals

Preliminary screening for chlorinated vapor intrusion (CVI) builds on the CSM with identification of significant preferential pathways (Section 5.4.1) and an assessment of distance between a CVOC source and a building (Figure 5-D). A CVI site can screen out from further consideration of VI if:

1. Buildings are more than one hundred feet from a CVOC soil source or ground water exceeding VI GWSLs (as measured at the top of the shallowest saturated zone), and
2. No significant preferential pathways are present.

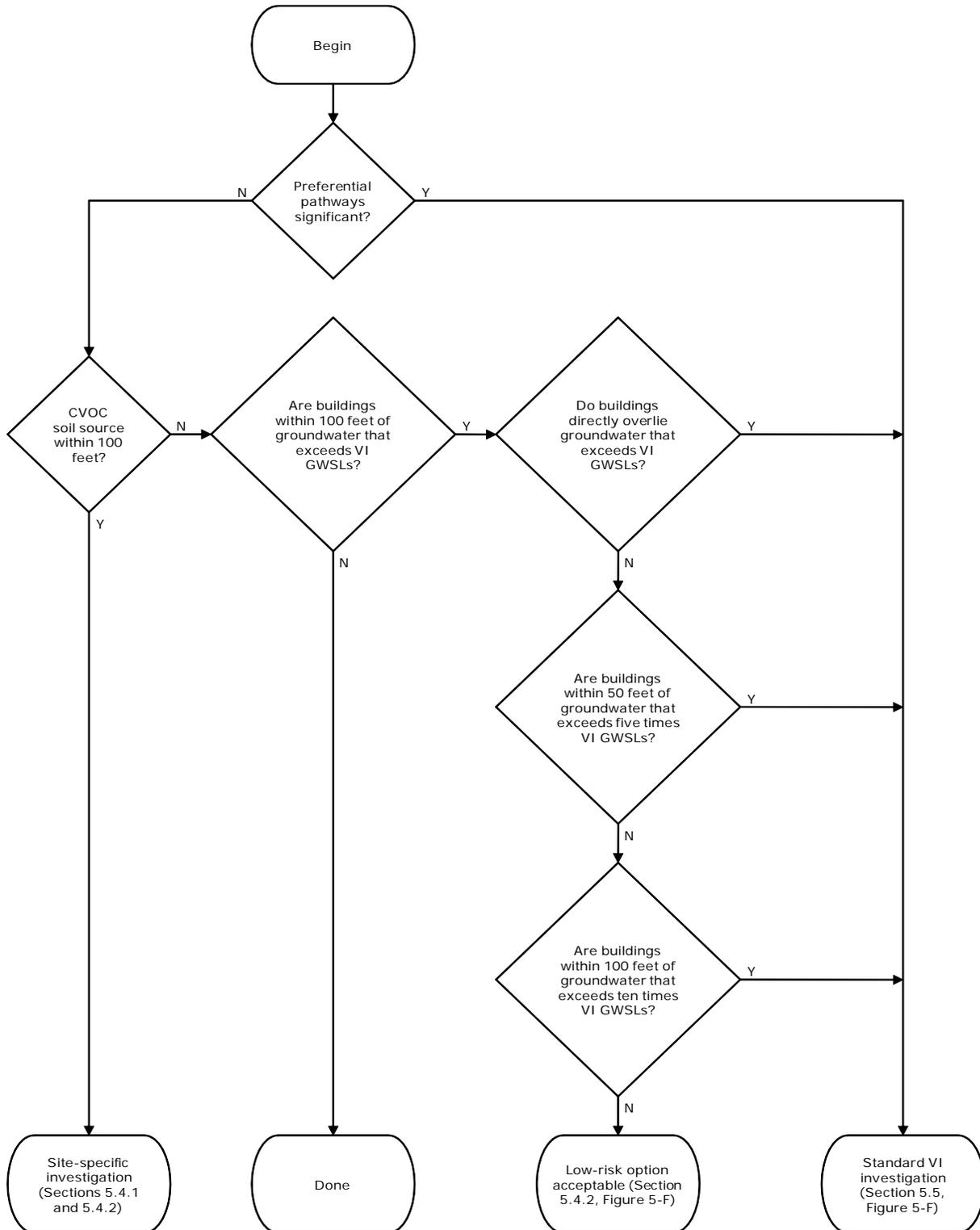
Note that soil source contamination directly underneath or near a building can indicate a higher potential for VI to occur (see Section 5.4.1 regarding LOEs). Where soil source contamination exists, work with the assigned project manager to determine whether a soil source VI investigation plan may be appropriate.

If the two screening criteria above are not satisfied, then the site can be further screened to determine if potentially affected buildings may be characterized as low risk for VI. Low risk building evaluation compares ground water contaminant measurements (measured at the top of the shallowest saturated zone) with distance-based VI GWSLs. IDEM considers a building to be low risk for VI if it satisfies the following criteria:

1. Directly beneath the building, there are no ground water CVOCs present at concentrations greater than VI GWSLs.
2. Within fifty feet of the building, there are no ground water CVOCs present at concentrations greater than five times VI GWSLs.
3. Within one hundred feet of the building, there are no ground water CVOCs present at concentrations greater than ten times VI GWSLs.
4. Any significant preferential pathways and soil source that may be present have been evaluated.

Low risk building investigation may employ SGe samples in lieu of SGss or CSA samples. However, due to the uncertainties associated with soil gas investigations, SGe sampling is only appropriate as a *stand-alone* screening tool when a building is at low risk for VI.

Figure 5-D: Preliminary Screening Process: CVOCs



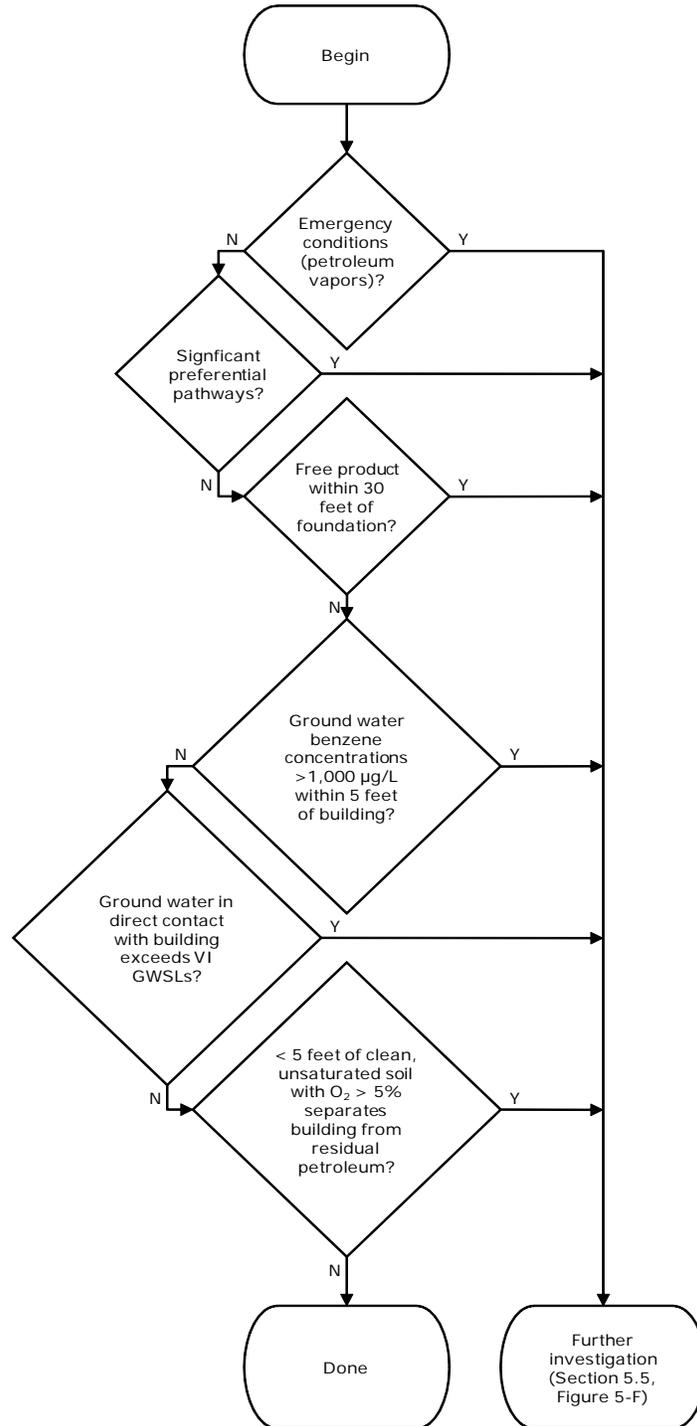
5.4.3 Preliminary Screening Process: Petroleum Chemicals

Figure 5-E illustrates a preliminary VI screening process for sites with petroleum hydrocarbon releases. Petroleum hydrocarbon vapor plumes are typically less extensive than CVOC vapor plumes. VI of benzene and other petroleum constituents occurs most often where contaminated ground water is inside a building or in contact with a building foundation, or light non-aqueous phase liquid (LNAPL) is located near a building foundation. Benzene, the petroleum constituent that drives the risk at VI sites, readily degrades in unsaturated, oxygenated soils (U.S. EPA, 2011d).

The presence of five feet (in the horizontal and vertical directions) of clean, unsaturated soil with an oxygen content greater than five percent between the petroleum contamination and the building generally rules out petroleum vapor intrusion (PVI) (Davis, 2009; Luo *et al.*, 2009). Soils in Indiana are generally sufficiently aerated if they are unsaturated and free of contamination. Therefore, further investigation of the PVI pathway is appropriate in situations where less than five feet of clean aerated soils are present, or where any of the following conditions exist:

- Emergency conditions (e.g., reports of petroleum vapors in the building)
- Significant preferential pathways
- LNAPL underlies a building or is within 30 feet, horizontally or vertically, of a building foundation
- The concentration of benzene in the shallowest ground water interval underlying a building exceeds 1,000 µg/L, or ground water in direct contact with a building exceeds VI GWSLs. Direct contact may lead to contaminant vapor migration through the foundation or actual penetration of contaminated water or LNAPL into the building. For example, a basement sump may draw contaminated ground water into the building, resulting in petroleum hydrocarbon vapor impacts to IA.

Figure 5-E: Preliminary Screening Process: Petroleum Chemicals



5.5 Further Investigation

Further investigation (Figure 5-F) is necessary at any site that does not screen out during the preliminary screening process. There are many possible approaches to further investigation of the VI pathway. The optimal approach will depend on circumstances and may change as the investigation proceeds. The RCG describes standard VI investigation procedures but allows for other site-specific investigation procedures to be proposed based on the CSM. The conclusions of a VI investigation are typically based upon relatively limited data collection to interpret a vapor flux dynamic that exhibits a high degree of variability. In most cases, a minimum of two rounds of vapor sampling is necessary to rule out the VI pathway once it has failed a screening procedure. Installation of a mitigation system in lieu of multiple sampling events is also an acceptable option, and may prove more cost effective at some sites.

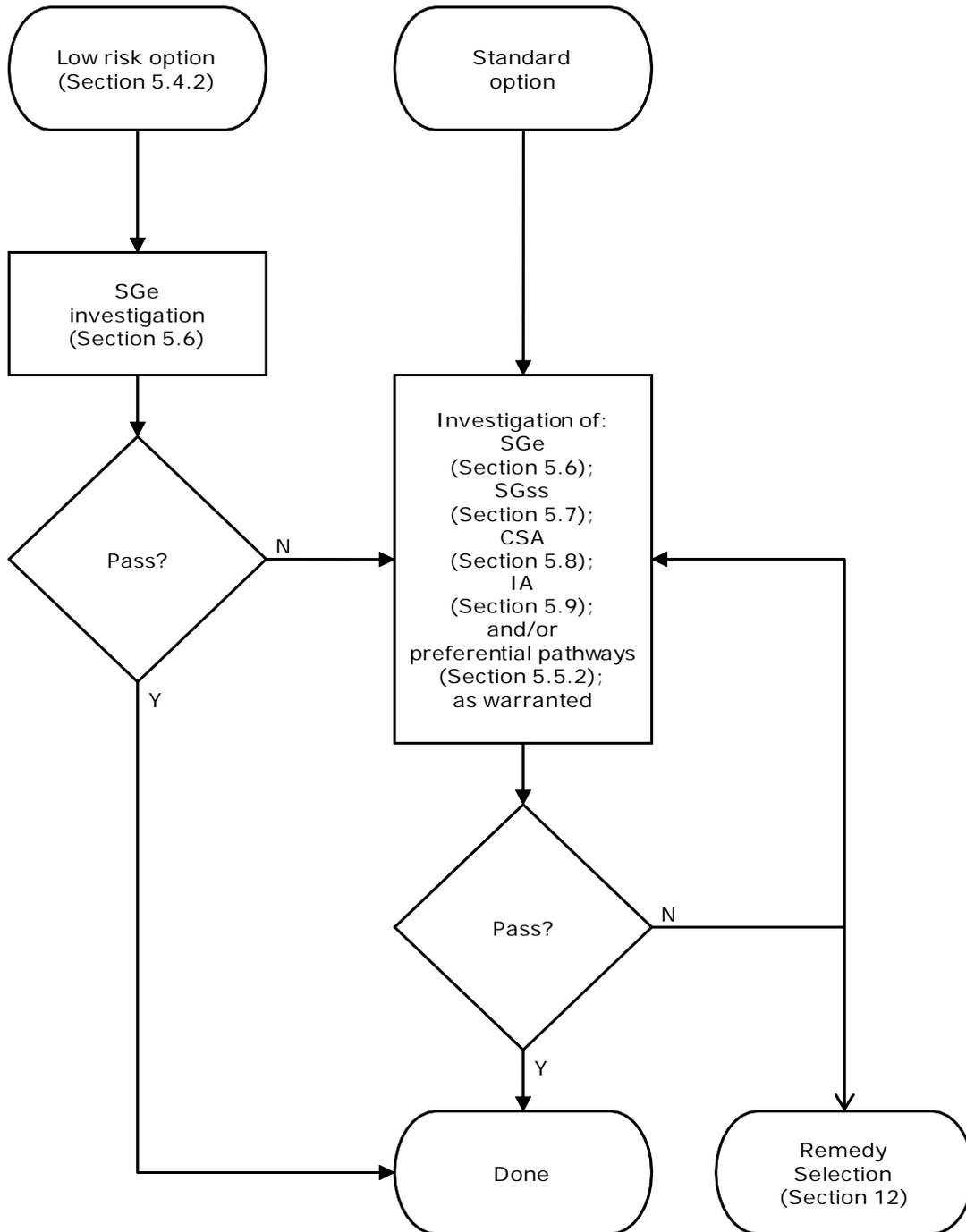
SGe sampling (Section 5.6) for stand-alone evaluation of VI risk is generally only appropriate for sites that qualify as low risk (Section 5.4.2), further investigation of undeveloped properties with potential VI issues, or preferential pathway investigations. Otherwise, IDEM recommends that further investigation begin with either SGss (Section 5.7) or CSA sampling (Section 5.8), or paired SGss/CSA and IA sampling (Section 5.9) of potentially affected buildings. If the building owner does not grant access for SGss or CSA sampling, IDEM recommends SGe or paired SGe/IA sampling.

Paired IA and SGss or CSA sampling helps establish the relationship between subsurface vapor and IA. It is a strong LOE that also helps to interpret potential sources of background contamination within the building. Other potential advantages of the paired approach include fewer SGss samples, less extensive preferential pathway evaluation, and less disturbance to building occupants.

Though paired sampling provides better information, SGss and CSA sampling may be acceptable as a stand-alone investigative tool. The stand-alone approach requires a sufficient number of samples to adequately characterize the spatial variability within the building footprint. Preferential pathways may provide a conduit for subsurface vapors to contaminate IA without significantly affecting the subsurface beneath the building (non-uniform horizontal distribution). Depending on the SGss sampling density, SGss sample results that are not paired with IA may not be sufficient to rule out VI. Preferential pathway investigations (Section 5.5.2) should include SGe evaluation wherever SGss sampling occurs without IA sampling. IDEM does not recommend sampling only IA due to inherent interpretation difficulties.

Section 10 discusses comparison of CSA, SGss, SGe, and/or IA sample results to applicable screening levels. A screening level exceedance may indicate the need for further investigation, remediation or mitigation.

Figure 5-F: Further Investigation



5.5.1 Further Investigation: Significant Preferential Pathways

Further investigation should include, where appropriate, an evaluation of significant preferential pathways. Digging or trenching (e.g., when installing underground utilities) destroys the native soil structure, and soil settlement may result in greater permeability than occurs in undisturbed natural soil. This is a special concern at sites where native soils exhibit lower permeability than backfill or bedding materials. The nature of significant preferential pathways investigations will vary according to the characteristics of the site and the sampling procedures used to evaluate VI in potentially affected buildings.

Evaluation of significant preferential pathways is critical when a building cannot be accessed for SGss, CSA, and IA sampling. Significant preferential pathway investigation can identify specific buildings within a neighborhood that warrant further VI evaluation, and may reveal how source vapors enter buildings. A significant preferential pathway investigation can also improve the placement of SGss sampling ports. Preferential pathway sampling may entail soil gas monitoring in and/or near the pathway. If a buried gas or electrical utility line is a significant preferential pathway, SGe sampling near the backfill material, rather than within the backfill material, is appropriate for safety reasons. When explosive vapors accumulate within a sewer at concentrations that could exceed the lower explosive limit, monitor vapor within the sewer and associated manholes.

Contamination in a preferential pathway is an indicator of likely VI. Any exceedance of SGss criteria in a preferential pathway may warrant further investigation.

5.5.2 Further Investigation: Sampling Procedures

Appropriate vapor sample collection procedures may vary by site and scenario. However, some procedures apply in most situations. This section describes certain sampling procedures or concepts that apply at most sites.

IDEM recommends use of summa-type canisters for vapor investigation. IDEM will evaluate alternative sampling devices and techniques on a site-specific basis. Tedlar® bags offer advantages when used with some specific sampling and analysis procedures. However, concerns over leaks, pressure changes during transport, cleanliness certification, and very short holding times (two to three hours) prevent acceptance of Tedlar® bags for general use in vapor investigations. Canisters should be batch-certified clean³⁷ and usually arrive from the laboratory equipped with flow regulators and a vacuum gauge. Laboratories typically pre-set flow regulators, so it is important to determine appropriate flow rates prior to delivery.

If the purpose of sampling is a stand-alone assessment of the VI pathway, IDEM recommends use of a fixed laboratory for sample analysis and U.S. EPA Methods TO-14A, TO-15, or TO-15 SIM (all canister-based methods). However, where use of an alternative sampling device or analytical procedure provides results of comparable quality to results using summa-type canisters and U.S. EPA methods, IDEM will consider approving such devices and techniques on a site-specific basis.

³⁷ A percentage of batch-certified clean canisters have been tested by the laboratory supplying them, and this certification is acceptable for routine air sampling and high concentration applications such as soil gas. Canisters that are individually certified clean have been separately checked by the laboratory, and are typically only needed for indoor air samples requiring high sensitivity (parts per trillion by volume).

Sorbent-type sampling devices used in active mode (air is mechanically drawn through the sorbent) with U.S. EPA Method TO-17 are generally acceptable for IA sampling (and potentially for CSA, SGss or SGe sampling) in many cases. However, due to variations in procedures and sorbent materials used, and potential site-specific complications, use of such devices should be discussed with IDEM prior to sampling.

Field duplicate samples provide information on the precision of collection procedures. Section 3.1 of U.S. EPA (2006a) provides general guidelines for collecting field duplicates. Most project sampling objectives do not require field duplicates. Where required, collect one field duplicate for every twenty samples per matrix for each method and analyze it as an independent sample.

Field blank samples provide information about sample contamination resulting from sampling equipment, sample containers, and the handling and transportation of samples. Field blanks typically consist of empty, clean, summa-type canisters, filled on-site with humidified, ultra-high purity nitrogen (or similar) gas, and then delivered to the laboratory with the other samples. Most project objectives do not require field blank analysis. However, if required, collect one field blank for every twenty samples and analyze it as an independent sample.

Where possible, avoid activities (e.g., smoking, solvent use) that may compromise analytical results. If such activities are reported during the sampling period, document them. Sample event documentation should include certification of canister cleanliness, records of regulator calibration, and evidence of appropriate chain of custody procedures. Section 3.9.1 lists appropriate analytical documentation elements.

Avoid collecting IA samples when subslab ports are being installed or opened for sampling, as doing so may bias the IA samples. Collect paired IA and SGss samples concurrently or sequentially within the same general time frame if this potential impact to IA samples is a concern.

5.6 Exterior Soil Gas (SGe) Sampling

SGe samples are whole air samples collected from within the soil or backfill matrix at locations outside the slab or footprint of a building. SGe sampling requires a borehole, usually advanced using a hand auger, hollow stem auger, or direct-push methods. IDEM prefers small-diameter (less than two inches) direct-push methods, as there is less disturbance of surrounding soils. Following installation of permanent or temporary sampling tubes in the boreholes, summa-type canisters are attached to the tubes and used to collect the SGe samples.

SGe sampling in combination with other LOEs is useful when evaluating preferential pathways, screening low risk buildings, identifying and delineating a contamination source, or estimating VI potential on undeveloped property. It is also useful when a property owner allows access for IA sampling but will not allow a hole to be drilled in the floor for collection of SGss samples. In this instance, it is better to pair the IA data with SGe data than nothing at all. Although SGe data provide important information, generally SGe sampling should not be used to estimate IA levels of contaminants, and is suitable as a *stand alone* tool for predicting IA concentrations *only* when a building meets the low risk criteria (Section 5.4.2).

5.6.1 SGe Sampling: Appropriate Conditions

Soil moisture content strongly affects migration of contaminant vapors through the subsurface (Tillman and Weaver, 2007). Wetting fronts moving downward through the unsaturated zone can cause underestimation of contaminant concentrations in SGe samples. Therefore, IDEM generally recommends waiting at least 72 hours after a significant precipitation event before collecting SGe samples. The actual amount of precipitation required to affect the movement of vapors will depend on a number of factors, including soil type, the soil moisture conditions prior to the precipitation, ground cover, and other factors that influence infiltration. Because of this, IDEM relies on the professional judgment of the consulting geologist to determine when sampling conditions are appropriate. The effect of significant precipitation can be recognized by observing high vacuum readings, extended sample collection time, and visible moisture droplets within the sampling train during sample collection. Detailed soil borings that take note of soil moisture conditions should be submitted for each soil gas sampling port installed at a site. As a general rule of thumb, for the purposes of SGe sampling, IDEM defines significant precipitation as an event yielding greater than one inch of precipitation. When evaluating the effect of water table fluctuations on VI, collect samples during a period when the water table is high and during a period when the water table is low.

5.6.2 SGe Sampling: Sample Number and Placement

IDEM recommends collecting SGe samples as close as possible to the target building (typically within five feet). This minimizes potential differences in the vapor environments beneath the building and beyond the building footprint.

Collect SGe samples from two locations near residential buildings: the side of the building closest to the ground water contamination, and the upgradient side of the building. If these two locations happen to be on the same side of the building, collect two SGe samples from separate locations on that side of the building. Given the variability involved with SGe sampling, the second location will provide additional confidence in the sample results. Professional judgment may suggest adjusting the location of the second sample to the side of the building most likely to be affected by VI, based on heterogeneities in the subsurface, building construction, etc. For large commercial buildings, a single SGe sample per side of the building is generally insufficient

to properly characterize vapor conditions in the subsurface, and additional SGe sampling locations will be necessary along multiple sides of the building.

Appropriate sample depth will depend on the vapor migration component of the CSM and the geologic material at that location. Unless site conditions dictate otherwise, IDEM generally recommends collecting SGe samples approximately five feet below the depth of the basement or building slab. SGe samples collected from depths less than five feet risk drawing ambient air (AA) from the surface into the sample, thereby biasing the results.

Sampling at multiple depths can provide important information about the movement and attenuation or degradation of vapors through the subsurface, particularly for petroleum chemicals. Deeper samples are often appropriate if the subsurface geology is complex. In these situations, IDEM recommends collecting SGe samples from multiple depths at each location, from the material most likely to transmit, or accumulate, the highest concentration of vapors.

5.6.3 SGe Sampling: Sampling Frequency and Duration

It will be necessary to collect SGe samples during appropriate conditions, in at least two distinct seasons, before an occupied building can be screened out by SGe sampling alone. If the results of the first two sampling events are contradictory or inconclusive, IDEM may request additional sampling.

Low vacuum and a low sample collection rate will minimize short-circuiting of vapors from outside the area of interest. IDEM recommends a sampling rate of 100 to 200 milliliters per minute (mL/minute) (CalDTSC/RWQCB, 2003). Approximate minimum fill times are five minutes for a one liter summa-type canister.

5.6.4 SGe Sampling: Procedures

To reduce the need for purging, SGe sampling equipment should have the smallest possible internal volume. Minimal purging reduces the risk of inducing air flow from outside the area of interest, and helps preserve sample integrity. IDEM recommends small-volume summa-type canisters (one liter) for SGe sample collection. All connections or fittings in the sampling equipment need to be tight, so no air leakage into the sample collection container occurs.

IDEM recommends installing permanent sampling ports, as this will improve the reproducibility of sample results. Calculate the volume of air in the sand pack after installing the sampling port, and use a large graduated syringe or hand-operated vacuum pump to slowly purge approximately three times the calculated volume of air immediately after installing and sealing the sampling port.³⁸ Avoid sampling for 24 to 48 hours after sampling port installation and sand pack purging, as this allows subsurface vapors to equilibrate. The SGe sampling event report should include purge volumes.

Prior to sample collection, determine the internal volume of the sampling apparatus, including the implant screen, and the tubing, but excluding the sample container volume and the sand pack volume. This dead volume of air in the sampling apparatus requires purging prior to sample collection. Slowly purge approximately three times the dead volume prior to sampling (DiGiulio, 2006). Measure and record purge volumes, which should remain consistent between sample locations.

³⁸ This should not be a large volume, assuming a small diameter borehole, a sand pack height of one foot or less, and a porosity of about thirty percent for the sand pack (DiGiulio, 2006).

To ensure that SGe samples are high quality and representative of subsurface conditions, perform a leak test prior to collecting each SGe sample. AA entering into the sample through leaks in the sampling train can ultimately bias the SGe results. Common tracers used during leak checks include: helium, propane, isopropanol, pentane, and butane. Choose a tracer that will not interfere with the analytical method for the sample. Document leak testing procedures and results in the report submitted to IDEM. See Hartman (2006), NYDoH (2006) and CalDTSC/RWQCB (2003) for detailed guidance on leak testing.

Vacuum during sampling should be as low as possible, less than or equal to 10 inches of water, and should not exceed 50 inches of water. A very slow draw rate will improve results where wet or fine-grained soils necessitate high vacuum. The SGe sampling report should include sample collection rate and vacuum readings.

5.7 Subslab Soil Gas (SGss) Sampling

SGss sampling means collection of air samples from immediately below the basement or slab of a building. The process involves drilling one or more holes through the concrete floor, placing a sleeve or probe through the concrete, and then collecting an air sample into an evacuated summa-type canister. SGss ports may be permanent or temporary, depending on the installation procedures and materials used.

IDEM considers paired SGss and IA samples best for evaluating VI potential into IA. Paired samples allow quantification of the actual increased risk from VI, while reducing concerns about potential sources of background contamination within the building. However, SGss sampling is acceptable as a stand-alone screening tool, provided there is an adequate investigation of preferential pathways and subslab spatial variability. In instances where subslab sampling is conducted without IA sampling, IDEM recommends a more structured preferential pathway investigation at each building location (e.g., one SGe sample per residence within the potential preferential pathway).

5.7.1 SGss Sampling: Appropriate Conditions

IDEM recommends collecting SGss samples during at least two different time periods to account for worst case conditions related to seasonal variability. One round of SGss samples should be collected during the winter heating season (approximately mid-November through March), when the indoor temperature is typically at least ten degrees higher than the outdoor temperature. Winter heating season SGss samples should be collected with building windows and doors closed and the building heating system in operation. Historically, the winter heating season has been considered the worst case sampling scenario for VI, because there is normally less external ventilation and building heating systems can create a pressure differential that pulls gases up from the subsurface.

A second round of SGss samples should be collected during the dry summer season. Soil moisture content and water table fluctuation may have a more significant impact on VI than winter heating season conditions. Some recent studies and professional experience show the highest transfer rates for VOCs from ground water to soil gas occur during falling water table conditions (McHugh, 2009). Generally, the water table is falling during the hot, dry summer months in Indiana (typically July through mid-September). Additionally, buildings equipped with cooling systems will have the windows and doors closed.

SGss sampling during both the winter heating and dry summer seasons accounts for seasonal variability and provides the best opportunity to capture worst case conditions. Most indoor air measurements represent a narrow “snapshot in time” because of problems with getting repeat access and uncertainty over seasonal and building variations. Due to these uncertainties and limited sampling data, IDEM recommends sampling during “worst case” conditions. Sampling during worst-case conditions provides limited exposure data that are likely to be biased high. This bias may be considered when evaluating the need for action if indoor air sampling can be conducted at a frequency that addresses seasonal and building variability. IDEM will consider alternative SGss sampling schedules, especially where sampling needs are urgent, seasonal variation is insignificant, or where building conditions, weather conditions, or other factors suggest that worst case conditions occur outside of the winter heating and dry summer seasons.

Differential pressure measurements are another LOE for evaluating VI. The difference in pressure between the IA and SGss provides a primary advective force for VI. VI will occur when

the pressure inside a building is lower than the pressure in soil gas below the building. If the pressure inside is positive compared to the subslab, there should be little or no VI potential. Cost-effective instrumentation is available to measure and log pressure differential over hours, days, or weeks using small diameter subslab sampling ports or pressure taps. These measurements can be used as an LOE to demonstrate whether worst case conditions exist during a sampling event.

5.7.2 SGss Sampling: Sample Number and Placement

Investigative goals, utility locations, owner preferences, and other practical considerations will affect the number and locations of SGss samples. Monitoring points should be installed at locations with minimal potential for AA infiltration via floor penetration (e.g., cracks, floor drains, utility perforations, sumps, etc.)

One centrally-located SGss sampling point is acceptable for most residential buildings when paired with IA sampling. Additional SGss sample locations may be necessary if the ratio of the IA to SGss results is unusually high and the data from a particular building does not compare well with data from neighboring buildings. To account for spatial variability, when collecting SGss samples with no corresponding IA samples, IDEM recommends a minimum of two SGss locations, one in the center of the building and the second near the edge of the building closest to the highest subsurface contamination.

IDEM recommends collecting three SGss samples at commercial/industrial buildings with a footprint less than 5,000 square feet, with another SGss sample added to the sampling plan for each additional 2,000 square feet. Other approaches may be necessary at large commercial/industrial buildings where this sampling density is unworkable. Alternative sampling plans should include:

- Collection of SGss samples in areas above the highest subsurface contamination
- Collection of SGss samples in areas where exposure to occupants is most likely (e.g., work areas, not closets or hallways)
- Collection of SGss samples from each building unit operating on a separate heating, ventilation, and cooling (HVAC) system

5.7.3 SGss Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway through the subslab of a building generally requires at least two rounds of SGss sampling (one during the winter heating season and one during the dry summer season). Collect the second round of SGss samples from the same locations as the first. The second sampling event is especially important when confirming SGss results used as a stand-alone determination of the VI pathway. If the results of the first two SGss sampling events are contradictory or inconclusive, IDEM may request additional sampling.

In order to minimize air infiltration, maximum flow rates through the SGss probe and related tubing should not exceed 200 mL/min during purging and sampling. Approximate minimum fill times are five minutes for a one liter summa-type canister and thirty minutes for a six liter canister. Alternative canister fill rates are possible depending on project objectives. For example, fill rates may be set to collect the SGss samples over eight or 24-hour periods, especially during concurrent collection of IA samples.

5.7.4 SGss Sampling: Procedures

While SGss sampling is conceptually simple, the actual process has numerous pitfalls and nuances that need to be addressed. U.S. EPA (2006a) is a general reference for conducting SGss sampling, suitable for use at Indiana sites, and is summarized in the following paragraphs.

IDEM recommends installing permanent SGss sampling ports to improve the reproducibility of SGss sample results at each location. U.S. EPA (2006a, Section 3.4) provides detailed guidance on construction and installation of permanent SGss monitoring ports. Materials chosen for SGss monitoring ports should be durable enough to last through multiple sampling events. Fittings should be compatible the SGss collection equipment. Minimize the number of fittings and tighten them as necessary to avoid system leaks.

Avoid sampling until the soil gas has equilibrated within the port (typically two hours). IDEM recommends one or six liter summa-type canisters for SGss sample collection.

U.S. EPA (2006a, Section 3.5) describes a procedure for collecting SGss grab samples in six liter summa-type canisters. Adjust this procedure as necessary to meet site-specific data quality objectives and to address the following recommendations:

- During colder months, building occupants should operate heating systems to maintain normal temperatures of 65-75°F for at least 24 hours prior to and during sampling.
- Purge three volumes of the sample probe and tubing immediately prior to sampling. Use a large graduated syringe or hand-operated vacuum pump to purge the sampling point. Avoid exceeding a maximum flow rate of 200 mL/min during purging and sampling in order to minimize air infiltration. Record purge volumes and include them in the SGss sampling event report.
- Document SGss sampling procedures using the guidelines outlined in Section 3.9 of U.S. EPA (2006).
- When SGss sampling is no longer needed at a particular building, remove the monitoring ports and seal the remaining holes to prevent migration of vapors through the slab.

To ensure that SGss samples are high quality and representative of subsurface conditions, perform a leak test prior to collecting each SGss sample. AA entering into the sample through leaks in the sampling train can bias the sample results and lead to artificially high or low contaminant concentrations in the sample. Common tracers used during leak checks include: helium, propane, isopropanol, pentane, and butane. Choose a tracer that will not interfere with the analytical method for the sample. Document leak testing procedures and results in the report submitted to IDEM. See Hartman (2006), NYDoH (2006) and CalDTSC/RWQCB (2003) for detailed guidance on leak testing.

IDEM is evaluating sorbent-type sampling devices for use in SGss sampling. Where such devices can provide results of comparable quality to results obtained using summa-type canisters and U.S. EPA analytical methods, TO-15 or similar, IDEM will consider approving the use of such devices and techniques on a site-specific basis.

5.8 Crawl Space Air (CSA) Sampling

SGss samples are not an option in buildings constructed over a crawl space. Such buildings will require collection of SGe or CSA samples, preferably in conjunction with IA samples and/or SGss samples (if there is a partial basement or slab). However, CSA samples may suffice in certain situations as a stand-alone method for investigating VI.

5.8.1 CSA Sampling: Appropriate Conditions

CSA samples should be collected during at least two different time periods to account for seasonal variability. Samples should be collected under the worst case conditions and time periods described in Section 5.7.1. The crawl space vents should be closed during all sampling events. IDEM will consider alternative sampling schedules, especially where sampling needs are urgent, seasonal variation is insignificant, or where building conditions, weather conditions, or other factors suggest that worst case conditions occur outside of the winter heating and dry summer seasons.

5.8.2 CSA Sampling: Sample Number and Placement

One centrally-located CSA sampling point is typically sufficient for most residential buildings. Crawl spaces are rare in commercial/industrial buildings. Such structures will require a site-specific sampling plan that includes enough samples to adequately characterize CSA concentrations. Placement of samples should take into consideration the location of the highest subsurface contaminant concentrations.

IDEM recommends collecting an AA background sample in conjunction with CSA sampling to determine whether an AA background source may be contributing to contaminant concentrations in the CSA. Measured AA concentrations should be used as a qualitative LOE, *not* directly subtracted from the measured CSA concentrations.

5.8.3 CSA Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway within a building over a crawl space requires collection of at least two sets of CSA samples, with the second set of samples collected from the same locations as the first. Additional sampling may be necessary if the results of the first two sampling events are contradictory or inconclusive.

IDEM recommends collecting CSA samples over a 24-hour period in residential buildings and over an eight-hour period in commercial/industrial buildings. However, project objectives may dictate alternative canister fill rates.

The sample duration for commercial/industrial sites should capture normal working conditions. For example, if shifts are a twelve hour period, then the samples should be collected for a twelve hour period. Alternatively, if multiple shifts occur it may be necessary to collect one 24-hour sample or two eight-hour samples.

5.8.4 CSAir Sampling: Procedures

IA sample collection procedures (Section 5.9.4) are suitable for CSA sampling.

5.9 Indoor Air (IA) Sampling

IA sampling and results interpretation are inherently problematic. For instance, it is easy to locate a sample in an area where the IA is not representative, such as where air is diluted by vents or air ducts. It is also easy to encounter elevated indoor air background (IAb) levels of the contaminant of interest. Therefore, it is often advisable to sample under conditions where exceedances of indoor air screening levels (IASLs) are most likely, and to simultaneously investigate contaminant vapor directly beneath the building. If sampling is conducted under these worst case conditions and IASLs are not exceeded, then one can be reasonably sure that there is not an IA VI problem. However, an exceedance of the IASLs under worst case conditions does not necessarily indicate a VI problem. Interpretation of IA data must also consider IAb levels and contaminant vapor concentrations beneath the building.

5.9.1 IA Sampling: Appropriate Conditions

IA samples should be collected during at least two different seasons to account for source and pressure differences associated with seasonal change. One round of IA samples should be collected during the winter heating season when building windows and doors are closed and the building heating system is in operation (approximately mid-November through March, when the indoor temperature is typically at least ten degrees higher than the outdoor temperature). Historically, the winter heating season has been considered the worst case period for VI, because there is less external ventilation (due to doors and windows being closed) and the building heating system creates a pressure differential that pulls gases up from the subsurface.

A second round of IA samples should be collected during the dry summer season. Soil moisture content and water table fluctuations may have a more significant impact on VI than winter heating season conditions. Some recent studies and professional experience show the highest transfer rates for VOCs from ground water to soil gas occur during falling water table conditions (McHugh, 2009). Generally, the water table is falling during the drier summer months in Indiana (typically July through mid-September). Additionally, buildings equipped with cooling systems will have the windows and doors closed.

IA sampling during the winter heating and dry summer seasons will account for seasonal variability and will also provide the best opportunities to capture worst case conditions. Alternative proposals should show that the effect of seasonal fluctuations is not significant, or that there is an immediate need to characterize IA conditions and evaluate current human exposures.

Differential pressure measurements are another LOE for evaluating VI. The difference in pressure between the indoor air and the soil gas in the subslab region provides a primary advective force for VI. VI will occur when the pressure inside a building is lower than the pressure in soil gas below the building. If the pressure inside is positive compared to the subslab, there should be little or no VI potential. Cost-effective instrumentation is available to measure and log pressure differential over hours, days, or weeks, using small diameter subslab sampling points or pressure taps. These measurements can be used as an LOE to demonstrate whether worst case conditions exist during a sampling event.

5.9.2 IA Sampling: Sample Number and Placement

For residential buildings, worst case IA samples are generally located in the basement or area where vapors first enter the building. Generally, IDEM recommends at least three 24-hour samples: one IA sample in the basement or assumed worst case location, one IA sample in the general living area, and one AA background sample. If the building has multiple levels, IDEM recommends one IA sample from each floor. Place summa-type canisters within the breathing zone (three to five feet above the floor) and collect the AA background sample upwind of the building.

Site-specific IA sampling plans are necessary for larger commercial/industrial buildings. When planning IA sample locations in commercial/industrial buildings, consider the following:

- Individual offices within a building.
- Individual retail spaces within a larger commercial/industrial complex.
- Areas operating under separate HVAC systems.
- Areas with higher exposure potential (where occupants spend most of their time).
- Areas above the highest subsurface contaminant concentrations.
- Areas with utility inlets.

Illustrate the location of the sample containers on a building floor plan diagram.

5.9.3 IA Sampling: Frequency and Duration

Assessing the risk posed from the VI pathway requires the collection of at least two rounds of IA samples. To minimize the variability between IA samples collected over time, collect the second round of IA samples from the same locations as the first. Pairing IA samples with SGss samples can help assess IAb issues. If the results of the first two sampling events are contradictory or inconclusive, IDEM may request additional sampling.

IDEM recommends completing IA sample collection over a 24-hour period for residential buildings and an 8-hour period for commercial/industrial buildings. Alternative canister fill rates are possible depending on project objectives. However, the fill rate must be established prior to obtaining canisters from the laboratory, since the pre-set flow regulators for the canisters are typically supplied by the laboratory.

5.9.4 IA Sampling: Procedures

To minimize the impact of IAb on IA sampling, building occupants should suspend (where practical) activities such as smoking, dry cleaning, painting, mowing, pesticide application, and the use of sprays, cleaners, and solvents, etc. prior to IA sampling. Note exceptions observed during sampling. U.S. EPA (2011c) and Commonwealth of Massachusetts (2002) contain discussions of background levels.

Pre-Sampling Activities: It is important to complete an [Indoor Air Building Survey Checklist](#)³⁹ at least 24 hours prior to IA sampling. Inspect each room and floor of the building for potential interference from background sources as well as preferential pathways. If feasible, remove possible contaminants prior to sampling. Interview occupants to gather pertinent information that may not be obvious from a building walkthrough or inspection, such as: occupation, hobbies, or activities of the occupants, or any recent home improvements.

Sample Containers: Use six-liter summa-type canisters that are either batch or individually certified clean to collect IA samples. The summa-type canisters should be equipped with flow regulators and a vacuum gauge. The flow regulator should be set to collect the air sample over the appropriate period.

Assemble and operate canisters and flow regulators according to directions provided by the laboratory performing the analysis. The following documentation must be completed as part of sample collection:

- Field records of the initial and final canister pressures, start and stop times for canister filling, and approximate fill rates.
- Records of any field measurements (ambient temperature and pressure; screening instrument results, etc.).
- Records of any leak tests.
- Documentation of canister cleaning (batch or individual certifications).

Begin Collection of AA Samples: Collect an AA sample along with IA samples to evaluate the potential impact of outdoor air on IA. Collect at least one AA sample upwind from the building(s) being sampled. Collect AA samples at least one hour prior to collecting IA samples (and SGss if collected in conjunction with IA samples). Measured AA concentrations should be used as a qualitative LOE. AA concentrations should not be subtracted from measured IA concentrations.

Quality Checks on Sampling: Follow general precautions (avoid smoking or the use of solvents, provide documentation that equipment is clean and calibrated, provide documentation of storage and transport of equipment, etc).

IA Sample Analysis: If the purpose of sampling is a stand-alone assessment of the VI pathway, use a fixed laboratory to analyze IA samples, and U.S. EPA Methods TO-14A, TO-15, or TO-15 SIM (all canister-based methods). Field laboratories and portable analytical instruments may be acceptable for the purpose of screening only on a site-specific basis.

³⁹ <http://www.in.gov/idem/files/la-073-gg.pdf>

5.9.5 Sorbent-Type IA Sampling

Sorbent-type sampling devices are being investigated for use in IA sampling. Such devices may be used in active mode (air is mechanically drawn through the sorbent) or passive mode (sorbent exposed to ambient flow). If the investigator is able to demonstrate that the use of a particular sorbent-type sampling device, along with U.S. EPA Method TO-17 or similar analytical procedure, can provide results of comparable quality to results using summa-type canisters and Method TO-15 or similar, then IDEM will consider approving the use of such devices and techniques on a site-specific basis. Sorbent-type sampling devices can be used in conjunction with summa-type canisters to gather additional data over an exposure duration suitable for each device.

Due to the variety of site-specific conditions and objectives typical of VI investigations, a broader approval of a particular, alternative sampling device or analytical technique is not possible at this time.

5.10 Indoor Air Background (IAb)

Atmospheric and indoor chemical sources may complicate interpretation of IA sample results. Many VOCs common to environmental investigations are present in tobacco smoke, cleaning supplies, craft and hobby supplies, stored fuels, and other common household products, and may exceed chronic screening levels for chemicals such as benzene, carbon tetrachloride, chloroform, methylene chloride, and PCE. For this reason, it is important to assess IAb sources and concentrations at a site when evaluating the VI to IA pathway. For more information, see the U. S. Department of Health and Human Services [Household Products Database](#).⁴⁰

The following LOEs are useful when determining whether IA chemicals are attributable to background sources or subsurface contamination:

- [Indoor Air Building Survey Checklist](#)⁴¹
- AA samples
- Concentration gradients within a building
- SGss to IA concentration ratios
- Individual contaminant ratios across media
- Presence of indicator chemicals
- Use of radon as a tracer gas to determine a site-specific attenuation factor

Indoor Air Building Survey Checklist

Before sampling IA, conduct a detailed inspection of the building's contents and survey occupant activities. Identify the presence of common household items (e.g., cleaning supplies, craft and hobby supplies, and fuels) that contain VOCs common to the release, as well as recent activities such as dry cleaning, or home improvements (e.g., painting or new carpet) that may contribute to exposures. See IDEM's [Indoor Air Building Survey Checklist](#)⁴¹ (Appendix IV) or U.S. EPA (2002a) for examples of building surveys.

AA Samples

AA sources (e.g., nearby manufacturing plants, dry cleaning facilities, etc.) may contribute to IA concentrations. When evaluating this possibility, collect at least one outdoor upwind AA sample, concurrent with the IA samples. The AA sample can serve as a reference for background conditions and allow comparison to IA results. Measured AA sample concentrations should be used as a qualitative LOE. AA sample concentrations should not be directly subtracted from the measured IA concentrations.

Concentration Gradients within a Building

Sampling may reveal contaminant concentration gradients or hot spots within a building. Concentration gradients between floors inside a building with higher concentrations in basements or lower levels may be consistent with subsurface VI or a preferential pathway; gradients with higher concentrations on upper floors may suggest an interior source.

⁴⁰ <http://householdproducts.nlm.nih.gov/>

⁴¹ <http://www.in.gov/idem/files/ia-073-gg.pdf>

SGss to IA Concentration Ratios

SGss to IA concentration ratios can be used to characterize potential VOC migration and attenuation from SGss to IA. This comparison may help determine whether IA VOCs originate in the subsurface or may be the result of indoor and/or ambient sources.

Most completed VI pathway conditions are characterized by VOC concentrations that are higher in SGss vapors than in IA. When IA VOC concentrations are higher than SGss VOC concentrations, there may be a background (indoor and/or ambient) source. Alternately, this could indicate the effect of a preferential pathway that is not properly represented by the SGss sample location(s).

Individual CVOC Ratios Across Media

Evaluating the ratio between ground water, SGss, and IA CVOC concentrations may distinguish between VI contributions and background sources. The primary CVOCs (tetrachloroethene and/or its degradation products) have similar properties related to the physical transport process. The individual CVOCs that comprise a gas mixture in SGss should enter a building at similar rates, and therefore be present at roughly the same ratios in IA as in the SGss. A notable difference in the CVOC ratios between SGss and IA may be attributable to IAb sources. Conversely, if the ratios of contaminants in the IA samples are similar to the ratios observed in the SGss samples, it can be presumed that the two are linked and there is a direct contribution from the subsurface source. Even if the ratio analysis suggests that indoor or ambient sources are likely responsible for some contribution to IA CVOCs, subsurface sources may also be contributing CVOCs to IA concentrations, especially if the SGss concentrations are much higher than concentrations in IA. In that case, the need for further investigation of background contributions should be determined through a balanced assessment of available LOEs.

Comparing contaminant ratios in ground water to IA may be a LOE; however, the value of this LOE depends on:

- Chemical-specific adjustment of relative volatility ratios using Henry's Law constants
- Adequate understanding of the ground water plume in the building vicinity
- Adequate investigation of preferential pathways
- Chemical-specific diffusion rates through the vadose zone
- Biodegradation

Indicator Chemicals

An indicator chemical is a substance that is associated with the subsurface contamination, but not background sources. *Cis*-1,2-dichloroethene, *trans*-1,2-dichloroethene, 1,1-dichloroethene, and 1,1-dichloroethane are common chlorinated break down products that are rarely found in background sources (U.S. EPA, 2011c).

The presence of indicator chemicals in IA samples is a good indication that infiltration is occurring and that SGss is the source of the observed contaminants. The opposite may also be true. The absence of an indicator chemical in IA that is present in SGss may indicate that little contamination is coming from the subsurface, suggesting that any air contaminants observed are from background sources.

Use of Radon as a Tracer Gas to Establish a Site-Specific Attenuation Factor

Some literature supports the use of radon as a tracer gas to estimate attenuation rates of SGss to IA. If IAb sources are suspected of contributing to IA sample concentrations, SGss and IA radon measurements can be taken to predict building-specific SGss to IA attenuation factors. The site-specific attenuation factor calculated by the radon measurements can be compared to the site-specific attenuation factor calculated by the VOC measurements. A good correlation of the two site-specific attenuation factors indicates that subsurface contamination is contributing to the IA concentrations. If the two site-specific attenuation factors do not correlate well, this may indicate that background sources are contributing to the IA concentrations.

5.11 Investigating Properties without Existing Structures

Properties with residual soil and/or ground water contamination may pose a threat of vapor exposure if buildings are constructed in the future. The potential for future exposure can be assessed through methods such as SGe sampling, ground water sampling, and flux chambers measurements. It may be appropriate to address the potential for vapor migration at a property without a building by incorporating vapor controls into the new building design, such as a vapor barrier with passive or active venting. In many cases, IDEM's closure conditions will include an Environmental Restrictive Covenant (Section 12) that requires including vapor control measures in the new building design. If the building will be constructed at some point in the distant future, the property owner may conduct further evaluation of the VI pathway at that time to determine if building control measures are needed.

5.12 Key Elements

VI evaluations should include information on the following as appropriate:

1. Source Area
 - a) VOC contaminated environmental media (e.g., soil, ground water, both)
 - b) Potential migration characteristics (e.g., stable, increasing, decreasing) of contaminants
2. Geology/Hydrogeology
 - a) Heterogeneity/homogeneity of soils and the lithologic units encountered and the expected/observed contaminant migration, including depth and lateral continuity of any confining units that may impede contaminant migration and/or highly transmissive units that may enhance contaminant migration
 - b) Distinct strata (soil type and moisture content, e.g., moist, wet, dry) and the distance between the vapor source and ground surface
 - c) Depth of vadose zone, capillary fringe, and phreatic (saturated) zone
 - d) Ground water characteristics (e.g., seasonal fluctuation, hydraulic gradient), including the relationship between the water table and well screening intervals, presence of any lens of clean ground water overlying contaminated ground water, or presence of a lens of clean ground water overlying ground water showing contamination that exceeds VI GWSLs.
3. Site Characteristics
 - a) Potential contaminant sources
 - b) Distance from the edge of ground water plume or other source to building
 - c) Surface cover between the vapor source area and the potentially impacted building
4. Preferential Pathways
 - a) Presence of fractured bedrock or karst geology in the area
 - b) Map showing the location of any underground utilities, underground process piping near contaminated soil or ground water, with particular emphasis on utilities or process piping that connect(s) contaminated areas to occupied buildings.
5. Buildings (Potential Receptors)
 - a) Map of existing and potential future buildings
 - b) Occupancy and use of existing buildings (e.g., residential, commercial/industrial). Interviews may be necessary to obtain this information
 - c) Building construction details, including:
 - i. Materials (e.g., wood frame, block)
 - ii. Openings (e.g., windows, doors)
 - iii. Elevator shafts (if any)
 - iv. Height (e.g., one story, two story, multistory)
 - d) Foundation construction details, including:
 - i. Type (e.g., basement, crawl space, slab on grade)
 - ii. Floor construction (e.g., concrete, dirt)
 - iii. Depth below grade

- iv. Any vulnerable characteristics of potentially affected buildings, such as earthen-floored basements, unlined crawlspaces, open sump pits or shallow ground water (less than five feet below the basement, crawlspace, or slab)
- e) HVAC system construction details, including:
 - i. Type (e.g., forced air, radiant)
 - ii. Equipment location (e.g., basement, crawl space, utility closet, attic, roof)
 - iii. Source of return air (e.g., inside air, outside air, combination)
 - iv. System design considerations relating to IA pressure (e.g., positive pressure is often the case for commercial buildings)
 - v. SGss ventilation systems or moisture barriers present on existing buildings, or identify building- and fire-code requirements for SGss ventilation systems (e.g., for methane) or moisture barriers below foundations

CSM Development: Background and Off-site Sources

6.1 Introduction

Sometimes all or part of the contamination at a site is not a result of site activities. For example, contamination may be naturally occurring, or may originate from off-site sources. The origin of contamination is important because the Indiana Department of Environmental Management (IDEM) does not routinely ask responsible parties to address contamination that did not arise from the subject site's activities.

There are many possible approaches to background evaluations, and IDEM will evaluate each demonstration for sound methodology and scientific validity consistent with United States Environmental Protection Agency (U.S. EPA) guidance (U.S. EPA 2002, 2007). This section provides example procedures and general guidelines for background and off-site source demonstrations.

These procedures rely critically on an adequate understanding of the site, as reflected in a conceptual site model. Essentially, they compare chemical concentrations found on-site with those found off-site. It is usually appropriate to eliminate a site from consideration as a source when chemical concentrations on-site are less than or equal to background concentrations. Conversely, on-site concentrations that exceed background concentrations suggest that the site may be a source.

6.2 Applicability

Most sites will not require a background or off-site source demonstration. However, this section may prove useful when attempting to show that contamination at a site did not arise from site activities. Guidance in this section may also apply when evaluating naturally-occurring site characteristics (e.g., soil fraction of organic carbon, soil pH, etc.) important in calculating site-specific screening levels.

While some of the guidance provided in this section may be applicable to the design of studies to develop regional or state-wide background screening levels, it was not written with that purpose in mind. IDEM recognizes the potential value of regional or state-wide background studies as a cost-effective approach for many smaller sites, and welcomes the opportunity to collaborate with stakeholders in the design and execution of such studies.

6.3 Definitions

There are two types of background: naturally occurring background and anthropogenic background. U.S. EPA (2002) defines **naturally occurring background** as substances present in the environment in forms that have not been influenced by human activity (e.g., arsenic in New Albany shale). U.S. EPA (2002) defines **anthropogenic background** as natural and human-made substances present in the environment as a result of human activities not specifically related to the site in question [e.g., lead and polyaromatic hydrocarbons (PAHs) deposited onto urban soil by vehicular exhaust]. The **background threshold value (BTV)** is an upper limit estimate of the background contaminant concentration (either naturally occurring or anthropogenic) used to represent environmental contaminants not specifically related to the site under investigation.

An **off-site source** is an identifiable localized point source outside the site of interest that contributed contamination to the site. (e.g., chlorinated solvents from a dry cleaner impacting a neighboring business that has no history of using those solvents). An off-site source demonstration employs the CSM approach to show that the site is not the source or is not the sole source of the contamination under investigation.

6.4 Background in Soils

Methods used to characterize background concentrations do not generally depend on the type of background substance (U.S. EPA, 2002). Therefore, this guidance does not differentiate between suggested procedures according to naturally occurring or anthropogenic substances.

6.4.1 Background in Soils: Selecting a Background Reference Area

A **background reference area** is the area where background samples are collected for comparison with samples collected on site. The background reference area should have physical, chemical, and geological characteristics similar to those of the site under investigation. It should also have virtually no impacts from site activities (U.S. EPA, 2002).

Possible background reference areas, subject to landowner approval, include public lands, woodlots, permanent pasture, or unused portions of cemeteries. Background reference areas are not necessarily limited to natural areas undisturbed by human activities. It may be difficult to find a suitable background reference area in an industrial complex. While background reference areas are normally selected from off-site areas, in some cases a non-impacted on-site area may be suitable as a background reference area (U.S. EPA, 2002). Because selection of a background sampling location is a matter of professional judgment, it is advisable to obtain concurrence from IDEM staff prior to obtaining background samples. It is not appropriate to bias the background data by sampling locations suspected to have high contaminant concentrations. For instance, soil lead concentrations along a major highway may not be representative of anthropogenic lead concentrations in a residential neighborhood. However, it is appropriate to collect some (but not all) background samples along roadways of a size typical for the site location (e.g., along a residential street if the site is in or adjacent to a residential neighborhood).

IDEM recommends using background reference areas within a two-mile radius for small to medium-sized sites if relevant background locations are present within this radius, although a greater radius may be necessary for larger sites. Samples collected beyond that distance may not have similar physical, chemical, or geological characteristics, and they may have been subject to different anthropological influences than the source area.

The following may not be suitable as background reference areas:

- Areas where hazardous substances, petroleum, solid or hazardous waste or waste waters are known or suspected to have been managed, treated, handled, stored, or disposed.
- Areas affected by roadway or parking lot runoff or road spray when evaluating chemicals associated with motor vehicles (e.g., lead or PAHs).
- Railroad tracks, right-of-ways or other areas affected by their runoff when evaluating chemicals associated with railroads and right-of-way maintenance.
- Storm drains or ditches presently or historically receiving industrial or urban runoff.
- Fill areas - unless the site under investigation is on similar fill, or IDEM agrees that the fill area is a valid background reference area.⁴²

6.4.2 Background in Soils: Sampling Background Reference Areas

IDEM follows U.S. EPA in recommending eight to ten or more samples for determining a BTV (U.S. EPA, 2007). In some cases, more than ten samples may be necessary to support a background demonstration, depending on methodology and site characteristics. Investigators should document that the number of samples is adequate to support the selected method. Because the data evaluation process sometimes reduces the size of the set of background samples, it may be prudent to collect extra samples during the initial sampling effort.⁴³

Representative background samples should come from equivalent stratigraphic positions in background reference areas comparable to the site. Suitable areas are (1) free of the influence of nearby sources of the contaminants under investigation, and (2) underlain by the same soil layers as the source area.

⁴² Fill in this context refers only to clean fill or fill that is excluded from the requirements of the solid or hazardous waste management regulations. Waste fill is beyond the scope of this guidance.

⁴³ Sometimes it is possible for the laboratory to hold samples for future analysis, subject to need and method holding times.

6.4.3 Background in Soils: General Statistical Considerations

Many different statistical methods can be applied to background demonstrations. IDEM will evaluate statistical treatments of background data for sound methodology and scientific validity using the following general considerations:

- Does the statistic used to calculate a BTV provide an appropriate standard of comparison considering the on-site sampling scheme (e.g., judgmental versus systematic)? For example, a BTV calculated as the 90th percentile (upper end of background range) provides a suitable value for point-by-point comparison to on-site samples judgmentally selected to represent the upper range of on-site concentrations (see example in Section 6.4.5). Similarly, the maximum non-outlier value of a small sample set provides an estimated BTV representing the upper end of the background range for comparison to judgmental on-site samples (see Section 6.4.7). Alternatively, a BTV calculated as the 95% upper confidence limit of the mean (UCL) provides an apples to apples comparison to the 95% UCL of the mean of systematic on-site samples (see Section 6.4.6).
- Are the requirements of the statistical test met? For example, verifying that data are normally distributed is a necessary precursor to using many parametric statistical tests (U.S. EPA 2002, 2007).
- Do multiple independent statistical methods that compare the site versus background support the conclusions of the demonstration? For example, U.S. EPA (2007) notes that statistical methods should always be supplemented with appropriate graphical displays.
- Are data transformations and back-transformations applied appropriately? For example, data sets with nondetect values can have unacceptably large transformation bias and lead to incorrect decisions (U.S. EPA 2007).
- Has the statistical methodology been shown to have sufficient power to support decision making?

ProUCL⁴⁴ addresses many of these considerations and recommends the appropriate statistic based on the characteristics of the data set.

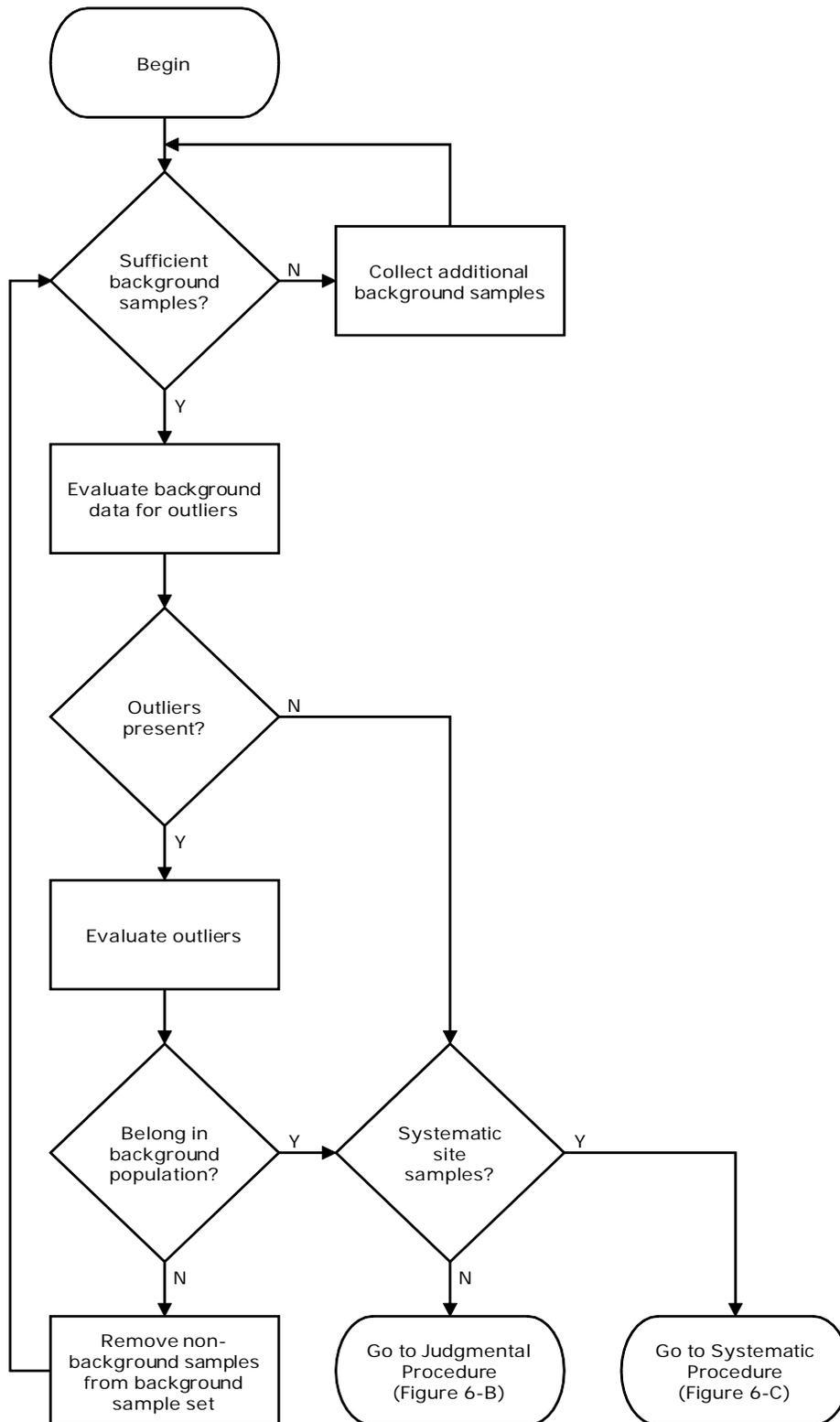
6.4.4 Background in Soils: Background Data Outlier Test

Analysis of background data begins with an outlier test (Figure 6-A). It is important to verify the presence of outliers using appropriate outlier tests and graphical displays before making a final decision to remove them. Graphical displays of a data set (e.g. Q-Q plot) may provide insight that may not otherwise be clear by looking at simple test statistics (U.S. EPA 2007). IDEM will evaluate outlier tests consistent with recent EPA guidance (U.S. EPA 2002, 2007).

A BTV is calculated from the remaining background data using the appropriate methodology according to the sample collection scheme for site samples - judgmental sampling (Section 6.4.5) or systematic sampling (Section 6.4.6). As always, IDEM will evaluate alternative proposals on their merits.

⁴⁴ *ProUCL* is a software application that can perform the necessary calculations and recommend an appropriate UCL. *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 6-A: Outlier Evaluation



6.4.5 Background in Soils: BTV Comparison to Judgmental Samples

Figure 6-B illustrates an example procedure for comparing a background data set to site samples collected under judgmental sampling. IDEM will evaluate alternative approaches consistent with recent U.S. EPA guidance (U.S. EPA 2002, 2007).

Example Procedure:

The BTV is the 90th percentile of the background sample set *after* addressing outliers. See the example calculation below. Compare the BTV to each on-site sample. If no on-site sample exceeds the BTV, it is reasonable to conclude that the on-site contaminants are background. On-site samples that exceed the BTV warrant further evaluation. Exceedances may indicate an area contaminated by site activities above background levels - particularly if they are significantly higher than the BTV or spatially concentrated. Samples only minimally above the BTV and scattered across the site may still be within the range of background.

The results of this comparison should be presented in the CSM along with the basis for any professional judgment and interpretation.

Example Calculation:

Calculate the 90th percentile of the background data set as follows:

1. Multiply the number of data points by 0.9 to find the position of the 90th percentile.

Example: 12 data points X 0.9 = 10.8 (position of the 90th percentile)

2. Arrange the individual data points in ascending order of their concentration values

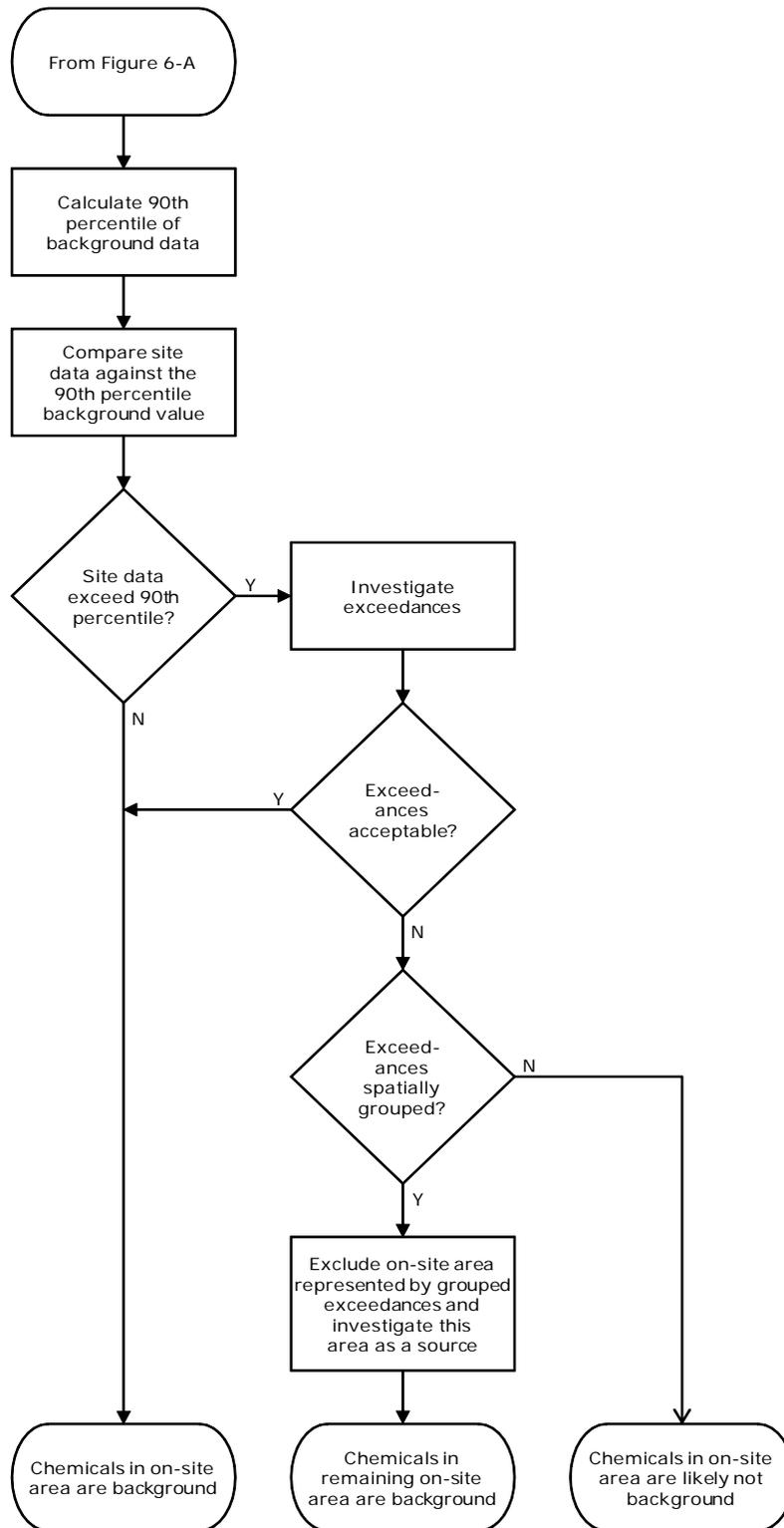
Example: 2, 5, 7, 12, 14, 16, 20, 23, 25, 27, 29, 32

3. Calculate the concentration corresponding to the 10.8th position as the value of the 10th position plus 80% of the difference between the 10th and 11th values:

$$27 + 0.8 \times (29 - 27) = 27 + 0.8 \times (2) = 27 + 1.6 = 28.6 \sim 29$$

Compare the 90th percentile concentration value (29, in the example) against each on-site data point.

Figure 6-B: Background Evaluation under Judgmental Sampling



6.4.6 Background in Soils: BTV Comparison to Systematic Samples

U.S. EPA's ProUCL software includes background comparison tools that are useful for comparing background sample sets to site samples collected under systematic sampling schemes. ProUCL applies several methodologies to each analysis and then recommends the appropriate statistic depending on the characteristics of the data. This capability helps to address the considerations discussed in Section 6.4.3.

Alternatively, the rest of this section provides an example procedure for comparing a background data set to site samples collected under systematic sampling schemes (Figure 6-C). IDEM will evaluate other approaches consistent with recent U.S. EPA guidance (U.S. EPA 2002, 2007).

Example Procedure:

When comparing the background data set to site samples collected under systematic sampling schemes, methods for calculating the BTV differ depending on whether the background data set contains nondetect values. For both methods the first step is to pool the background sample data (eight or more samples) and evaluate the data for the presence of outliers using the guidelines in Section 6.4.4. After addressing the disposition of potential outliers, evaluate the remaining results to determine whether they include any nondetect values.

For background sample sets that *do not* contain nondetect values, calculate the 95% UCL of the background data set using Hall's Bootstrap.⁴⁵ Use this UCL as the BTV, and compare it to the mean of the on-site samples for the area being evaluated. If the mean of the site samples is less than or equal to the BTV, the on-site contaminants are background. If the mean of the site samples is greater than the BTV, then the site samples may indicate contamination above background levels.

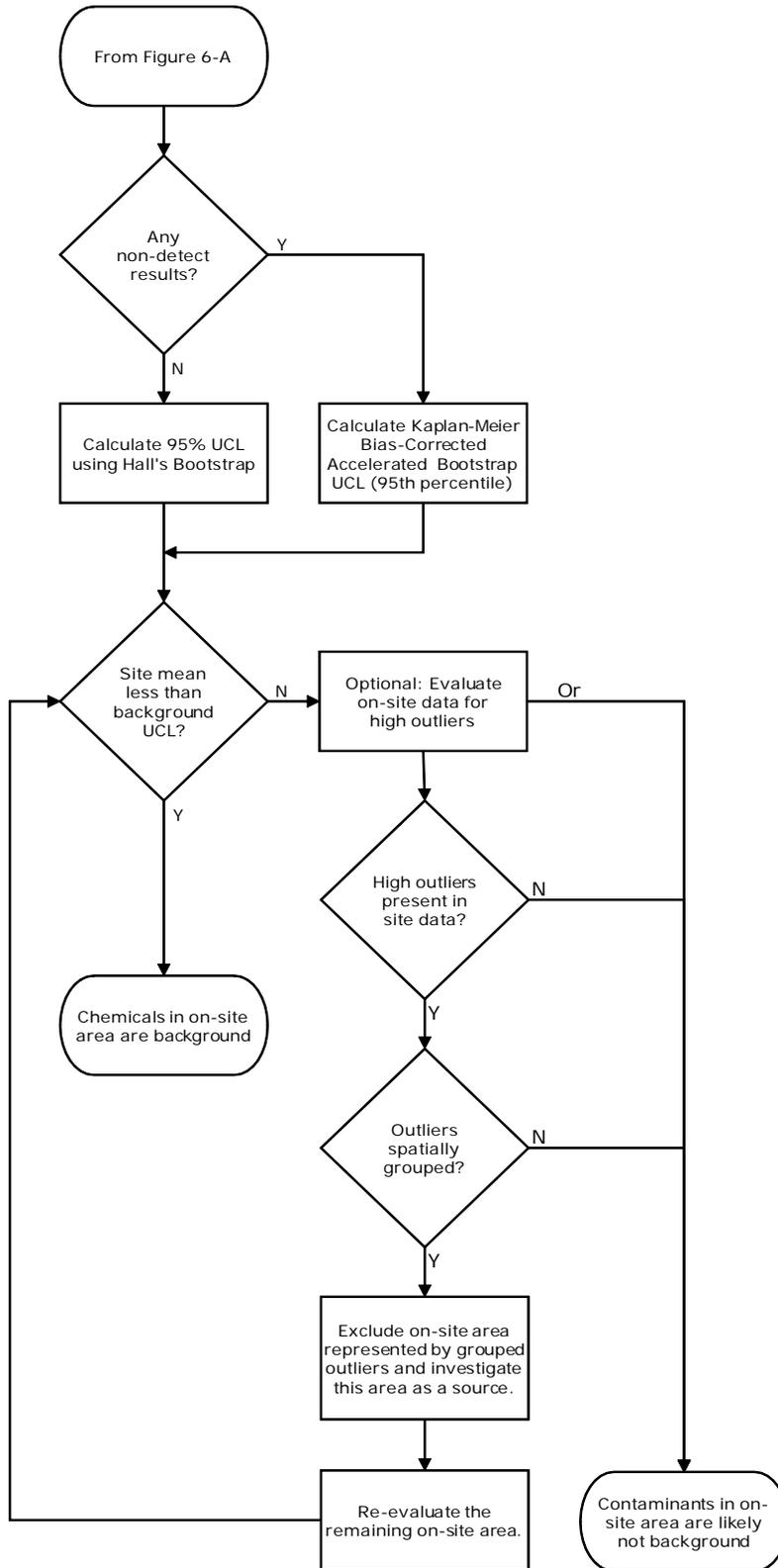
If the background data set *does* contain nondetect values, calculate its Kaplan-Meier Bias-Corrected Accelerated (BCA) Bootstrap UCL (at the 95th percentile).⁴⁵ As before, use this UCL as the BTV, and compare it to the mean of the on-site samples. If the mean does not exceed the BTV, it is reasonable to conclude that the on-site contaminants are background.

If the on-site mean exceeds the BTV for either method, investigators may want to evaluate *on-site* samples for high outliers using the guidelines in Section 6.4.4, or other appropriate methods. High outliers may indicate an area contaminated by site activities above background levels if they are spatially concentrated. If there are no outliers in the on-site samples or the outliers are not spatially grouped, then the entire evaluation area is likely contaminated above background levels. If there is an area of grouped outliers in the site data, it may be useful to exclude that area from the background evaluation, and focus further investigation or remediation efforts in that area. The remaining area can then be reevaluated for background. Calculate the mean of the remaining on-site data for comparison to the BTV.

The results of this comparison should be presented in the CSM along with the basis for any professional judgment and interpretation.

⁴⁵ ProUCL can perform this calculation. IDEM recommends using the latest version of ProUCL and selecting the maximum of 10,000 bootstrap operations for this calculation.

Figure 6-C: Background Evaluation under Systematic Sampling



6.4.7 Background in Soils: Small Background Sample Sets

Many small remediation sites have difficulty obtaining the requisite number of background samples for a statistical determination of a BTV - particularly given the necessity of collecting background samples from appropriate locations (Section 6.4.1). This section provides an example procedure for estimating the BTV from small background sample sets for comparison to on-site samples (Figure 6-D).

IDEM will evaluate alternative proposals consistent with recent U.S. EPA guidance (U.S. EPA 2002, 2007). Since the influence of a high outlier could be disproportionate in a small sample set, appropriate methods should have a conservative bias.

Example Procedure:

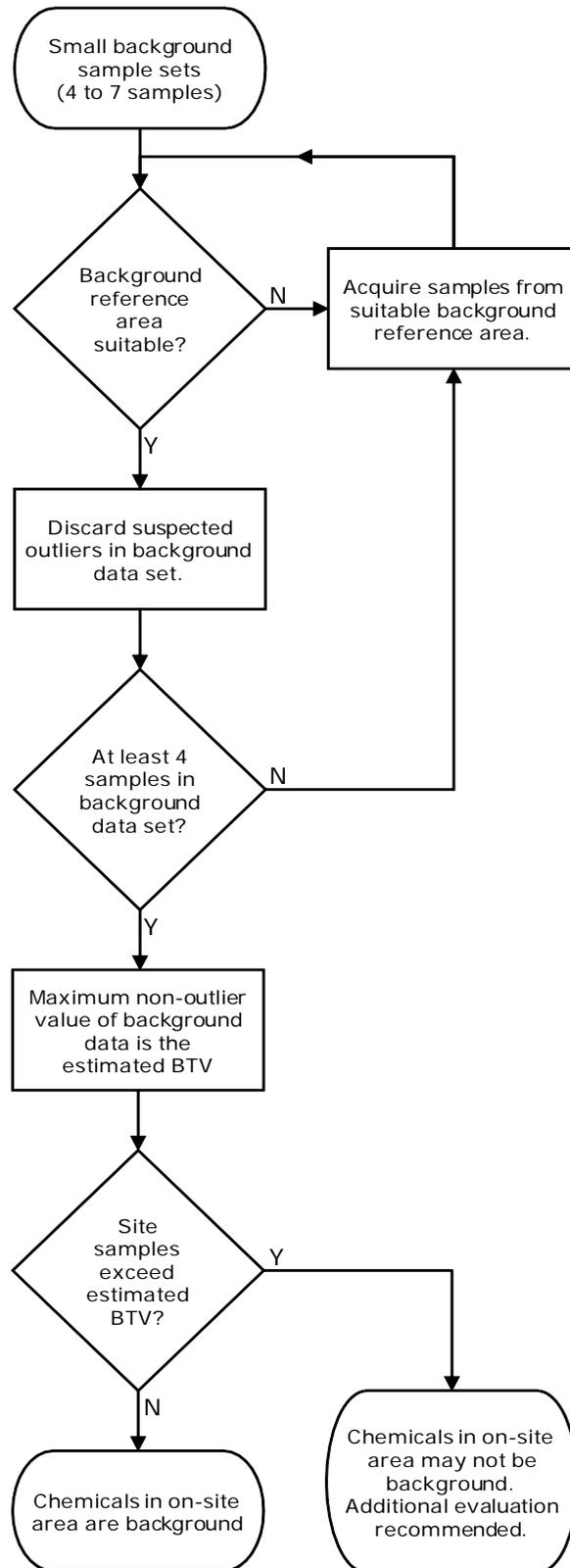
For data sets containing four to seven samples, IDEM recommends using professional judgment to evaluate the suitability of the background reference area and to evaluate suspected outliers. If the background reference area is suitable, an estimate of the BTV may be made from a background sample set with a minimum of four non-outlier values. If the background reference area is questionable or the background sample set contains fewer than four values it may be necessary to acquire additional background data. IDEM recommends using the procedures in Sections 6.4.5 or 6.4.6 when eight to ten or more samples can be obtained.

For small sample sets, the estimated BTV is the maximum value of the background sample set. The estimated BTV is compared point by point to the on-site samples. If the on-site sample(s) exceed the estimated BTV, the site may be a source, and it may be advantageous to acquire additional background data sufficient to calculate a BTV using the procedures in Section 6.4.5 or 6.4.6.

When using this procedure to determine a representative site-specific value for the fraction of organic carbon, pH, synthetic precipitation leaching procedure (SPLP) or other soil characteristic for use in calculating a site-specific closure level, the median value of the sample data should be used.

The results of this evaluation should be presented in the CSM along with the basis for any professional judgment and interpretation.

Figure 6-D: Background Evaluation Using Small Background Sample Sets



6.4.8 Background in Soils: Other Approaches

U.S. EPA (2007) identifies additional procedures for the BTV comparison to systematic site samples. This includes the use of two-sample hypothesis testing, and graphical methods to compare two or more populations. IDEM will evaluate such approaches for consistency with U.S. EPA guidance.

Background values from literature sources or from studies completed for other remediation sites may be useful for evaluating background in soils in some cases. Proposals including such studies should present the information in the context of the CSM and document that the study provides a representative background reference. Background values from studies not in close proximity to the site under investigation may not be suitable for direct application to a site.

6.5 Background in Ground Water

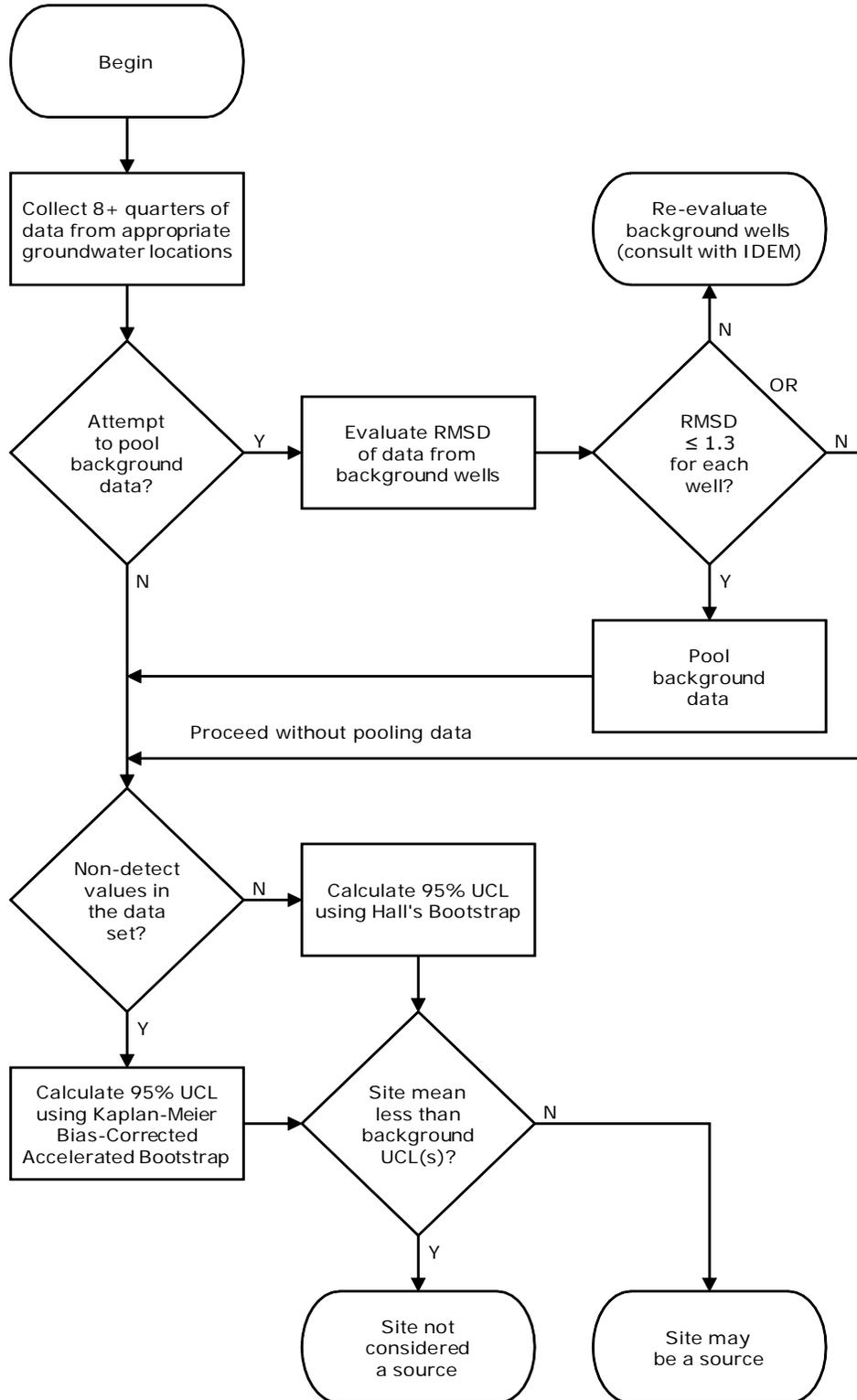
Figure 6-E illustrates a procedure for evaluating background in ground water. Appropriate ground water background sampling points are typically upgradient of, and hydraulically connected to, the site. The suitability of the location of the background sampling point should be based on the following hydrogeologic assumptions:

- The ground water background samples come from areas unaffected by site releases
- The upgradient and downgradient well samples are drawn from the same aquifer and the wells are screened at essentially the same hydrostratigraphic position. The fate and transport characteristics of ground water contaminants likely will differ in each aquifer, resulting in unique concentration patterns.
- The ground water flows in a definable pathway from upgradient to downgradient wells beneath the area under investigation. Undefined or incorrectly defined flow paths may invalidate statistical comparisons.
- The ground water flow moves at a sufficient velocity beneath the site, so that the same ground water observed at upgradient well locations is subsequently monitored at downgradient wells over the course of the evaluation.
- The time between sampling events and velocity of the ground water flow is sufficient to ensure collection of independent samples.

To minimize sampling variability, collect all ground water samples using the same or similar sampling equipment and methods. Because ground water moves, background evaluations in ground water take more time than soil evaluations. Sampling over time also allows for evaluation of fluctuations in contaminant concentrations caused by climate and rainfall. Collect a minimum of eight quarterly samples from each well used in the evaluation.

When using more than one background well it is necessary to evaluate the distribution of the background data. This may be accomplished by evaluating the root mean squared deviation (RMSD) of each background well using Equation 6-B.

Figure 6-E: Ground Water Background Evaluation



Equation 6-B: Root Mean Squared Deviation

$$RMSD = \sqrt{\frac{\sum_{i=1}^n (C_{ai} - C_{wi})^2}{N}}$$

where:

C_{wi} = the contaminant concentration for a given sampling event in the well currently under evaluation

C_{ai} = the average concentration of the contaminant in those background wells not currently under evaluation. For example: if there are four background wells, and well 2 is currently under evaluation, this value is the average of the contaminant concentrations in wells 1, 3, and 4; and

N = the total number of background wells.

If the RMSD values are ≤ 1.3 for *each* background well, it is acceptable to pool the background well data. If an RMSD value is greater than 1.3 for any background well, then either proceed without pooling the data, or re-evaluate the background wells. Depending on site conditions, there may be several options for re-evaluating background wells. Consultation with IDEM regarding suitable options is recommended.

If the background data set (pooled or not) contains nondetect values, use the Kaplan-Meier Bias-Corrected Accelerated (BCA) Bootstrap method to calculate a UCL at the 95th percentile level.⁴⁶ Otherwise, calculate the 95th percentile UCL using Hall's Bootstrap.⁴⁶ Compare the appropriate UCL(s) derived from the background data to the mean contaminant concentration in each of the downgradient wells. If the mean of contaminant concentrations from on-site wells is less than or equal to the background UCL(s), the site is probably not a source. Otherwise, IDEM may consider the site a source.

6.6 Off-site Sources

There is no standard approach to demonstrating that contamination arises from an off-site source. Each demonstration is inherently site-specific and IDEM will evaluate each demonstration on its merits. However, IDEM expects that successful demonstrations will typically employ the CSM approach and multiple lines of evidence (LOEs). An off-site source demonstration should characterize the contamination that is attributed to an off-site source; characterize any temporal variation in concentrations; and identify the particular locations where contamination is coming onto the subject property. Suitable LOEs might include ground water concentration gradients, surface and/or ground water flow direction, suspected source operating history, surface or subsurface soil sample results, prevailing wind direction, etc.

⁴⁶ ProUCL can perform this calculation.

Risk Evaluation: Introduction

7.1 Introduction

Risk assessment is the collection and analysis of data to characterize the nature and magnitude of risk posed by one or more chemicals. Risk assessment is a complex topic and a full treatment is beyond the scope of the *Remediation Closure Guide* (RCG). What follows is a brief discussion of some of the steps that are important in assessing potential risks at release sites. The United States Environmental Protection Agency (U.S. EPA 1989a, 1991c, 1991d, 1991e, 1991f, 2004b, and 2009g) offers detailed guidance on various aspects of risk assessment. Sections 8 through 11 provide more detail on risk evaluation for the soil direct contact, ground water, vapor, and ecological exposure scenarios.

Risk assessment begins with the identification of potential contaminants, potential receptors, and exposure scenarios. An adequate conceptual site model (CSM) should provide all of this information. The next step – exposure assessment (Section 7.2) – involves calculation of a reasonable exposure estimate for each potentially exposed population. A standard risk assessment then combines exposure and toxicity assessments (Section 7.3) to characterize risk (Section 7.4). As noted earlier, this can be a complex and involved process.

However, there are acceptable alternatives to conducting a full risk assessment. For example, the Indiana Department of Environmental Management (IDEM) publishes risk-based **screening levels** that incorporate IDEM-approved toxicity parameters, exposure assumptions, and target risk levels suitable for several different exposure and land use scenarios. Succeeding sections also describe some of the many ways to develop **site-specific levels**. All permit direct comparison against observed concentrations (Section 7.2.3).

Risk management attempts to eliminate exposure via specific pathways, typically through engineering controls (ECs) or institutional controls (ICs). In doing so, this approach leaves the realm of risk assessment, simply removing effectively managed pathways from further risk assessment. However, risk management strategies always include ongoing commitments (Section 1.3.4).

7.2 Exposure Assessment

Exposure assessment estimates the magnitude, frequency, and duration of exposures via specific pathways to provide an estimate of dose. It incorporates information from the conceptual site model and assumptions about the behavior of receptors to derive estimates of exposure to contamination. U.S. EPA (1989a, 1992) offers a more complete description of exposure assessment.

7.2.1 Identifying Receptors and Exposure Scenarios

CSMs should identify potential receptors and associated exposure scenarios. A potential receptor is a person or organism that may undergo exposure to contamination as the result of a release. Examples of potential receptors include:

- People who live in an area
- Workers at a commercial or industrial facility
- Recreational users of a park or trail
- Persons who drink ground water
- Wild animals living in a wetland

Exposure scenarios are circumstances in which contamination does or could move from a source to a receptor. There are many possible exposure scenarios. IDEM publishes screening levels for some of the most common:

- Direct contact with soil by residents, commercial/industrial workers, and excavation workers (Section 8)
- Direct contact with ground water by residents (Section 9)
- Potential ground water contamination caused by downward migration of contamination through the unsaturated soil column (Section 9)
- Vapor inhalation by residents and commercial/industrial workers (Section 10)

Section 11.2 includes a brief discussion of additional exposure scenarios and references related to their evaluation.

7.2.2 Estimating Exposures

Following identification of receptors and exposure scenarios, the exposure assessment process uses assumptions about contact frequency and duration to estimate exposure patterns. For example, IDEM's ground water noncarcinogenic screening levels assume that a child consumes one liter of water during each of 350 days per year, for six years.

Site-specific evaluations may modify commercial/industrial, recreational, and excavation exposure assumptions based on site-specific factors, or current peer-reviewed research. IDEM considers potential long-term *residential* land use activities to be similar everywhere. Nevertheless, IDEM will consider changes to residential exposure assumptions for the purpose of providing central estimates of potential risks in conjunction with upper bound point estimates and a clear statement of the uncertainty associated with these estimates. IDEM will evaluate submittals that propose modified exposure assumptions using the following criteria:

- U.S. EPA acceptance
- Consistency with evaluation of central tendency and upper bound point estimates
- Reliance on ICs for limiting exposure
- Uncertainty
- Applicability and relevance

7.2.3 Estimating Media Concentrations

Exposure assessment also requires estimates of chemical concentrations in environmental media. IDEM refers to such estimates as **exposure point concentrations** (EPCs). EPCs are necessary for estimating risk through risk characterization, or for comparison against screening levels or site-specific levels. See Sections 8.4, 9.3, and 9.7 for guidance on calculating EPCs for soil direct contact, ground water direct contact, and migration to ground water scenarios, respectively.

7.3 Toxicity Assessment

Toxicity assessment addresses two related questions – whether exposure to a particular chemical causes harm, and the nature of the relationship between exposure dose and the likelihood of harm. These are usually challenging questions. Attempts to answer them may involve experiments on animals or studies of exposed workers, and the results are often tentative and difficult to interpret. In any case, those activities are outside the scope of IDEM's functions, and the agency relies on other organizations for toxicity information.

Toxicity values differ between carcinogens and noncarcinogens. Toxicity values for carcinogens are slope factors (SFs) for ingestion and inhalation unit risks (IURs) for inhalation. Toxicity values for noncarcinogens are reference doses (RfDs) for ingestion and reference concentrations (RfCs) for inhalation.

7.4 Risk Characterization

Risk characterization combines the exposure assessment and the toxicity assessment to provide an estimate of risk. Risk characterization typically provides conclusions about risks associated with a site as well as an evaluation of uncertainty and bias in the risk assessment.

Risk assessments that rely on screening levels or site-specific levels reveal only whether or not risk exceeds a given level, like a thermometer that reads either “above 70°F” or “below 70°F.” Further, screening level calculations typically employ, by design, default values (and sometimes worst case assumptions) that tend to overstate risks.

In contrast, a risk characterization provides a quantitative risk estimate, like a thermometer that reads a full range of temperatures. To the extent practicable, such assessments should also provide central tendency risk estimates in conjunction with upper bound risk estimates and a clear statement of the uncertainty associated with those estimates. Especially when coupled with the use of realistic exposure assumptions, risk characterization provides a more meaningful evaluation of risks associated with a site (U.S. EPA, 2005). The result should better inform decision making.

However, risk characterization is typically more resource intensive than using screening levels or site-specific levels. Responsible parties will need to weigh the costs and potential benefits of each approach for themselves.

A full description of the risk characterization process is beyond the scope of this document. Section 1.3.3 provides additional discussion and U.S. EPA (1989a, 2004b, and 2009g) provides detailed guidance.

7.5 Target Risk Level

The 1990 National Contingency Plan⁴⁷ calls for the use of a target risk range of 10^{-4} to 10^{-6} when evaluating the need for remedial action due to the presence of carcinogenic chemicals at Superfund sites. EPA (1991f) clarified the use of the target risk range in risk assessments as follows:

“Generally, where a risk assessment indicates that a cumulative site risk to an individual using reasonable maximum exposure assumptions for either current or future land use exceeds the 10^{-4} lifetime excess cancer risk end of the risk range, action... is generally warranted at the site. For sites where the cumulative site risk to an individual based on reasonable maximum exposure for both current and future land use is less than 10^{-4} , action generally is not warranted, but may be warranted if a chemical specific standard that defines acceptable risk⁴⁸ is violated, or unless there are non-carcinogenic effects or an adverse environmental impact that warrants action. A risk manager may also decide that a lower level of risk to human health is unacceptable and that remedial action is warranted where, for example, there are uncertainties in the risk assessment results. [EPA decisions about] remedial actions taken at sites posing risks within the 10^{-4} to 10^{-6} risk range must explain why remedial action is warranted... Furthermore, the upper boundary of the risk range is not a discrete line at 10^{-4} , although EPA generally uses 10^{-4} in making risk management decisions. A specific risk estimate around 10^{-4} may be considered acceptable if justified based on site-specific conditions...”

IDEM will evaluate target risk proposals within the 10^{-4} to 10^{-6} risk range consistent with the intent summarized above. This means that target risk proposals should characterize site risks using standard U.S. EPA risk assessment methodologies rather than calculating site-specific levels. Risk characterization best incorporates the decision-making process associated with Superfund and IDEM’s broad application of risk based decision making across all cleanup programs.

⁴⁷ 40 Code of Federal Regulations (CFR) Section 300.430(d)(1)

⁴⁸ Examples include maximum contaminant levels (MCLs), maximum contaminant level goals (MCLGs), or applicable or relevant and appropriate requirements (ARARs).

7.6 Additivity: Multiple Contaminants

Risk-based screening and site-specific levels are usually based on chemical-specific toxic effects on a particular end point (target organ) or mode of action. However, people may experience simultaneous exposure to two or more chemicals that affect the same target organ, or exhibit the same mode of action. When this happens, it is theoretically possible for those chemicals to produce an additive effect where exposed persons may incur a risk that exceeds a noncarcinogenic hazard quotient of 1, or a carcinogenic risk of 10^{-4} .

It is not necessary to evaluate additivity when soil chemical concentrations do not exceed screening levels. The inherently protective procedures used to derive screening levels make it very unlikely that exposures to multiple chemicals present at or below screening levels will result in excessive risk or hazard to the exposed population. This is particularly true of carcinogens, where an order of magnitude difference exists between the screening level target risk (10^{-5}) and the upper end of the risk range (10^{-4}). It is appropriate to consider the potentially additive effects of multiple chemicals in a single medium when site-specific exposure factors are integrated into the derivation of site-specific levels, or a risk characterization suggests potential site risks exceeding 10^{-4} or a hazard index of 1.

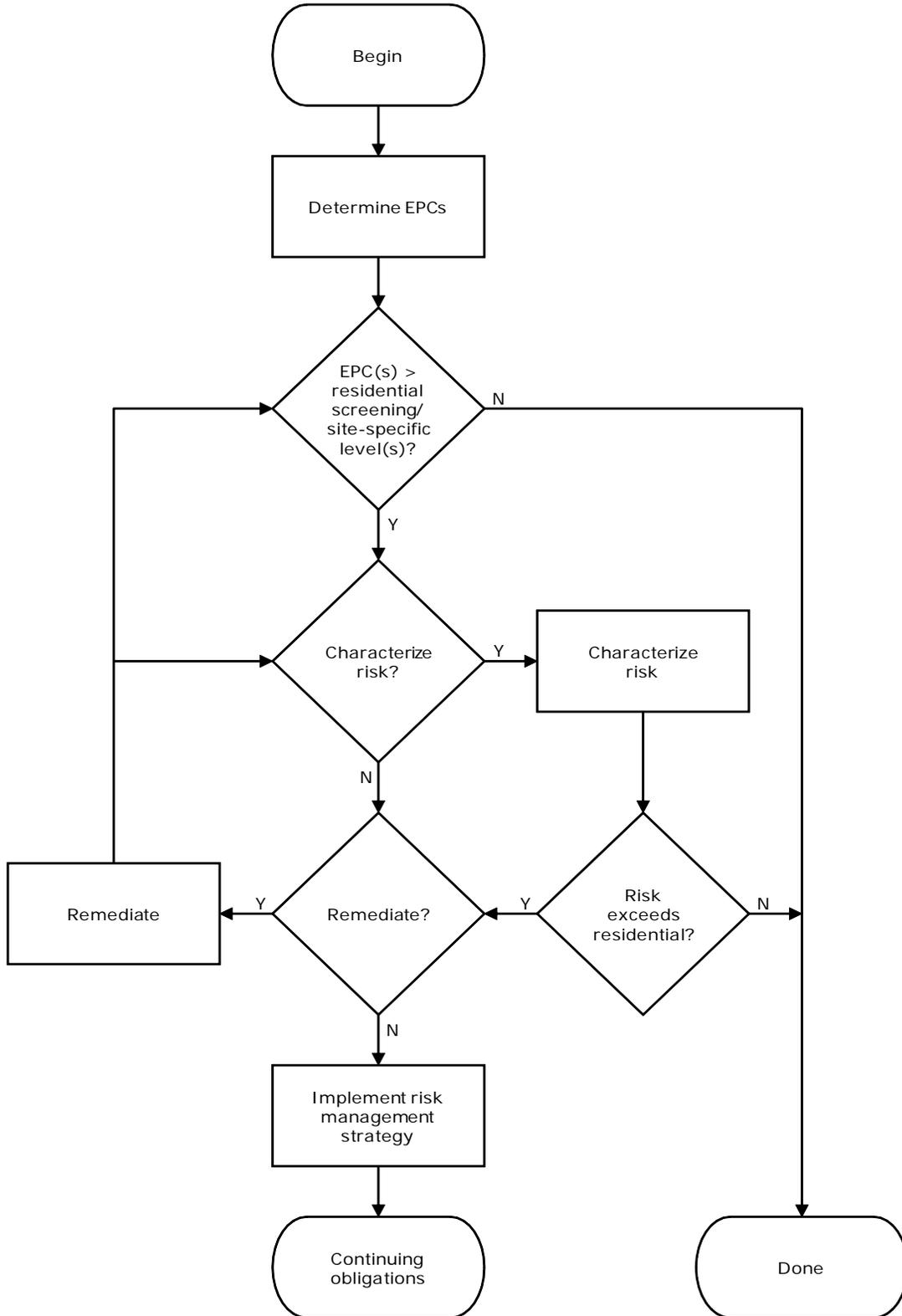
The cumulative hazard index of chemicals that affect the same target organ should not exceed 1, and the cumulative target risk of chemicals that exhibit the same mode of action should not exceed 10^{-4} . U.S. EPA risk assessment guidance views these criteria as “points of departure”, and IDEM will generally require some further action at sites where these risks are exceeded. Further action may include remediation, risk management, or a demonstration utilizing appropriate lines of evidence that the risk characterization overstates the actual risk.

7.7 Summary

The screening level approach integrates toxicity assessment with exposure assessment and tolerable risk to provide a protective estimate of a safe dose or screening level. Under the screening level approach, risk evaluation involves a direct comparison of screening levels against EPCs. If EPCs are below appropriate remediation objectives for a particular exposure scenario, then the exposure scenario is unlikely to pose an unacceptable risk.

Figure 7-A is a *simplified* decision tree that illustrates the application of EPCs and remediation objectives in making various site-related decisions. When EPCs are less than residential screening or site-specific levels, no further action is necessary. Options in the case of an exceedance include risk characterization, remediation, and/or implementation of risk management strategies. In general, site closure requires meeting remediation objectives in relevant media or controlling risks through appropriate and effective risk management strategies.

Figure 7-A: Application of Remediation Objectives and EPCs in Risk Evaluation



Risk Evaluation: Soil Direct Contact

8.1 Introduction

Soil direct contact is associated with a group of exposure scenarios where receptors come into contact with potentially contaminated soil. The Indiana Department of Environmental Management (IDEM) publishes screening levels for four such scenarios:

- Residential soil contact
- Commercial/industrial soil contact
- Excavation worker exposure
- Recreational user exposure (limited subset)

Soil direct contact occurs via one or more of four absorption routes:

- Absorbing chemicals through the skin when touching soil
- Inhaling vapors while in direct contact with potentially contaminated soil
- Inhaling potentially contaminated soil particles (e.g., dust)
- Ingesting potentially contaminated soil

Because these absorption routes often exist simultaneously for a given receptor, IDEM's published screening levels combine the ingestion, inhalation, and dermal absorption routes into a single value for each exposure scenario. While screening levels are a useful benchmark during initial risk evaluations, it is also possible and often appropriate to derive and use other remediation objectives.

8.2 Applicability

Direct contact can occur at or near the existing soil surface, to subsurface soil left on the surface following excavation, or to soils exposed during trenching or excavation activities. IDEM considers both current and potential exposures when evaluating soil direct contact risk. The origin of a release, current and expected land use, and contaminant type are important considerations when evaluating soils for direct contact risk.

8.3 Evaluating Soils for Direct Contact Risk

The origin of the release is an important consideration when evaluating direct contact risk. When evaluating a surface release, it may be necessary to begin sampling soil at the ground surface, proceeding vertically and horizontally until the extent of contaminated soil is adequately understood. Conversely, an underground storage tank release may not warrant a surface investigation. The potential for soil direct exposure, rather than predetermined soil depths, drives the evaluation.

For example, the greatest risk from recreational exposure at a city park (e.g., baseball field or playground) may be from routine exposure to the top few inches of soil. Gardening or landscaping activities may result in soil direct contact risk to a depth of two feet or more. Deeper soils, once excavated and left on the surface, may pose a future direct contact risk. Where excavation or utility work is reasonably likely to expose workers to soils at depth, evaluate those soils for direct contact risk.

Current and expected future land use are also important when assessing soil direct contact risk. Evaluations of potential exposure scenarios require judgment regarding the reasonable likelihood of unacceptable risk based on current and future land use(s). Important factors in this evaluation include:

- Chemical type (volatile organic compounds, metals, etc.)
- Chemical distribution
- Chemical concentration and mass

Some chemicals are more likely than others to pose long-term soil direct contact risk. For example, IDEM's residential soil direct contact screening levels assume exposures over a 30-year period. However, volatile chemicals are unlikely to persist at the soil surface because they tend to dissipate into the air. Conversely, semivolatile compounds and metals are likely to persist in surface soil and may pose a greater long-term direct contact risk.

Chemical distribution is important when evaluating the potential of subsurface soil to contribute to future direct contact risk. For example an isolated "hot spot" of contaminated subsurface soil is less likely to be excavated and become surface soil than is a larger area of contaminated subsurface soil. Vertical distribution is also important. Shallower soils are more likely to be excavated than deeper soils. IDEM considers it generally unlikely that soils deeper than 15 feet below ground surface will be brought to the surface in the future, and in most cases it is not necessary to evaluate soils deeper than 15 feet for soil direct contact risk.

Contaminant concentration and mass are other factors to consider when evaluating direct contact risk for subsurface soil. Highly concentrated contamination (e.g., 100 times the screening level) may result in an overall higher average concentration if the soil is mixed and brought to the surface. This is also a function of depth and distribution: highly contaminated soil at a relatively shallow depth (e.g., four to ten feet) that is uniformly distributed across a relatively large area is more likely to result in excessive direct contact risk if the soil is brought to the surface.

Excavation worker exposure can occur below the ground surface during trenching or excavation activities. Excavation worker remediation objectives apply in subsurface soils to an appropriate site-specific depth wherever excavation is reasonably likely. Other site-specific considerations may also be relevant; IDEM will evaluate other site-specific considerations on their merits.

8.4 Soil Direct Contact: Exposure Point Concentrations (EPCs)

Methods for deriving EPCs vary according to sampling approach. For judgmentally collected samples, the individual sample results for each potential contaminant are generally the EPCs. Where judgmentally collected samples are of sufficient density and spacing, it may be appropriate to estimate the upper confidence limit of the mean (UCL)⁴⁹ to represent the EPC. If the sampling locations are judgmentally guided using field instruments (e.g., photoionization detector), the resulting UCL is likely to be biased high. Nevertheless, some investigators may wish to use this approach to derive a conservative EPC, particularly where a few individual sample results exceed remediation objectives. For systematically collected samples, the EPC is an appropriate UCL calculated for each potential contaminant using results from a sample array that corresponds to the area under evaluation. The resulting UCL is the EPC.

Different procedures are appropriate when deriving soil direct contact EPCs for lead. When deriving screening levels for lead, IDEM uses the Integrated Exposure Uptake Biokinetic (IEUBK) Model for residential child exposure and the Adult Lead Methodology (ALM) for commercial and industrial exposures. Because those models utilize central tendency parameters, U.S. EPA (2003, 2007) suggests basing EPCs for evaluation of soil direct contact with lead on the arithmetic mean (unweighted average) of lead samples from soil particles less than 250 μm in diameter.⁵⁰ While U.S. EPA guidance focuses on residential yards, the arithmetic mean is also appropriate for larger areas, provided the sample design reasonably represents exposure across those areas. Stratified grid sampling⁵¹ is one means of accomplishing this, as it limits the size of each exposure area under evaluation.

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

⁴⁹ 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.

⁵⁰ This typically requires sieving soil during the sample collection process.

⁵¹ See U.S. EPA (1996a, especially Chapter 4) for additional guidance.

8.5 Soil Direct Contact: Screening Levels

As noted earlier, IDEM publishes soil direct contact screening levels for several exposure scenarios. A comparison (Section 8.7) of EPCs derived from site analytical data against appropriate screening levels is usually the first step when evaluating potential exposure risk. *Appropriate screening levels depend on the likely exposure scenario.*

Figure 8-A highlights the location of soil direct contact screening levels in the screening levels table. In this example, Chemical G has the following soil direct contact screening levels:

Residential soil direct contact	(Column A)	1200	mg/kg
Commercial/industrial soil direct contact	(Column B)	3700	mg/kg
Excavation worker soil direct contact	(Column C)	6200	mg/kg

Figure 8-A: Soil Direct Contact Screening Levels

		A ↓	B ↓	C ↓
		Soil Exposure		
		Direct Contact		
Chemical Name	CASRN	Res (mg/kg)	C/I (mg/kg)	Exc (mg/kg)
Chemical A	1-1	380	960	56000
Chemical B	1-2	340	2000	4200
Chemical C	1-3	120	370	620
Chemical D	2-1	1700	12000	20000
Chemical E	2-2	85000	100000	100000
Chemical F	2-3	280	2100	3600
Chemical G	3-1	1200	3700	6200
Chemical H	3-2	2500	2500	2500
Chemical I	3-3	1.8	4.5	260
Chemical J	4-1	0.21	0.65	1.1
Chemical K	4-2	14	34	2000
Chemical L	4-3	42000	100000	100000

Note: For ease of presentation, this sample of the screening levels table does not include columns related to ground water or vapor exposure.

Most of IDEM's screening levels appear in Table A-6 of Appendix A. Recreational soil direct contact screening levels for a smaller subset of chemicals appear in Table A-7.

8.6 Soil Direct Contact: Site-specific Levels

Appendix A describes the procedures that IDEM uses to derive screening levels from U.S. EPA's Regional Screening Level (RSL) tables.

U.S. EPA (2011) describes procedures for deriving screening levels. Those procedures use equations that incorporate many different parameters, some of which exhibit a considerable range of values. U.S. EPA typically employs parameter values at the protective end of their ranges when deriving screening levels. However, those parameter values may not accurately reflect conditions at a particular site. Where that is the case, it *may* be worthwhile to collect site-specific data for one or more parameters and use those data in conjunction with the relevant equations to derive site-specific levels. When properly derived, site-specific levels are entirely appropriate for use in evaluating potential exposure risks.

Sometimes, even large changes in particular parameter values have little or no effect on the site-specific levels of a chemical. In other cases, effects may be substantial in some chemicals and negligible in others. IDEM suggests careful consideration of the potential benefits and expense of performing site-specific evaluations before undertaking them. A sensitivity analysis using an iterative evaluation of the reasonable range of potential values for each parameter may prove useful.

8.7 Soil Direct Contact: Closure

In general, areas where soil direct contact EPCs are less than residential remediation objectives are typically eligible for unconditional closure of the soil direct contact exposure pathway.

Options for sites where EPCs exceed residential remediation objectives include:

- Removal or treatment of contamination until EPCs are below residential remediation objectives.
- Implementation of institutional controls and, if necessary, engineering controls, that reduce exposures to acceptable levels.
- A demonstration, using risk characterization or appropriate lines of evidence, that a remedy is not necessary.

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

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 well⁵³ 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](http://www.epa.gov). 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 evaluation⁵⁵. 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.

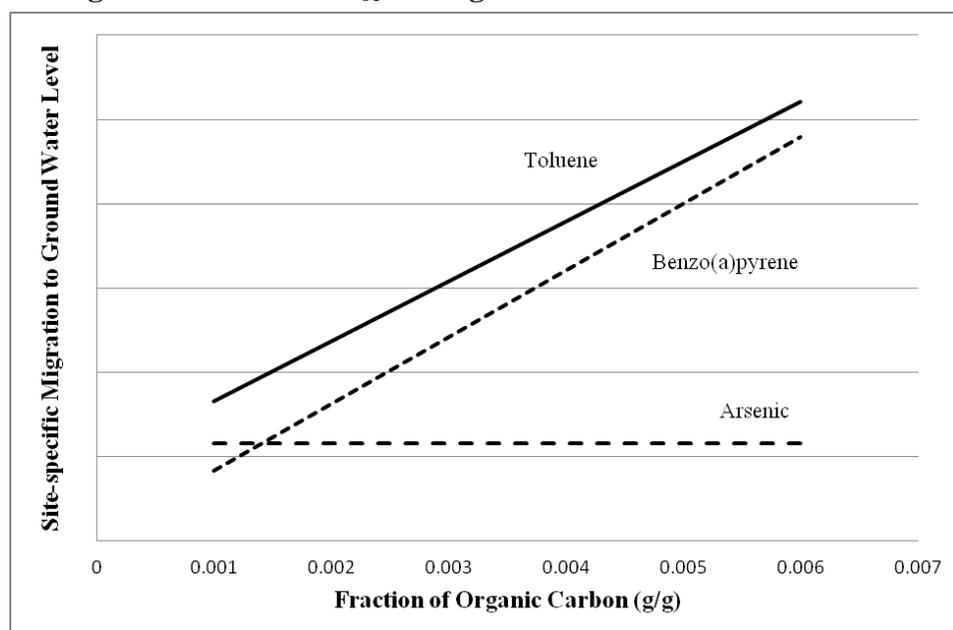
It is also possible to determine site-specific migration to ground water levels based on background concentrations. Suitably applied, any of these remediation objectives are acceptable for closure purposes. Karst terrain and geologic areas where fractures control ground water flow require site-specific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

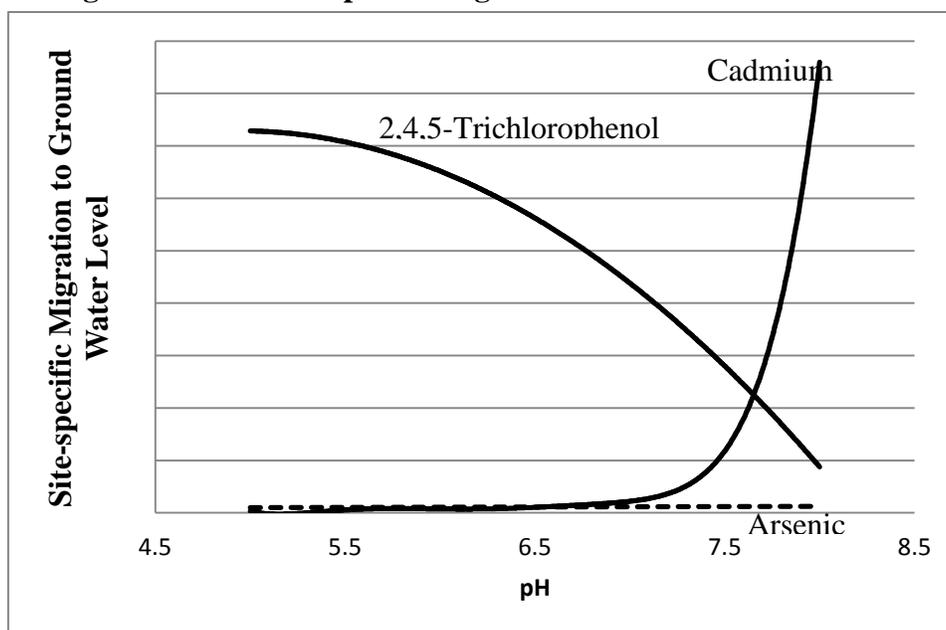
Table 9-A. K_d Values for Selected Metals at Soil pH values of 6.0, 7.0, and 8.0

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

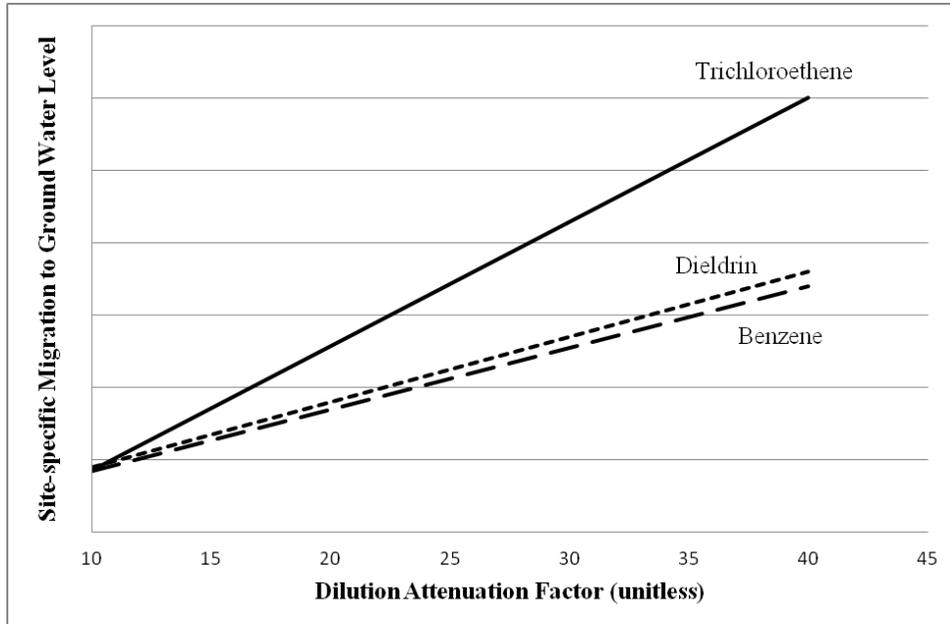


U.S. EPA (1996b, Tables C-2 and C-4) contains K_d and K_{oc} values for various metals and ionizable organics under a range of different soil pH values. IDEM recommends using these tables in conjunction with site-specific soil pH data and the equations in U.S. EPA (2011) to derive site-specific migration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

<u>Source Size</u> ⁵⁷	<u>DAF</u>
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.

Risk Evaluation: Vapor

10.1 Introduction

Vapor intrusion (VI) occurs when contamination volatilizes and migrates from ground water, soil or non-aqueous phase liquids through the soil or some preferential pathway and into nearby buildings. VI can be a significant source of exposure in indoor air (IA).⁵⁸ This section provides guidelines for an integrated approach to assessing VI risks using ground water, exterior soil gas (SGe), subslab soil gas (SGss), crawl space air (CSA), and/or IA sampling information gathered through the conceptual site model (CSM) development process discussed in Section 5.

Risk evaluation for the VI pathway involves considerable uncertainty due to the many variables that affect vapor migration and intrusion, and the difficulty in getting a sufficient number of samples to characterize current and potential future exposure. Conflicting sample results and multiple possible interpretations of the CSM frequently complicate VI risk evaluation. Multiple lines of evidence (LOEs), samples taken under assumed worst case conditions, and conservative risk estimations are necessary to account for the uncertainty inherent in the VI pathway.

10.2 Applicability

Evaluation of potential risk to vapor receptors is appropriate whenever volatile contaminants are present and the preliminary screening process in Section 5.4 indicates a need for further evaluation. Rather than evaluate every volatile chemical present at a site, it may be more efficient to individually evaluate the “risk drivers” associated with a release (e.g., benzene from a gasoline release). However, many chlorinated solvents have toxic degradation products; in such cases it is appropriate to evaluate the parent and degradation products as a group.

10.3 Land Use Categories

The Indiana Department of Environmental Management (IDEM) uses three land use categories when evaluating VI:

Residential properties include homes, apartments, day care centers and schools. Assess residential properties relative to the residential screening levels presented in Table A-6.

Commercial/industrial properties include office complexes, retail businesses, etc. This category also includes industrial facilities where the chemicals found in the subsurface are not used in site processes. Assess these properties relative to the commercial/industrial screening levels presented in Appendix A, Table A-6. For purposes of this document, an Occupational Safety and Health Administration (OSHA) regulated facility is one where workers may simultaneously undergo exposure to the same chemical(s) through VI *and* through routine operations at the facility. If the VI chemicals under evaluation are used as part of the site process, the facility is subject to OSHA permissible exposure levels (PELs) rather than IDEM VI screening levels.

⁵⁸ The risk from contaminants volatilized into indoor air directly from contaminated tap water is evaluated as a component of the ground water direct contact pathway. See Section 9.1.

10.4 Screening Levels

Table A-6 lists indoor air screening levels (IASLs) and VI ground water screening levels (GWSLs) for many volatile chemicals. IDEM will evaluate site-specific screening levels calculated for CSA, SGss, and SGe using guidance in U.S. EPA (2011), other suitable guidance, or by dividing the IASL by an appropriate media specific attenuation factor listed in Table 10-A.

Table 10-A: Attenuation Factors by Medium

Medium	Attenuation Factor
Ground water	0.001 for residential/commercial/industrial 0.0001 for some commercial/industrial (see below)
CSA	1
SGss	0.1 for residential/commercial/industrial 0.01 for some commercial/industrial (below)
Shallow* SGe	0.1 for residential/commercial/industrial 0.01 for some commercial/industrial (below)
Deep** SGe	0.01 for residential/commercial/industrial 0.001 for some commercial/industrial (below)

*Shallow = five feet or less below the building foundation

**Deep = more than five feet below the building foundation

It may be appropriate to adjust the attenuation factors downward by a factor of ten for certain commercial/industrial buildings as shown in the table above. Justification of such adjustments should consider the following criteria:

- *Building size.* Commercial/industrial buildings typically have a significantly larger footprint than homes. The interior of the building should be open to air flow rather than subdivided into smaller offices or businesses.
- *Foundation thickness and structural integrity.* Commercial/industrial buildings are often slab-on-grade construction with thicker, more intact concrete slabs than residences.
- *Ceiling height.* Ceilings are usually considerably higher in commercial/industrial buildings, increasing the air volume compared to residences.
- *Air exchange rate.* Higher ventilation rates in commercial/industrial buildings should result in lower IA concentrations, if the rate of VI from the subsurface is constant.

As of this writing there is no widely accepted process for deriving soil screening levels. However, if a contaminant source exists in the vadose zone beneath or in close proximity to a building, SGss data are necessary for evaluation of the VI pathway into the building. In such cases, IDEM recommends evaluation of ground water data in conjunction with soil gas data, particularly if a contaminant plume extends beyond the vadose zone source. Soil contamination directly beneath or near a building, as well as the existence of preferential pathways, can indicate a higher potential for VI to occur through soil contamination. Where soil contamination exists, IDEM recommends working with the agency through the assigned project manager to develop a site-specific VI investigation plan.

10.4.1 Chronic IASLs and Subchronic Indoor Air Action Levels (IAALs)

IASLs use toxicity criteria associated with long term, or chronic, exposure (a 30-year exposure duration for residential buildings, and a 25-year exposure duration for commercial/industrial

buildings). IASLs are appropriate for preliminary screening, deciding whether further investigation is necessary, and for closure evaluation. Carcinogenic effects drive chronic exposure risk for most commonly encountered VI chemicals. IDEM has established a screening level target cancer risk of 10^{-5} as protective of human health. Considering the inherent uncertainties associated with having minimal indoor air quantitative data, IDEM considers the target risk of 10^{-5} as a reasonable point of demarcation for evaluation of chronic carcinogenic exposure and employs a 10^{-5} target cancer risk in derivation of IASLs (See Section A.5 for additional detail). While IASLs generally identify indoor air concentrations that must be addressed prior to site closure, the target risk of 10^{-5} is not a completely inflexible line. IDEM may consider a risk estimate around 10^{-5} acceptable if justified by LOEs related to site-specific conditions.

The National Contingency Plan risk range of 10^{-4} to 10^{-6} is generally not applied to indoor air inhalation exposures. IDEM will use the 10^{-5} target risk on a per-chemical basis to protect from exceeding 10^{-4} cumulative risk over the long term, recognizing that most indoor air measurements represent a narrow “snapshot in time” because of problems with getting repeat access and uncertainty over seasonal and building variations. If indoor air sampling can be conducted at a frequency that addresses these uncertainties, IDEM will consider accepting chronic remediation objectives where the cumulative target risk does not exceed 10^{-4} and a hazard index of 1.

IAALs assume short term, or subchronic exposure. Subchronic exposures typically represent up to ten percent of a human lifetime, and conventional risk assessment guidance typically identifies this period as a range of two to seven years. Subchronic criteria are generally appropriate for use in determining whether an interim measure, such as a VI mitigation system, is warranted due to the likelihood that receptors in a building may have already had a two to seven year exposure prior to the VI investigation. However, benchmark toxicity criteria are generally not available for subchronic inhalation exposures, so IDEM will assess subchronic exposure by incorporating a tenfold adjustment to the IASLs. At the higher concentrations associated with this tenfold increase, it is important to evaluate each chemical for both the carcinogenic and noncarcinogenic endpoints to determine the risk driver. This means that if the carcinogenic risk from inhalation of VI-related chemicals exceeds 10^{-4} or a hazard index of 10, prompt action is generally warranted. IAALs can be derived by simply multiplying the IASLs in Table A-6 by a factor of ten.

10.5 Vapor: Closure

Interpretation of VI sampling results can be a complex process, especially when evaluating IA data. Initial evaluation of sampling data simply involves the comparison of results to the applicable screening level. This comparison provides some indication of whether a VI problem may exist. However, a single sample result above or below a screening level is not enough evidence to establish or rule out a completed VI pathway.

When evaluating sampling results for the purpose of assessing the VI pathway, it is important to first determine that the samples were taken according to proper sampling procedures, in the proper locations, and under conditions conducive to vapor transport (Section 5). These factors provide additional confidence when interpreting sampling results. The sections below provide general guidelines for interpreting VI sample results under current conditions, and assume that subsurface remediation is underway to alleviate any future VI issues. If the chosen remedy for a site involves leaving contamination in place, the VI pathway may require periodic re-evaluation for changes in contaminant concentrations, subsurface conditions, and building conditions.

10.5.1 SGe Sample Results

SGe sampling is only appropriate as a stand alone screening tool if either:

1. The site has been characterized as “low risk” using the LOEs in Section 5.4.2, or
2. The site is an undeveloped property with no existing buildings.

If the owner of the potentially affected building does not grant permission or access for SGss sampling, SGe sampling should be paired with IA sampling. When SGe sample results are below the applicable screening levels at all sampling locations for a minimum of two sampling events, the VI pathway can be considered incomplete under current conditions and no further investigation is needed for the building or property in question.

If any SGe sampling result exceeds the applicable screening levels, further investigation of the building is warranted. When possible, paired SGss and IA sampling should be conducted. If the owner of the potentially affected building does not grant permission for SGss sampling, SGe sampling should be paired with IA sampling.

For undeveloped properties with no existing buildings, an exceedance of the SGe screening levels establishes the potential for a completed VI pathway in future buildings. In this scenario, the VI remedy should involve remediation or restrictions applied via an institutional control.

10.5.2 SGss and CSA Sample Results

Whenever SGss and CSA samples are not paired with IA samples, the evaluation should include a preferential pathway evaluation (Section 5.5.1). If preferential pathway sampling results are below applicable SGss screening levels and SGss or CSA sample results are below applicable screening levels for a minimum of two sampling events, the VI pathway can be considered incomplete under current conditions and no further investigation is needed for the building in question.

If the preferential pathway samples indicate the presence of site contaminants above SGss screening levels, or if any SGss or CSA sampling result exceeds the applicable screening levels, the building warrants further investigation. That investigation should include paired SGss/CSA and IA sampling.

10.5.3 IA Sample Results

Interpreting IA sample results requires consideration of spatial and temporal variability and possible contributions of ambient air or indoor air background (IAb) sources. Spatial and temporal variability are influenced by many factors, including: subsurface conditions, building construction and airflow dynamics, and meteorological conditions. Because of these site-specific factors, IA can change on a daily basis. It is not realistic to screen out the vapor pathway with any confidence based upon a single “snapshot in time”. Therefore, IDEM recommends multiple rounds of paired IA and SGss sampling.

IA sample results are evaluated under two separate exposure scenarios: sub-chronic exposure and chronic exposure:

Sub-chronic Exposure

Prompt action is necessary to reduce exposure if IA exceeds IAALs. Prompt action does not necessarily mean evacuating the building, but it does mean addressing the exposure within a period of months rather than years. It can include source removal, source remediation,

installation of a venting system, SGss depressurization system, or any other means that will reduce exposure to an acceptable level. If IA levels are between IASLs and IAALs, then a chronic VI problem may exist. Further investigation or additional sampling will be necessary to assess potential risk. IAALs can be derived by multiplying the IASLs in Table A-6 by a factor of ten.

Chronic Exposure

A chronic exposure problem may exist if IA exceeds IASLs. This can occur from vapor intruding at low levels over long periods of time. It may be necessary to further characterize the exposure through additional sampling events or by using long-term sampling techniques.

Concentrations near IASLs may also be the result of common IAb sources. Section 5 discusses IAb considerations, as well as LOEs to establish whether contaminants detected in IA are the result of VI or IAb.

When IA is below IASLs at all sampling locations for a minimum of two sampling events, IDEM will consider the VI pathway incomplete under current conditions. If source remediation is underway, no further investigation of the building is necessary. However, if a remedy leaves contamination in place or SGss sample results show the potential for VI to occur if building conditions change, then the VI pathway may require periodic re-evaluation.

If the VI pathway is complete, and IA exceeds IASLs, then action is necessary to reduce exposure. Possible actions include: source removal, source remediation, installation of a venting system, SGss depressurization system, or any other means of reducing exposure to an acceptable level. The action required to address the VI pathway can be determined on a site-specific basis through the evaluation of the following LOEs:

- SGss and IA contaminant concentrations
- Source contaminant concentrations
- Estimated time of exposure prior to discovery
- Source remedy selection
- Estimated time until contaminant concentrations decrease to acceptable levels.

Risk Evaluation: Ecological and Other Scenarios

11.1 Ecological Risk Assessment

The preceding sections describe the investigation and assessment of the soil direct contact, ground water, and vapor intrusion (VI) pathways. In addition to these pathways, it is important to evaluate whether site conditions warrant an ecological risk assessment (ERA) or additional human health risk evaluation. This section provides guidance on when and how to evaluate these pathways, and references to additional information sources. The Indiana Department of Environmental Management recommends a step-wise approach to ERA.

11.1.1 Screening Level ERA (SLERA)

Every investigation should include a SLERA. The SLERA includes a desktop review and site inspection to determine if ecologically susceptible areas (ESAs; see Section 2.6) exist at or near the site, and whether a release could have occurred within or migrated to ESAs, resulting in a completed exposure pathway. If not, further ecological risk assessment is not necessary. Investigation reports should document the findings of the SLERA, including information on any rare, threatened, or endangered species in the site vicinity. If such species or their habitats are present on or near the site, additional evaluation may be necessary.

If there is uncertainty regarding whether habitats are contaminated, or if they are expected to be contaminated, then environmental media should be sampled and the results compared to ecological screening levels (ESLs). Pre-existing data may be suitable for screening purposes. However, it is important to ensure that the data are sufficient for this purpose and they should be reviewed for completeness and conformity with data quality objectives (e.g., analytical detection/reporting limits should be lower than the ESLs). Sources of ESLs for soil, sediment, surface water, and/or air include Buchman (2008), USDOE (1997), U.S. EPA (1997f, 2003c) and MacDonald *et al.*, (2000). IDEM will evaluate other ESLs, site-specific ecological remediation objectives, and ecological risk characterizations on their merits.

If the results of the SLERA demonstrate that all potential contaminant concentrations are below appropriate screening levels, then the ecological assessment is complete. If the SLERA identifies potential contaminant concentrations above ESLs within ESAs, it is appropriate to conduct a baseline ERA (U.S. EPA, 1997b).

11.1.2 Baseline ERA

Additional investigation is warranted if potential contaminant concentrations exceed screening levels. Complete guidance for conducting baseline ERAs is outside the scope of this document. However, Ohio EPA (2008) and U.S. EPA (1997b, 1998a, 1998b) contain additional information on baseline ERAs.

11.1.3 Special Considerations for ERA

Data sets and potential contaminants for an ERA may differ from those selected for human health. Exposures may occur in different areas, and different screening levels may apply. Therefore, it may be appropriate to conduct screening for human health and ecological assessments independently. Data quality objective development should consider receptor type, exposure pathway, screening levels, and detection/reporting limits.

Other chemical and physical parameters (e.g., pH, dissolved oxygen levels, total organic carbon levels, redox potential, water temperature) may be relevant to the ERA, depending on the environmental medium and receptors under consideration.

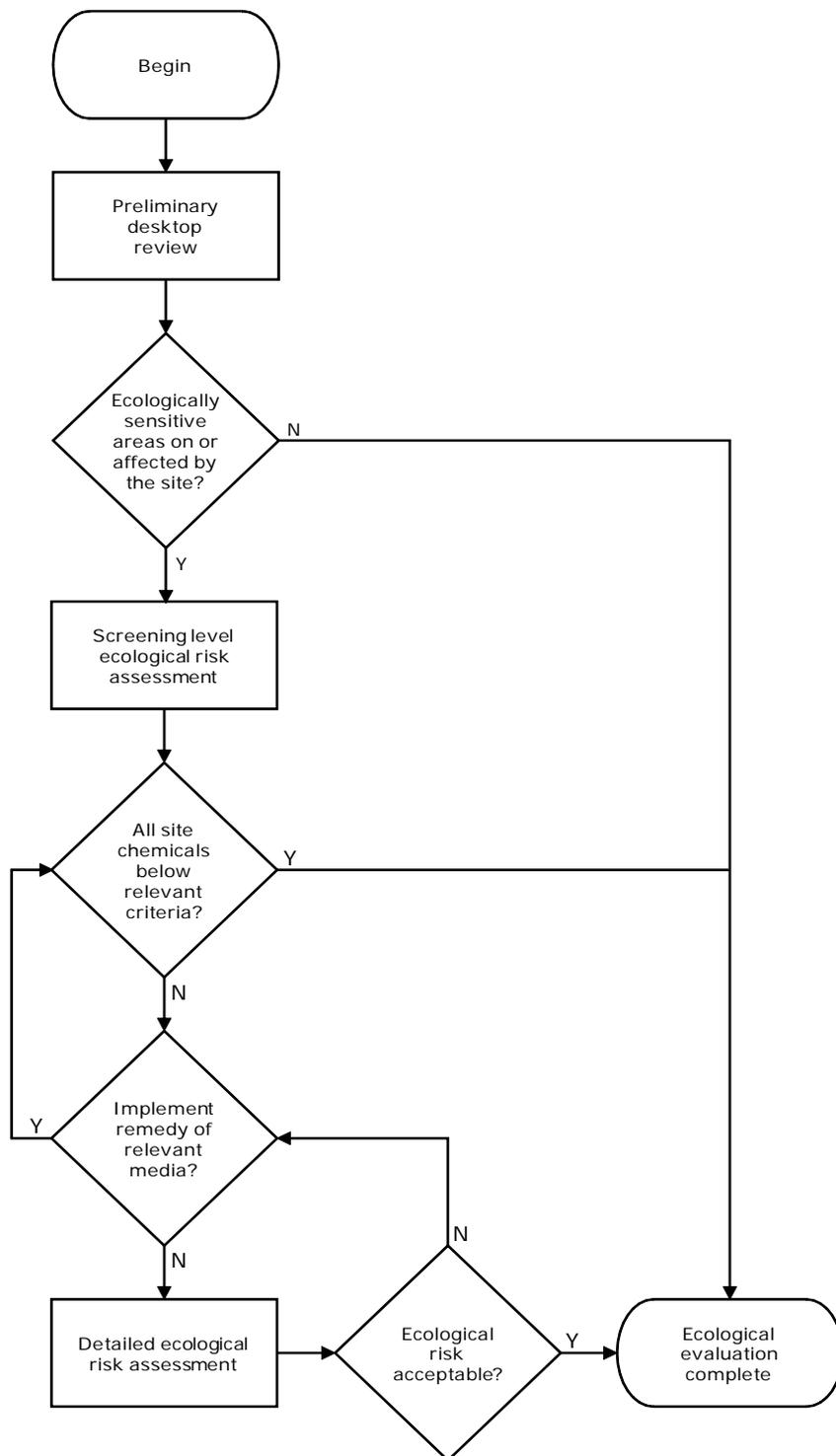
Persistent, bioaccumulative, and toxic (PBT) chemicals are of particular concern for ecological risk. PBTs move through the food chain and affect upper trophic levels. Ohio EPA (2008) provides some examples:

- Aldrin
- Chlordane
- DDT/DDD/DDE
- Dieldrin
- Hexachlorobenzene
- Hexachloro-1,3-butadiene
- Hexachlorocyclohexanes (alpha-HCH, beta-HCH, gamma-HCH, or lindane)
- Mercury and its compounds
- Polychlorinated biphenyls (PCBs)
- 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD)
- Toxaphene

U.S. EPA (2000b) contains additional information on bioaccumulative chemicals.

SLERAs and baseline ERAs may identify representative receptors or species of concern based on the ESA(s) or species present at or near the site. If protection of an upper trophic level species is an assessment endpoint (e.g., river otter), the risk assessment should also evaluate effects to species lower on the food chain (e.g., fish, macroinvertebrates).

Figure 11-A: Ecological Risk Evaluation Process



11.2 Human Health Risk Evaluation: Other Scenarios

Sections 8, 9, and 10 provide methods for evaluating risks for a number of human health exposure scenarios. Site-specific conditions may warrant the evaluation of additional scenarios. Evaluations should consider both current and reasonable future uses of sites and off-site impacted areas.

Selected examples of possible site-specific exposure scenarios appear below, arranged by media. IDEM does not offer specific guidance on conducting these site-specific evaluations but refers users to guidance (including but not limited to U.S. EPA 1989a, 1991a, 1991g, 1996a, 1996b, 2002f, 2004b, 2009g). Investigators may also wish to consult IDEM when evaluating site-specific scenarios. IDEM will evaluate risk characterizations for these scenarios on a site by site basis.

Surface Water

Surface water includes (but is not limited to) rivers, streams, wetlands, reservoirs, lakes, and ponds. Possible exposure scenarios for surface water include use as drinking water, recreational exposure activities, and ingestion of fish.

Sediment

Sediments are primarily particulate matter, typically mixtures of clay, silt, sand, organic matter, and minerals that often lie below water. Sediment contamination often occurs in conjunction with surface water contamination, and sediments can be a major repository for toxic and persistent chemicals released into overlying surface waters. Exposure may occur directly through recreational activities or indirectly through fish ingestion.

Soil

In addition to those described in Sections 8 and 9, other soil-related scenarios may be important on a site-specific basis. Specifically, uptake by biota may be of concern for crops, grazing animals, and/or game animals.

Ground Water

Sections 9 and 10 provide information on the risks associated with the direct contact and VI scenarios for ground water. Possible additional scenarios include indirect exposure through irrigation of crops, plant uptake, and water for livestock. In some cases, utility workers digging trenches may also undergo exposure to volatiles in shallow ground water.

Air

For certain sites, air deposition may be significant. Direct deposition to plants or particulate deposition on soil may be of concern for crops or livestock.

Remedy Selection and Implementation

12.1 Introduction

A **remedy** consists of one or more measures taken to control unacceptable risks to human health and/or the environment arising from a contaminant release. Examples include:

- Contaminant removal
- Contaminant treatment
- Natural or enhanced biodegradation
- Contaminant containment, immobilization, or stabilization
- Thermal destruction
- Treatment at the point of exposure
- Land use and activity restrictions, including environmental restrictive covenants (ERCs) and environmental restrictive ordinances (EROs)
- Long-term monitoring or periodic reporting
- Engineering controls (ECs)
- Combinations of the above, or other options

This section provides guidance on the process of choosing and implementing a remedy. It also provides guidance on institutional controls (ICs), mainly ERCs and EROs. The most effective ICs often work in conjunction with other controls and active treatment of contaminants (U.S. EPA 2010d).⁵⁹

12.2 Applicability

Some releases do not require a remedy. For example, areas that meet residential remediation objectives (e.g., screening levels or site-specific levels) are generally eligible for unconditional closure.⁶⁰ Similarly, a site that undergoes remediation and subsequently meets residential remediation objectives no longer requires a remedy, and will be eligible for unconditional closure.⁶¹ An **unconditional closure** is a true “walk away” closure that adequately addresses risk from a release without relying on any continuing activity and/or activity restriction. All other closures are **conditional closures**. That is, they require a remedy of some sort.

12.3 Interim Remedial Action

Interim remedial action may be necessary in some cases to reduce or eliminate an immediate threat which could pose an unacceptable risk of harm to human health or the environment if present for even a short amount of time. It may also prove prudent and cost effective to use an interim remedial action to reduce contaminant mass during the conceptual site model (CSM) development and remedy selection processes. The interim remedial action may include removal or treatment of free product, or addressing sources of contamination with complete exposure

⁵⁹ 40 CFR 300.430(a)(1)(iii)(C); 40 CFR 300.430(a)(1)(iii)(D)

⁶⁰ The Indiana Department of Environmental Management (IDEM) may require a remedy to protect natural resources or the environment, even at sites where potential contaminant concentrations do not exceed human health remediation objectives. Prior closure determinations may no longer be valid if new information indicates a potential threat to human health and/or the environment.

⁶¹ Certain land uses (e.g., highways, railroads) *may* not require ERCs or EROs for closure, even when underlying contamination exceeds residential remediation objectives.

pathways or imminent likelihood of a completed pathway (acute vapor intrusion (VI) levels, impacts to well head, etc.)

12.4 Remedy Selection

The formal remedy selection process is typically undertaken after characterization of the release has been performed, the risks to human health and the environment have been assessed, and the CSM indicates that there are one or more exposure scenarios with an unacceptable risk.

However, the formal remedy selection process need not prevent implementation of suitable interim remedial actions (Section 12.3).

As discussed in Section 1.3, Indiana Code (IC) 13-25-5-8.5 directs responsible parties to specify remediation objectives for sites where releases occur, and states that they shall be based on one of the following:

- *IC 13-25-5-8.5(b)(1) background levels of hazardous substances and petroleum that occur naturally on the site;*
- *IC 13-25-5-8.5(d)(1) Levels of hazardous substances and petroleum calculated by the department using standard equations and default values for particular hazardous substances or petroleum;*
- *IC 13-25-5-8.5(d)(2) Levels of hazardous substances and petroleum calculated using site specific data for the default values in the department's standard equations; or*
- *IC 13-25-5-8.5(d)(3) Levels of hazardous substances and petroleum developed based on site specific risk assessments that take into account site specific factors, including remedial measures, restrictive covenants, and environmental restrictive ordinances that: (A) manage risk; and (B) control completed or potential exposure pathways.*

An effective remedy will adequately address risks to human health and the environment, and may require multiple components and more than one remediation objective. Exposure can be reduced by decreasing contaminant levels, reducing the mass or volume of contamination, reducing the mobility of the contamination, or by restricting or controlling activities or access to the contamination by receptors. There may be many possible effective remedies for a release, and they can vary dramatically in scope and expense.

The nature of the remediation technology proposed is contingent on site-specific factors. Commonly used, well documented remedial techniques are more likely to be approved by IDEM with less data than experimental techniques, although various alternatives may be proposed. In some cases, remedial alternatives proposed will need to be modified and resubmitted to IDEM.

There are many potential active remedies (e.g., removal and disposal, bioremediation, pump and treat, chemical oxidation, etc.). It is beyond the scope of this document to list all possible remedial technologies. Active remediation includes approaches that reduce the mass, toxicity, mobility, or concentration of contaminants in soil and ground water, or contains them to physically prevent exposure or migration. The benefits of active remediation include:

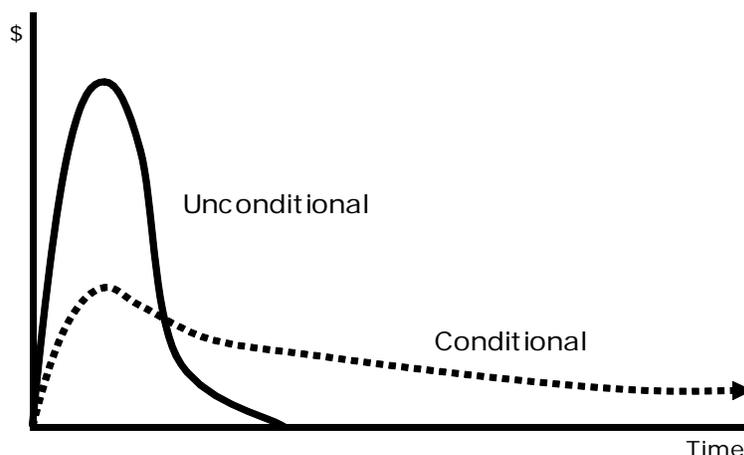
- Possible unconditional closure of site
- Shortening the length of time that the site will need to be monitored or maintained or otherwise restricted
- Wider variety of beneficial future uses
- Lower risk of future liability

12.5 Remedy Evaluation

When considering approval of potential remedies, IDEM will take several factors into account⁶², including many of those listed below. However, entities implementing remedies are generally free to consider the advantages and disadvantages of various options for themselves⁶³. Important factors include:

- Effectiveness (i.e., will the remedy sufficiently reduce exposure, and continue to do so over the likely lifetime of the contaminant?)
- Cost, including cost over time (Figure 12-A). Long-term costs associated with a conditional closure may ultimately prove more expensive than achieving an unconditional closure. IDEM will take a special interest in this factor when the state (e.g., the Excess Liability Trust Fund) pays for some or all of the remedy cost.
- Acceptability to affected parties
- Potential, if any, to make the original situation worse (e.g., by facilitating the spread of contamination, or its transformation into a more toxic form)
- Planned use⁶⁴ (Section 2.4) of the site and all impacted properties. The level of confidence in future planned use is important when assessing potential risk posed by the site contamination and selecting the appropriate remedy.

Figure 12-A: Projected Expense Over Time



Remedy proposals should include, among other things, a description of the risk exposure assumptions developed from the CSM, the proposed remedy, and the logic for its selection. The proposals should also demonstrate how the remedies meet the remediation objectives defined in IC 13-25-5-8.5.

⁶² Some programs [e.g. Leaking Underground Storage Tank (LUST), RCRA] also have rules that must be followed (ex. free product abatement for LUST sites).

⁶³ Those seeking liability protection under CERCLA, IC 13-23, IC 13-24, and IC 13-25-4 will generally have additional obligations as criteria that must be met.

⁶⁴ Local governments generally have jurisdiction in land use decisions.

12.6 Remedy Implementation and Decision Documentation

The selected site remedy decision should be clearly documented. IDEM has developed two new state forms to ensure that remedy decisions are clearly presented, and weighed against the appropriate criteria. These forms are intended to serve as an executive summary of the remedy selection and remedy implementation, and should be completed by the responsible party (or their environmental contractor.). The forms should be submitted with any corrective action plan or remediation work plan, or any request to approve site closure. IDEM staff will indicate approval by signing and returning a copy of the form to the requestor.

The [Record of Remedy Selection](#)⁶⁵ (RRS) (State Form 54471) presents the remedial or corrective action plan when IDEM must approve the selection of the remedial (or corrective) action. It certifies that the remedy selection process was carried out properly; describes the technical parameters; specifies the remedy components and remediation goals; and provides a consolidated source of information - including the rationale behind the selection.

The [Record of Site Closure](#)⁶⁶ (RSC) (State Form 54472) presents the site closure decision. It describes the technical parameters; specifies the remedy components and remediation goals; and provides a consolidated source of information - including the rationale behind the selection.⁶⁷

12.7 Risk Management

Risk management strategies reduce or eliminate specific exposure pathways through ECs or ICs. ICs include legal restrictions on the use of a property. There are many kinds of ICs, including ERCs and EROs.

Effective ICs or ECs reduce or eliminate exposure via specific exposure pathways. Where remedies incorporate controls that effectively reduce exposures, one option is to use the equations in U.S. EPA (2011) to calculate site-specific levels that take the effect of those exposure controls into account. Another is to perform a site-specific risk assessment.

Risk management remedies that eliminate exposure via a specific pathway simply remove that pathway from the risk evaluation. However, effective risk management strategies require compliance with selected land use, ground water, and/or activity restrictions, and may require an ongoing commitment to operation and/or maintenance of the remedy. When applicable, the ongoing commitment will vary with the nature of the remedy, and could range from periodic inspections designed to monitor compliance with the terms of an ERC all the way up to operation and maintenance of a complex engineered system.

When the responsible party or participant does not own the property, IDEM may consider lines of evidence (LOEs) to demonstrate that an ERC or ERO is not necessary to protect human health and the environment. LOEs may include the location, extent, toxicity, or persistence of the contamination. In situations where a third party owns the property and is unwilling to agree to an ERC, evidence of unsuccessful attempts to obtain the ERC should be provided to IDEM for its consideration. In lieu of an ERC or an ERO, IDEM may, at its discretion, provide a conditional site closure that identifies conditions that must be maintained or performed after site closure.

⁶⁵ <https://forms.in.gov/Download.aspx?id=8834>

⁶⁶ <https://forms.in.gov/Download.aspx?id=8845>

⁶⁷ In cases where IDEM can approve the remedy selection and site closure simultaneously, the RSC may present all information about the remedy selection and remedial action(s) performed, so an RRS would not be necessary.

12.8 Environmental Restrictive Covenants (ERCs)

IC 13-25-5-8.5(e) directs IDEM to consider and give effect to ERCs in evaluating risk-based remediation proposals. An ERC is a legal measure designed to protect human health by limiting exposure to contamination at sites where contamination remains in place. ERCs limit human exposure by restricting activity on, use of, and/or access to contaminated properties, or by requiring the maintenance of an EC. ERCs should be recorded in the office of the recorder of the county in which the real property is located, and the ERC must cross-reference the most recent deed of record in the recorder's office.

When an ERC is proposed as a remedy or component of a remedy, IDEM will evaluate it to determine (a) whether the activities, land use restrictions, and obligations proposed are sufficient to protect human health and the environment, and (b) whether it attaches to the correct real estate and includes all the necessary elements of a restrictive covenant as defined in 13-11-2-193.5. IDEM recommends submission of a draft for review prior to recording an ERC. IDEM may suggest changes to proposed ERC language, and may deny closure if IDEM determines the restrictions are not sufficiently protective or the ERC is not enforceable by IDEM.

12.8.1 Legal Requirements for ERCs

IDEM will evaluate a proposed ERC to determine whether it meets the statutory criteria set out in the definition of "restrictive covenant" in IC 13-11-2-193.5. An ERC executed after June 30, 2009:

- (A) limits the use of the land or the activities that may be performed on or at the land or requires the maintenance of any engineering control on the land designed to protect human health or the environment;*
- (B) by its terms is intended to run with the land and be binding on successors;*
- (C) is recorded with the county recorder's office in the county in which the land is located;*
- (D) explains how it can be modified or terminated;*
- (E) grants the department access to the land;*
- (F) requires notice to a transferee of:

 - (i) the land; or*
 - (ii) an interest in the land;**of the existence of the restrictive covenant; and**
- (G) identifies the means by which the environmental files at the department that apply to the land can be located.*

The actual property owner must execute an ERC in order for IDEM to consider the ERC as a remedy or a component of a remedy. Optional ERC templates that meet these requirements are available on [IDEM's remediation program web pages](http://www.in.gov/idem/5371.htm).⁶⁸

⁶⁸ <http://www.in.gov/idem/5371.htm>

12.8.2 Selection of Restrictions and Obligations

IC 13-25-5-8.5(d)(3) allows ERCs that manage risk or control completed or potential exposure pathways to be considered as a part of a risk based remediation proposal. IDEM will review and consider the effect of proposed use or activity restrictions and obligations in addressing the risks identified in the CSM. IDEM may approve or disapprove of use or activity restrictions and obligations based on this evaluation.

When determining the appropriate restriction or obligation to require at a site, consider the following:

- The contaminated media
- Current and reasonably expected future use of the ground water
- Current and reasonably expected future use of the site and neighboring properties
- Contaminant mobility
- The nature of the contamination (e.g., naturally attenuating?)
- Current and potential receptors
- Availability of public water supply systems

In some cases, IDEM may request maps, GPS coordinates, and/or legal surveys that describe certain ECs or restrictions that apply to a portion of a property. Table 12-A illustrates some of the factors to consider when selecting appropriate restrictions for a site. The table is not comprehensive - other site-specific restrictions may be necessary.

Table 12-A: Restrictions and Remedies

Type	Exposure Pathway	Comments
Ground water use restriction	Ground water direct contact	Use when: Ground water exceeds residential remediation objectives.
Residential use restrictions	Soil direct contact	Use when: Easily accessible soils exceed residential soil direct contact remediation objectives. The remedy includes caps, covers, or the possibility of methane generation. Unexploded ordnance may be present. Consider when: Multiple exposure pathways may present increased long-term exposure risk (e.g., a combination of highly contaminated soil, ground water, and soil gas).
Excavation prohibition, restrictions, or notice	Soil direct contact: excavation worker	Use when: Unexploded ordnance may be present. The remedy includes an engineered cap. The remedy includes a soil or vegetative cover. Contamination remains above excavation worker remediation objectives. Consider when: Residual contamination remains at residential properties (e.g., fuel oil contamination beneath a house).
Prohibition on building construction	Soil direct contact, ground water direct contact, and VI	Consider when: Very high levels of contamination will remain in place for a long time (particularly chlorinated volatile organic compounds (VOCs)). Hazardous waste or contamination remains contained in place. Landfills produce methane (additional regulations may apply).
Vapor mitigation systems ⁶⁹	VI	Use when: Indoor air contamination is confirmed, particularly for residences. Consider when: Ground water contamination exceeds VI screening levels.
Capping/covers ⁷⁰	Soil direct contact; migration to ground water	Use when: Easily accessible soil exceeds remediation objectives. Consider when: Vadose zone soils exceed migration to ground water remediation objectives in wellhead protection areas, susceptible areas, or landfills. The site or surrounding property contains potable water wells.
Agricultural use restriction	Ingestion; possible soil direct contact	Use when: Contaminants may bioaccumulate in food chain. Unexploded ordnance may be present. Engineered cap or cover must be maintained. Consider when: Easily accessible soils exceed residential soil direct contact remediation objectives. Agricultural use or gardening seems likely.

⁶⁹ Occupational Safety and Health Administration regulations may apply at commercial/industrial sites

⁷⁰ Caps may involve other obligations, such as storm water management. Restriction wording should include prohibition on disturbing the cap, and describe operation, maintenance, and possible monitoring of the cap.

12.8.3 Recording ERCs

ERCs are typically recorded at the end of remedy implementation process. However, there are instances (e.g., when the property is going to be transferred or when full implementation of a remedy may take a long time) in which it may be appropriate to record an ERC prior to the end of the remedial process.

The following documentation will typically be necessary before IDEM will grant closure:

- Copies of the most recent deed for the property to verify property ownership. The deed may also be used as the legal description to be attached to the ERC as an exhibit.
- Copies of recorded ERCs, signed by the property owner, which are part of the approved remedy.

The appropriate county health department and any relevant well permitting authority should each receive a copy of any recorded ERC that prohibits ground water use.

IDEM may require the owner of an existing or former hazardous waste facility [Resource Conservation and Recovery Act (RCRA)] or Comprehensive Environmental Response, Compensation, and Liability Information Site (CERCLIS) site to record an ERC on the property if the commissioner determines an ERC is necessary to protect human health and the environment. IDEM may require that such ERCs include a description of the identity, quantity, and location of hazardous substances remaining on the property⁷¹ and include provisions ensuring that ECs are undisturbed and effectively maintained.

12.8.4 ERC Modification or Termination

Certain circumstances may warrant modification or termination of an ERC. Some examples include site contamination no longer in excess of residential remediation objectives (through natural attenuation), the need to enhance restrictions due to a change in land use, or the complete or partial cleanup of a site (e.g., removing contaminated soil after a building is demolished). In most instances, confirmatory sampling will be necessary; therefore, advance coordination with IDEM is recommended.

Requests for an ERC modification or termination must be made in writing to the appropriate remediation program at IDEM. If IDEM concurs, a modification or termination document stating the reasons for the change, and IDEM's approval of the change, will need to be recorded in the same manner as the original ERC. A copy of the recorded modification or termination must be provided to IDEM.

⁷¹ Per IC 13-25-4-24(c)

12.9 Environmental Restrictive Ordinances (EROs)

An ERO is an ordinance adopted by a municipal corporation⁷² that seeks to control the use of ground water in a manner and to a degree that protects human health and the environment against unacceptable exposure to a release of hazardous substances or petroleum, or both. IDEM neither encourages nor discourages local governments from adopting EROs. It is up to the community to decide if adopting the ordinance is appropriate, taking into account current and future planned use of water resources. Per IC 13-25-5-8.5(e), IDEM must consider and give effect to EROs in evaluating risk based remediation proposals.

Because IDEM has the responsibility to ensure that remedies protect human health, it will review EROs for effectiveness. Effective EROs *prohibit* use of contaminated ground water for potable use and, depending on the contaminant(s), remaining concentrations, and plume dynamics, *may* prohibit use of ground water for other purposes (e.g., irrigation, cooling water, etc.). EROs may not be acceptable where plumes encroach or fall within a wellhead protection area (WHPA).⁷³

ERO effectiveness depends in part on understanding the present and future extent of ground water contamination, and ensuring that the ERO area fully encompasses that extent and a recommended additional buffer zone area. The CSM will inform design of the ERO area, and the design may also employ LOEs from a plume behavior evaluation (Section 4).

EROs that allow for special use exceptions or variances may unintentionally permit future exposure to contaminated ground water. Therefore, before granting a variance or exception, local government units should ensure that the proposed changes will not result in unacceptable exposure.

Depending on site-specific factors (unusually toxic or persistent contaminants, large and/or unstable plumes, etc.) IDEM may condition its approval of a remedy that relies on an ERO on the responsible person's compliance with continuing obligations. For example, IDEM may condition closure approval on the responsible person's continued ground water monitoring to ensure that the plume does not extend beyond the established boundaries of the ERO. In addition, the responsible person may need to take other remedial measures to control exposure via pathways (such as VI) not addressed by the ERO.

⁷² As defined in IC 36-1-2-10. For purposes of this guidance, a municipal corporation may include counties, municipalities, townships, local hospital corporations, or any entity that may enact an ordinance.

⁷³ Either the five-year time of travel of a delineated WHPA or a 3,000-foot fixed radius WHPA for a community water system. In accordance with IC 5-14-3-4(b)(19)(H), locations of approved WHPAs are not available on line. For general information regarding WHPAs consult the [IDEM Wellhead Protection Program web page](#); to determine whether a specific site is within a WHPA, contact IDEM's Ground Water Section via phone at 317-232-8603.

12.9.1 ERO Evaluation Criteria

IDEM will thoroughly evaluate EROs proposed as a component of a remedy. Approval of an ERO for one site does not ensure that other contaminated sites within the boundaries of the ERO will automatically be granted closure based on that same ERO. Use of an ERO as a proposed remedy will be evaluated on a case-by-case basis and evaluated according to the facts at each site. ERO evaluations will include at a minimum:

1. An assessment of plume extent and stability of the ground water plume. There should be sufficient understanding of the contaminant mass flux within a ground water plume to demonstrate that the contaminant plume will not migrate beyond the boundaries established in the ERO at levels that would not be considered protective of human health. This may be accomplished by:
 - a. Identifying characteristics of the site and the contaminant plume that provide a level of confidence that the plume is near its maximum extent and concentration;
 - b. Demonstrating that the contaminant plume is stable or shrinking, prior to acceptance of an ERO as an IC at a particular site; or
 - c. Long term monitoring that demonstrates that the contaminant plume does not extend beyond the boundaries established in the ERO.
2. Location of the site with respect to the ERO coverage area. The ERO coverage area should include the contaminant plume, predicted plume expansion area, and usually should include a buffer zone.
3. Evaluation of the site receptor survey. Section 2 provides guidance on identification of water well users. The receptor survey should thoroughly document all water use within and near the ERO boundaries including:
 - a. Potable well users within ERO extent (noting that some commercial/industrial wells are also used for potable water);
 - b. Commercial/industrial, dewatering, and irrigation wells;
 - c. Nearby water withdrawals (such as high-capacity wells near the ERO coverage area that may impact the contaminant plume);
 - d. Food or drug manufacturing facilities that utilize ground water wells.
4. Input from the local government unit that has enacted or that has proposed adoption of the ERO. Responsible parties and their consultants are encouraged to work directly with the local government unit. Because IDEM must rely on local governments to enforce EROs, municipal involvement throughout the review process will help IDEM evaluate the effectiveness of proposed EROs. Local governments should be contacted for information including:
 - a. Current and future local water resource planning;
 - b. Procedures for granting exceptions and variances to the ERO;
 - c. Local point of contact for ERO monitoring and compliance;
 - d. Notification provisions for EROs.

IDEM will notify local government units, including public water supply systems, in writing of any formal proposal to utilize an ERO at a particular site; and will request input on the items listed above if the information has not already been provided in the work plan.

5. Future effectiveness of the ERO (notice to interested parties). IDEM has the responsibility to ensure that remedial decisions are protective of human health. One of the documented limitations with the use of local ground water ordinances as an IC is that their continued

effectiveness hinges on public acceptance and awareness of the ordinance. In Indiana, this is particularly important given the lack of comprehensive state-wide well permitting requirements. Continued compliance with an ERO is necessary for the ERO to remain effective at managing risk and controlling completed or potential exposure pathways. Therefore, a plan or mechanism that ensures continuing public awareness of, and compliance with, the ERO can help to ensure that the ERO remains effective at managing exposure pathways. Some examples of such plans may include but are not limited to:

- a. If there is an existing local well permitting authority, notification to that entity of the existence of the ERO so that no potable wells, or wells that may exacerbate the contamination, are permitted.
 - b. Active monitoring and outreach by the local government unit so there is an ongoing public awareness of the ERO.
6. Evaluation of the ERO language. IDEM will evaluate each ERO on its own merits, and there is no requirement to follow a particular template. However, clear, unambiguous ERO language is recommended, such as:
- a. A statement indicating that the purpose of the ERO is to protect public health, and that the ordinance has been enacted as a response to ground water contamination.
 - b. Language that specifically excludes all use of ground water as a potable drinking water source for human and domestic purposes and prohibits the installation of new wells. An ordinance that just requires hookup to an existing water supply if supply lines are available, or one that allows existing wells to remain in use, may not be sufficiently protective of human health.
 - c. A clause that states that the ERO shall not in any way restrict or limit the ability of parties to perform remediation or to monitor contamination.
 - d. Language that limits the variances or exceptions allowed by the ERO⁷⁴, and requires the proper handling and disposal of water that is withdrawn.
 - e. If the ERO does not apply everywhere within the boundaries of the local government unit, the extent of the ERO should be easily identifiable and clearly defined within the ERO (e.g., map or illustration showing ERO boundaries, legal description of ordinance boundaries, or common reference points such as street names). A buffer zone outside of the modeled/measured contaminant plume area is recommended to compensate for the potential influence on the plume by nearby water withdrawals. ERO boundaries should be fixed and should not be subject to change without amending the ERO (e.g., no boundaries defined by zoning districts or the availability of public water).
 - f. Language that specifies that the ERO applies at all depths and is not limited to specific aquifers.

Final acceptance by IDEM will depend on ERO content, effectiveness, and adoption by the local unit of government. IDEM will not issue closure documentation prior to receiving certification from an authorized official that the approved ERO meets the requirements of the governing statute and has been lawfully adopted by the local unit of government.⁷⁵ IDEM will draft site closure documents so that closure decisions may be revisited if IDEM receives or becomes aware of new information. Examples of circumstances where this is likely to happen include: 1) the

⁷⁴ Examples include irrigation wells, heat pump wells, cooling water wells, fire protection wells, construction dewatering wells.

⁷⁵ The ERO copy should be certified [signed by the local authority and attested by the town clerk-treasurer (IC 36-5-2-10.2) or city clerk (IC 36-4-6-17)].

ERO is subsequently amended in a manner that allows contaminant plume migration beyond the established ERO control area or would allow exposure to contaminated ground water, 2) the ERO is repealed, 3) variances/exceptions are granted that could allow for exposure to contaminated ground water, or 4) there is evidence that exposure to contaminated ground water is occurring within an ERO approved as an IC. IDEM will enter all EROs utilized as a component of a site remedy in IDEM's Institutional Controls Registry (Section 12.11).

12.9.2 ERO Notification Provisions

In accordance with IC 36-1-6-11(c) and IC 36-2-4-8(4), EROs should include the following notice requirements:

- Giving written notice to IDEM not later than 60 days before amendment or repeal of the ERO;
- Giving written notice to IDEM not later than 30 days after passage, amendment, or repeal of an ERO.

Local government units should send these notices to IDEM at the following address:

IDEM, Office of Land Quality
Remediation Services Branch
Attn: Branch Chief
IGCN-Suite 1101
100 N Senate Ave
Indianapolis, IN 46204-2251

12.10 Engineering Controls (ECs)

ECs are physical measures, such as caps, vegetative covers, liners, slurry walls, vapor mitigation systems, extraction wells, or treatment methods that are capable of managing risk by:

- Controlling downward migration or infiltration of surface run-off or precipitation;
- Controlling migration of contaminants through the subsurface;
- Reducing contaminant levels; or
- Limiting or eliminating the completion of exposure pathways.

ECs should usually be supported by ICs, which ensure that the ECs stay in place and are maintained. For instance, ERCs should contain an obligation to operate and maintain any ECs used at the property. Written operation and maintenance plans should be developed and approved to ensure long term reliability of ECs.

12.11 Institutional Controls Registry

All sites where an IC has been utilized as a remedy component will be entered in IDEM's Institutional Controls Registry. The registry allows IDEM to track sites with ICs and provides external stakeholders (local government units, water utilities, real estate developers, concerned citizens, etc.) notice of sites subject to restricted use or obligations.

IDEM posts an [IC Registry summary report](#)⁷⁶ every month. The report contains site-specific information on each IC site such as the site address, city, county, remediation program, and a listing of land use restrictions and engineered controls. Additional information for each site can be found by clicking on the active links on the left hand side of the summary report; a window to

⁷⁶ http://www.in.gov/idem/files/institutional_controls_registry_report.pdf

IDEM's electronic Virtual File Cabinet is opened via one of the links, allowing the viewer to examine the base ERC, ordinance, or other relevant site document. The summary report also contains a link to the Indiana Map viewer, an interactive state-wide portfolio of GIS data that illustrates the location of each IC site.

12.12 Financial Assurance (FA)

Certain conditional closures may entail substantial future expense. Examples include remedies with large ongoing operational, maintenance, and/or sampling costs, or remedies that require periodic replacement of expensive, limited-life components. FA is a guarantee that funds will be available for such expenses in the event that the responsible party becomes insolvent. In this context, the term responsible party refers to the property owner, operator, or program participant who is providing the FA.

Therefore, where there is a substantial potential exposure risk from failure or need for eventual replacement of a costly remedy, IDEM may request that responsible parties establish and maintain FA to operate and maintain the remedy as a condition of closure. Forms of FA include a trust fund, an irrevocable standby letter-of-credit (LOC), a surety bond, insurance, and financial test or corporate guarantee. IDEM does not intend to routinely request FA, and will determine the need for FA based on the nature of the remedy, and the cost and consequences of its failure. When FA is considered necessary, it will be established under an agreement such as an Agreed Order or Voluntary Remediation Agreement.

12.12.1 FA: Determining Amount

The FA amount requested of the responsible party will be no less than the cost estimate to operate, maintain and inspect ECs for which FA is required for the duration of the risk. If the duration of the risk is expected to last for an extended time period, FA will need to be structured for an appropriate rolling time period.

Cost estimates to operate and maintain the remedy are based on the costs to the responsible party of hiring a third party to conduct the necessary activities. Generally the cost estimate is calculated by multiplying the annual cost estimate by the number of years necessary to operate and maintain the remedy. In cases where a remedy will require the eventual replacement of an engineered system or control, the cost estimate includes the cost of such replacement.

When a remedy involves FA, the closure mechanism will obligate the responsible party to review and update cost estimates at least once every five years, or more often if necessary to reflect changing circumstances, either by completing a new cost estimate in current dollars, or by multiplying the previous year's cost estimate by a specified inflation factor. The financial instruments will then need to be updated to cover the new cost estimates, and both the cost estimate and adjusted instruments submitted to IDEM.

Some costs, such as erosion control and ground water sampling, might be reduced over time as the cover vegetation matures and a meaningful amount of monitoring data is accumulated. Due to site-specific conditions, a shorter or longer remedy operation and maintenance period might be determined to be appropriate; however, FA will need to be maintained until the threat of harmful exposure no longer exists.

When evaluating the amount of FA needed to ensure the effectiveness of the remedy, IDEM will apply the following guidelines:

- Activities are described in an operation and maintenance plan in sufficient detail to facilitate review of the cost estimates.
- Cost estimates are itemized in detail.
- Cost estimates reflect the costs to hire a third party to conduct the remedy operation and maintenance activities.

12.12.2 FA: Timeframe for Establishing

After the nature and extent of contamination has been adequately determined, any interim remedial/clean-up activities have been completed, and a long-term remediation and/or exposure control method has been approved by IDEM, the responsible party should then proceed to obtain FA via one of the mechanisms listed below. IDEM will not issue a closure certification, covenant not to sue, or other closure documentation until after review and acceptance of the financial mechanism by IDEM staff. When closure is based on the provision and maintenance of FA and a responsible party fails to maintain adequate FA, the conditions for closure will no longer be met and IDEM may require the responsible party to take further action.

12.12.3 FA Instruments

The following five types of financial instruments are allowed under current RCRA rules. The responsible party may propose to use any of these instruments, and IDEM will evaluate the appropriateness of the requests. Each instrument is briefly described below.

1. *Trust Fund.* A trust fund is an agreement between three parties wherein the responsible party sets aside a specific amount of cash or funds, which is held in trust by a third party (the Trustee) for the purpose of paying for operation and maintenance of the remedy. IDEM is named as the beneficiary of the trust. In the event of bankruptcy, IDEM uses the funds in the trust to hire a third party contractor to operate and maintain the remedy.
2. *Letter of Credit.* An irrevocable standby LOC is a document issued by a bank or other financial institution that guarantees the payment of a responsible party's obligation for up to a stated dollar amount for a specified time. The responsible party arranges with a financial institution to issue an LOC payable to IDEM, assuring that the responsible party will pay for operation and maintenance costs when necessary. Essentially, an LOC substitutes the bank's credit for that of the responsible party, eliminating the financial risk to the state. An LOC is always accompanied by a stand-by trust agreement, which creates a trust into which IDEM will deposit the funds from the LOC in the event that it must cash in the LOC in order to continue operation and maintenance of the remedy should the responsible party be unable to do so.
3. *Surety Bond.* Like an LOC, a surety bond is an agreement between two parties. One party (the Surety) guarantees that the financial obligations of the second party (the Principal) will be met. For purposes of FA, the responsible party is the Principal. By means of the bond, the Surety guarantees to IDEM that it will meet the responsible party's obligations if the responsible party is unable to do so. A surety bond is always accompanied by a stand-by trust agreement, which creates a trust into which IDEM will deposit the face value of the surety bond in the event that the responsible party has failed to meet its obligations under the terms of the bond.

4. *Insurance.* A responsible party may obtain an insurance policy for a face value amount at least equal to the cost estimate for the operation and maintenance of the remedy. Through a policy, the insurer agrees to reimburse the responsible party upon direction from IDEM, for costs incurred to operate and maintain the remedy. The insurer must be licensed by a state (use of offshore insurers is not allowed) and may not cancel, terminate, or fail to renew the policy unless the responsible party fails to pay the premiums.
5. *Financial Test.* A responsible party may demonstrate the ability to cover the costs of operation and maintenance of the remedy without a third-party guarantee by passing a financial test. With this form of FA, the company is responsible for paying costs associated with operation and maintenance of the remedy. These tests document that the responsible party has sufficient assets located within the United States to cover operation and maintenance costs. Only companies with large net assets (i.e., net worth) relative to the total estimated costs of remedy operation and maintenance are likely to pass a financial test. The responsible party demonstrates that they continue to pass the financial test by submitting updated information to IDEM after the close of each fiscal year.

A responsible party may obtain a written guarantee from a separate but related company to cover remedy operation and maintenance costs in the event the responsible party is unable to do so. The related company demonstrates the ability to serve as a guarantor for the responsible party by passing the financial test.

Appendix A: Screening Levels

A.1 Introduction

Indiana Code (IC) 13-25-5-8.5(d)(1) directs responsible parties to specify remediation objectives for sites where releases occur. There are several general classes of remediation objectives. This section concerns one such class, specifically:

*Levels of hazardous substances and petroleum calculated by the department using standard equations and default values for particular hazardous substances or petroleum.*⁷⁷

The Indiana Department of Environmental Management (IDEM) refers to the levels defined above as **screening levels**. IDEM relies on the values found in the Regional Screening Level (RSL) tables (U.S. EPA, 2011b and updates) and guidance from the *Regional Screening Level User's Guide* (U.S. EPA, 2011) when deriving screening levels. However, IDEM's screening levels are not necessarily the same as those that appear in the RSLs. This section describes the derivation of IDEM screening levels from RSLs and provides the rationale for any differences.

When adapting screening levels from the RSLs, IDEM adjusts the target cancer risk for carcinogens from 10^{-6} to 10^{-5} . The standard target hazard quotient for noncarcinogenic risk is 1. The noncancer toxicity model assumes that a threshold exists for toxic effects and that there are no noncancer toxic effects when the hazard quotient is less than 1.

Screening levels are not necessarily closure levels. They are simply one type of remediation objective. However, when appropriate investigation of a release shows sample results below screening levels, the release is typically eligible for closure. Table A-6 contains screening levels for more than seven hundred individual chemicals or mixtures of chemicals.

IDEM will revise its screening levels yearly, using the procedures described herein. IDEM will base the revision for each year on the U.S. EPA RSL table that is in effect on the last day of the preceding year. All versions of the IDEM screening level tables will be available through links on the [Risk-based closure web page](#).⁷⁸

A.2 Chemical Names and Numbers

Table A-6 contains eleven columns. Up to nine of those columns contain screening levels for each chemical, specific to certain exposure scenarios. Subsequent subsections describe how IDEM derives each type of screening level.

The first column contains the names of individual chemicals or mixtures of chemicals. Most entries in this column appear in alphabetical order. However, some classes of chemicals appear under a common, overarching name. For example, polynuclear aromatic hydrocarbons appear as a group, under that name. Note that many chemicals have multiple names, and it may be necessary to look in more than one location in the table to find specific chemicals.

The second column contains Chemical Abstract Service (CAS) numbers for those chemicals that have them. CAS numbers are unique chemical identifiers, and may be useful for finding chemicals that have multiple common names.

⁷⁷ IC 13-25-8.5(d)(1)

⁷⁸ <http://www.in.gov/idem/4153.htm>

A.3 Soil Direct Contact

Soil direct contact screening levels assume exposure via ingestion, dermal contact, and inhalation of volatiles and particulates. Table A-6 contains soil direct contact screening levels for residential, commercial/industrial, and excavation worker scenarios.

The soil direct contact screening levels that appear in Table A-6 are not always health protective levels. In some cases, the soil direct contact screening levels default to one of two **limiting factors**: the soil saturation limit, or the maximum cap.

The **soil saturation limit** (C_{sat}) is the concentration in soil at which a chemical exceeds the absorptive limits of the soil particles. Chemicals at concentrations above C_{sat} may be present as free phase product, and U.S. EPA (2011) notes that the presence of free phase chemicals may violate assumptions underlying the screening levels equations. IDEM intends the soil saturation cap to prompt further evaluation of sites that may contain free phase chemicals. IDEM uses C_{sat} values from the RSL Summary Table, where available, to cap soil direct contact screening levels.

U.S. EPA (2011) notes that chemical concentrations greater than ten percent may violate some screening level equation assumptions (e.g., soil adherence and wind-borne dispersion assumptions). For this reason, IDEM caps soil direct contact screening levels at 100,000 milligrams per kilogram (mg/kg; ten percent by weight). Therefore, the soil direct contact screening levels that appear in Table A-6 are the lowest of the health protective level, C_{sat} (if any), and the cap.

A.3.1 Soil Direct Contact: Residential

The third column of Table A-6 contains screening levels, expressed in mg/kg, for the residential soil direct contact exposure scenario. IDEM derives these levels from values appearing in the RSL resident soil table as follows:

1. Multiply the carcinogenic screening level (if any) appearing in the RSL resident soil table by ten to produce a carcinogenic screening level at a target cancer risk of 10^{-5} . Multiply the resulting number by a factor of 1.4 to account for IDEM's exposure frequency assumption (250 days per year) versus the U.S. EPA default exposure frequency (350 days per year).
2. Select the lower of the following as the IDEM residential soil direct contact screening level:
 - The 10^{-5} carcinogenic screening level (if any)
 - The noncarcinogenic screening level (if any) appearing in the RSL resident soil table, multiplied by 1.4
 - C_{sat}
 - 100,000 mg/kg

For the residential soil direct contact exposure scenario, IDEM adopted U.S. EPA's residential screening level for lead. U.S. EPA considers this level protective of young children in a residential setting (U.S. EPA, 1994).

A.3.2 Soil Direct Contact: Commercial/Industrial

The fourth column of Table A-6 contains screening levels, expressed in mg/kg, for the commercial/industrial soil direct contact exposure scenario. IDEM derives these levels from values that appear in the RSL Industrial Soil Table as follows:

1. Multiply the value (if any) appearing in the carcinogenic screening level column of the RSL Industrial Soil Table by ten to produce a carcinogenic screening level at a target cancer risk of 10^{-5} .
2. Select the lower of the following as the IDEM commercial/industrial soil direct contact screening level:
 - The 10^{-5} carcinogenic screening level (if any)
 - The noncarcinogenic screening level (if any) from the RSL Industrial Soil Table
 - C_{sat}
 - 100,000 mg/kg

IDEM calculates lead screening levels for the commercial/industrial scenario using U.S. EPA's Adult Lead Model (U.S. EPA, 2003b).

A.3.3 Soil Direct Contact: Excavation Worker

The fifth column of Table A-6 contains screening levels, expressed in mg/kg, for the excavation worker soil direct contact scenario. The RSLs do not contain screening levels for the excavation worker scenario. Therefore, IDEM calculates excavation worker soil direct contact screening levels using the industrial soil equations in U.S. EPA (2011) and somewhat different exposure assumptions than those that U.S. EPA uses to derive commercial/industrial soil direct contact screening levels. Table A-1 illustrates differences in the assumptions that IDEM uses to calculate commercial/industrial and excavation worker soil direct contact screening levels.

Table A-1: Exposure Assumptions

	Commercial/ Industrial	Excavation Worker
Averaging Time (years)	25	1
Exposure Frequency (days/year)	250	45
Exposure Duration (years)	25	1
Ingestion Rate (milligrams/day)	100	330

Application of these parameter assumptions and the equations in Section 4.2 of U.S. EPA (2011) yields the following relationships between screening levels for the excavation worker and commercial/industrial worker exposure scenarios:

Equation A-1: Ingestion of Noncarcinogens for the Excavation Worker Scenario

$$SL_{Exc-Ing-NC} = \left(\frac{500}{297} \right) SL_{CI-Ing-NC}$$

Where $SL_{Exc-Ing-NC}$ is IDEM's excavation worker screening level for the noncarcinogenic ingestion exposure pathway and $SL_{CI-Ing-NC}$ is IDEM's commercial/industrial screening level for the noncarcinogenic ingestion exposure pathway.

Equation A-2: Dermal Contact with Noncarcinogens for the Excavation Worker Scenario

$$SL_{Exc-Der-NC} = \left(\frac{50}{9} \right) SL_{CI-Der-NC}$$

Where $SL_{Exc-Der-NC}$ is IDEM's excavation worker screening level for the noncarcinogenic dermal contact exposure pathway and $SL_{CI-Der-NC}$ is IDEM's commercial/industrial screening level for the noncarcinogenic dermal contact exposure pathway.

Equation A-3: Inhalation of Noncarcinogens for the Excavation Worker Scenario

$$SL_{Exc-Inh-NC} = \left(\frac{50}{9} \right) SL_{CI-Inh-NC}$$

Where $SL_{Exc-Inh-NC}$ is IDEM's excavation worker screening level for the noncarcinogenic inhalation exposure pathway and $SL_{CI-Inh-NC}$ is IDEM's commercial/industrial screening level for the noncarcinogenic inhalation exposure pathway.

Equation A-4: Ingestion of Carcinogens for the Excavation Worker Scenario

$$SL_{Exc-Ing-Carc} = \left(\frac{12,500}{297} \right) SL_{CI-Ing-Carc}$$

Where $SL_{Exc-Ing-Carc}$ is IDEM's excavation worker screening level for the carcinogenic ingestion exposure pathway and $SL_{CI-Ing-Carc}$ is IDEM's commercial/industrial screening level for the carcinogenic ingestion exposure pathway.

Equation A-5: Dermal Contact with Carcinogens for the Excavation Worker Scenario

$$SL_{Exc-Der-Carc} = \left(\frac{1250}{9} \right) SL_{CI-Der-Carc}$$

Where $SL_{Exc-Der-Carc}$ is IDEM's excavation worker screening level for the carcinogenic dermal contact exposure pathway and $SL_{CI-Der-Carc}$ is IDEM's commercial/industrial screening level for the carcinogenic dermal contact exposure pathway.

Equation A-6: Inhalation of Carcinogens for the Excavation Worker Scenario

$$SL_{Exc-Inh-Carc} = \left(\frac{1250}{9} \right) SL_{CI-Inh-Carc}$$

Where $SL_{Exc-Inh-Carc}$ is IDEM's excavation worker screening level for the carcinogenic inhalation exposure pathway and $SL_{CI-Inh-Carc}$ is IDEM's commercial/industrial screening level for the carcinogenic inhalation exposure pathway.

Equation A-7: Noncarcinogenic Screening Level for the Excavation Worker Scenario

$$SL_{Exc-NC} = \frac{1}{\left(\frac{1}{SL_{Exc-Ing-NC}}\right) + \left(\frac{1}{SL_{Exc-Der-NC}}\right) + \left(\frac{1}{SL_{Exc-Inh-NC}}\right)}$$

Where the value of any quotient in parentheses is set to zero when its denominator is zero.

Equation A-8: Carcinogenic Screening Level for the Excavation Worker Scenario

$$SL_{Exc-Carc} = \frac{1}{\left(\frac{1}{SL_{Exc-Ing-Carc}}\right) + \left(\frac{1}{SL_{Exc-Der-Carc}}\right) + \left(\frac{1}{SL_{Exc-Inh-Carc}}\right)}$$

Where the value of any quotient in parentheses is set to zero when its denominator is zero.

IDEM selects the lower of the noncarcinogenic screening level (Equation A-7) and carcinogenic screening level (Equation A-8), C_{sat} , and 100,000 mg/kg as the IDEM excavation worker screening level. IDEM calculates lead screening levels for the excavation worker scenario using U.S. EPA's Adult Lead Model (U.S. EPA, 2003b).

Note that this approach uses the same chronic toxicity parameter values employed in the derivation of commercial/industrial screening levels. Where available, subchronic toxicity parameter values may be more appropriate when deriving excavation worker screening levels.

A.4 Ground Water

Table A-6 includes screening levels for both residential ground water direct contact and residential migration to ground water. Residential ground water direct contact screening levels account for exposure through ingestion of water, dermal contact with water, and inhalation of volatiles arising from ground water use in the home.

Residential migration to ground water screening levels apply to chemicals present in vadose zone soils. Exceedance of residential migration to ground water screening levels suggests the potential for chemicals in the soil to leach to ground water at concentrations that exceed residential ground water direct contact screening levels. Consistent with U.S. EPA, IDEM does not provide screening levels for commercial/industrial ground water direct contact or commercial/industrial migration to ground water scenarios.

A.4.1 Ground Water: Residential Migration to Ground Water

The sixth column of Table A-6 contains residential migration to ground water screening levels, expressed in mg/kg. IDEM calculates these screening levels using Equation A-9:

Equation A-9: Migration to Ground Water Screening Levels

$$SL_{MTG} = SL_{GW} \times DAF \times \left[(K_{oc} \times f_{oc}) + \frac{\theta_w + (\theta_A \times H')}{\rho_b} \right]$$

Where

- SL_{MTG} = Migration to ground water screening level, in mg/kg
- SL_{GW} = Ground water screening level, in micrograms per liter ($\mu\text{g/L}$), from column seven of Table A-6. This level may be a maximum contaminant level (MCL) for some chemicals.
- DAF = Dilution attenuation factor (DAF, unitless). As recommended in US E.P.A. (2011) for source areas of 0.5 acres, IDEM uses a default DAF value of 20. IDEM will accept other values that are appropriately derived using site-specific data. See Section 4.11.5 of US E.P.A. (2011) for additional information.
- K_{oc} = Chemical-specific organic carbon partition coefficient, in liters per kilogram (L/kg). For most chemicals, IDEM uses K_{oc} values from the RSL Chemical-specific Parameters Supporting Table when calculating IDEM migration to ground water screening levels. For metals, IDEM uses the K_d values appearing in Section 4.11 of U.S. EPA (2011) in place of ($K_{oc} \times f_{oc}$).
- f_{oc} = Fraction of organic carbon, in grams per gram (g/g). IDEM uses a default value of 0.002 when calculating IDEM migration to ground water screening levels. IDEM will accept other values that are appropriately derived from site-specific data.
- θ_w = Water filled soil porosity, in liters of water per liters of soil. IDEM uses a default value of 0.3 when calculating IDEM migration to ground water screening levels. IDEM will accept other values that are appropriately derived from site-specific data.
- θ_A = Air filled soil porosity, in liters of air per liters of soil. IDEM uses a default value of 0.13 when calculating IDEM migration to ground water screening levels. IDEM will accept other values that are appropriately derived from site-specific data.
- H' = Chemical-specific dimensionless Henry's Law constant (unitless). IDEM uses values from the RSL Chemical-specific Parameters Supporting Table when calculating IDEM migration to ground water screening levels.
- ρ_b = Dry soil bulk density, in kilograms per liter (kg/L). IDEM uses a default value of 1.5 when calculating IDEM migration to ground water screening levels. IDEM will accept other values that are appropriately derived from site-specific data.

pH has a significant effect on the ability of metals and ionizing organics (i.e., carboxylic acids, phenols, and amines) to migrate through the soil column, and thus to ground water. The RSLs for migration to ground water assume a pH of 6.8⁷⁹. The migration to ground water screening levels are not applicable outside a soil pH range of 6.0 to 8.0. Site soils outside this range merit development of site-specific migration to ground water screening levels for ionizing organics or metals at the site. U.S. EPA (1996b) provides guidance for determining pH-specific K_d values. Alternatively, see Section 9.10 for guidance on the synthetic precipitation leaching procedure.

⁷⁹ Except beryllium, cadmium, mercury, nickel, and silver.

A.4.2 Ground Water: Residential Direct Contact

The seventh column of Table A-6 contains ground water screening levels for the residential consumption scenario, expressed in micrograms per liter ($\mu\text{g}/\text{l}$). For chemicals that have an MCL, IDEM uses the MCL as the residential ground water screening level. For chemicals without MCLs, IDEM derives residential ground water screening levels from values that appear in the RSL Tapwater Supporting Table as follows:

1. Multiply the value (if any) appearing in the carcinogenic screening level column of the RSL Tapwater Supporting Table by ten to produce a carcinogenic screening level at a target cancer risk of 10^{-5} .
2. Select the lower of the 10^{-5} carcinogenic screening level (if any) and value (if any) appearing in the noncarcinogenic screening level column of the RSL Tapwater Supporting Table as the IDEM residential ground water screening level.

A.5 Vapor

IDEM calculates screening levels for residential indoor air, commercial/industrial indoor air, and vapor intrusion ground water screening levels (VI GWSLs) for both residential and commercial/industrial land uses. Indoor air screening levels assume target cancer risk of 10^{-5} for both residential and commercial/industrial scenarios. Indoor air action levels for both scenarios assume a target cancer risk of 10^{-4} . Residential land use assumes a 30-year exposure, and commercial/industrial assumes a 25-year exposure. IDEM only calculates vapor intrusion screening levels for chemicals with inhalation toxicity data.

A.5.1 Vapor: Residential Ground Water

The eighth column of Table A-6 contains residential VI GWSLs for a dozen chemicals, expressed in $\mu\text{g}/\text{L}$. IDEM calculates VI GWSLs using Equation A-10:

Equation A-10: Vapor Intrusion Ground Water Screening Levels

$$VIGWSL = \frac{C_{IA}}{\alpha_{GW} \times H'_{TS} \times 1000L/m^3}$$

Where:

$VIGWSL$ = Vapor intrusion ground water screening level, in $\mu\text{g}/\text{L}$.

C_{IA} = Residential indoor air screening level, in $\mu\text{g}/\text{m}^3$

α_{GW} = Ground water to indoor air attenuation factor (unitless). IDEM's default ground water to indoor air attenuation factor is 0.001.

H'_{TS} = Temperature adjusted Henry's Law constant. When calculating VI GWSLs, IDEM uses the methodology in U.S. EPA (2001a) to adjust Henry's Law constants, assuming a soil temperature of 12.5°C .

A.5.2 Vapor: Commercial/Industrial Ground Water

The ninth column of Table A-6 contains commercial/industrial VI GWSLs for a dozen chemicals, expressed in $\mu\text{g/L}$. IDEM uses the same methodology when calculating residential and commercial/industrial VI GWSLs, except that the latter employs an attenuation factor of 0.001 and commercial/industrial indoor air screening levels instead of residential indoor air screening levels in Equation A-10.

A.5.3 Vapor: Chronic Residential Indoor Air

The tenth column of Table A-6 contains screening levels for the chronic residential indoor air scenario, expressed in $\mu\text{g/m}^3$. IDEM derives these levels from values that appear in the RSL Resident Air Supporting Table as follows:

1. Multiply the value (if any) appearing in the carcinogenic screening level column of the RSL Resident Air Supporting Table by ten to produce a residential indoor air carcinogenic screening level at a target cancer risk of 10^{-5} .
2. Select the lower of the 10^{-5} carcinogenic screening level (if any) and the value (if any) appearing in the noncarcinogenic screening level column of the RSL Resident Air Supporting Table as the IDEM residential indoor air screening level.

A.5.4 Vapor: Chronic Commercial/Industrial Indoor Air

The eleventh column of Table A-6 contains screening levels for the chronic commercial/industrial indoor air scenario, expressed in $\mu\text{g/m}^3$. IDEM derives these levels from values that appear in the RSL Industrial Air Supporting Table as follows:

1. Multiply the value (if any) appearing in the carcinogenic screening level column of the RSL Industrial Air Supporting Table by ten to produce a commercial/industrial indoor air carcinogenic screening level at a target cancer risk of 10^{-5} .
2. Select the lower of the 10^{-5} carcinogenic screening level (if any) and the value (if any) appearing in the noncarcinogenic screening level column of the RSL Industrial Air Supporting Table as the IDEM commercial/industrial indoor air screening level.

A.6 Other Screening Levels

IDEM does not provide screening levels for every conceivable exposure scenario. Evaluation of risk via some exposure pathways will require site-specific risk assessment. In other cases, responsible parties may wish to perform site-specific risk assessments for routine exposure scenarios using assumptions that more accurately reflect site conditions and exposures.

Examples of possible site-specific exposure pathways appear in Table A-2 below. For specific guidance on conducting risk assessments, refer to U.S. EPA guidance (including but not limited to U.S. EPA 1989, 1991a, 1996a, 1996b, 2002, 2004a, 2009d). Screening levels based on a site-specific risk assessment may take into account other aspects of risk management, including institutional controls. As noted in Section 11, an ecological risk assessment is appropriate for sites where releases may impact ecologically sensitive areas.

Table A-2: Site-specific Exposure Media and Associated Pathways

Medium	Examples of Associated Pathways
Soil	<ul style="list-style-type: none"> ● Runoff to surface water ● Biota (e.g., produce consumption, plant uptake associated with meat, dairy and game)
Ground water	<ul style="list-style-type: none"> ● Industrial process water ● Inhalation of volatiles from ground water in excavations ● Biota uptake in irrigated produce
Air	<ul style="list-style-type: none"> ● Particulate deposition on soil ● Biota uptake from air deposition on plants and soil ● Biota uptake from air deposition on surface waters
Surface water	<ul style="list-style-type: none"> ● Recreational ● Drinking water ● Biota
Sediment	<ul style="list-style-type: none"> ● Recreational ● Biota

U.S. EPA provides screening level calculators for some exposure scenarios not covered in the RSL tables. These include calculators for recreational surface water exposure, fish consumption, and recreational soil direct contact exposure (Section A.6.1).

A.6.1 Recreational Exposure

Recreational exposure can occur in a wide variety of settings: sports fields, playgrounds, public parks, rail trails, etc. The vast array of potential recreational land uses makes it infeasible for IDEM to publish a single screening level applicable to every recreational scenario. Fortunately, U.S. EPA has developed a [recreational screening level calculator](#)⁸⁰ that will generate screening levels based on site-specific parameters provided by users. IDEM offers suggested parameter input values for the U.S. EPA calculator for three common recreational exposure scenarios: trails (Section A.6.1.2), sports fields (Section A.6.1.3), and community parks (Section A.6.1.4). Table A-7 also contains a small set of recreational soil direct contact screening levels for the three scenarios listed above. Alternatively, IDEM will evaluate proposals to use parameter values that are appropriate for the exposure scenario at a particular site.

A.6.1.1 Recreational Exposure: General Considerations

IDEM recommends adopting certain parameter values when using the U.S. EPA recreational screening level calculator, regardless of the recreational exposure scenario. For example, IDEM employs a target cancer risk of 10^{-5} when deriving screening levels, rather than the U.S. EPA default screening target cancer risk of 10^{-6} , and recommends that users elect to calculate recreational screening levels using a target cancer risk of 10^{-5} . The calculator also provides an opportunity for users to select particulate emission factor and volatilization factor values suited to specific climatic zones. IDEM recommends selecting factors from a city with a climate similar to that of the site under evaluation (e.g., Chicago, Illinois, Cleveland, Ohio, Harrisburg, Pennsylvania, or Huntington, West Virginia). The calculator allows adjustment of the site size parameter and the fraction of vegetative cover parameter. Users should select the site size and vegetative cover parameter values that most closely resemble the site under evaluation.

⁸⁰ Currently at http://epa-prgs.ornl.gov/cgi-bin/chemicals/csl_search

A.6.1.2 Recreational Exposure: Trail Scenario

The trail scenario applies to recreational soil direct contact at a capped trail, such as a paved multi-use path for walking, cycling, jogging, skating, and other activities.

Table A-3: Recommended Exposure Factor Inputs for Trail Scenarios

Age Segment (yr)	Adherence Factor ^a (AF) (mg/cm ²)	Body Weight ^b (BW) (kg)	Exposure Duration (ED) (yr)	Exposure Frequency ^c (EF) (day/yr)	Exposure Time ^d (ET) (hr/event)	Intake Rate ^c (IRS) (mg/day)	Skin Surface Area ^e (SA) (cm ² /day)
0 thru 2	0.04	9	2	75	1	6	2600
2 thru 6	0.04	16	4	75	1	6	2900
6-16	0.04	44	10	104	1	6	5000
16 thru 30	0.01	76	14	75	1	3	5700

Sources of parameter values:

^aU.S. EPA. 2004b (Exhibit 3-3)

^bU.S. EPA. 2011e (Table 8-1)

^cIDEM. 2011. Best professional judgment.

^dWolter *et al.* 2001.

^eU.S. EPA. 2004b (Exhibit C-1)

A.6.1.3 Recreational Exposure: Sports Field Scenario

The sports field scenario applies to recreational soil direct contact in areas used for organized sports (e.g., soccer, baseball, softball, lacrosse, kickball, etc.) Note that this scenario assumes an exposure frequency of thirty days. At some high-use sports fields it may be necessary to evaluate whether this assumption is reasonable. If a higher frequency is appropriate, then adjust the exposure frequency values in Table A-4 accordingly.

Table A-4: Recommended Exposure Factor Inputs for Sports Field Scenario

Age Segment (yr)	Adherence Factor ^{a,c} (AF) (mg/cm ²)	Body Weight ^b (BW) (kg)	Exposure Duration (ED) (yr)	Exposure Frequency ^c (EF) (day/yr)	Exposure Time ^c (ET) (hr/event)	Intake Rate ^d (IRS) (mg/day)	Skin Surface Area ^e (SA) (cm ² /day)
0 thru 2	0.12	9	2	30	2	100	2600
2 thru 6	0.12	16	4	30	2	100	2900
6-16	0.12	44	10	30	3	100	5000
16 thru 30	0.07	76	14	30	2	50	5700

Sources of parameter values:

^aU.S. EPA. 2004b (Exhibit 3-3)

^bU.S. EPA. 2011e (Table 8-1)

^cIDEM. 2011. Best professional judgment.

^dU.S. EPA. 2011e (Table 5-1)

^eU.S. EPA. 2004b (Exhibit C-1)

A.6.1.4 Recreational Exposure: Community Park Scenario

The community park scenario applies to recreational soil direct contact at properties designed to provide a wide variety of recreational opportunities. Such properties often have multiple facilities, including trails and sports fields in addition to children's play areas, picnic shelters, basketball courts, tennis courts, baseball/softball fields, jogging trails, nature trails, dog walking areas, football fields, amphitheatres and/or other facilities. Note that residential screening levels may be better suited to playground areas that present an opportunity for high daily soil direct contact rates for pre-school children.

Table A-5: Recommended Exposure Factor Inputs for Community Park Scenario

Age Segment (yr)	Adherence Factor ^a (AF) (mg/cm ²)	Body Weight ^b (BW) (kg)	Exposure Duration (ED) (yr)	Exposure Frequency ^c (EF) (day/yr)	Exposure Time ^c (ET) (hr/event)	Intake Rate ^d (IRS) (mg/day)	Skin Surface Area ^e (SA) (cm ² /day)
0 thru 2	0.2	9	2	75	2	100	2600
2 thru 6	0.2	16	4	75	2	100	2900
6-16	0.2 ^c	44	10	104	2	100	5000
16 thru 30	0.07	76	14	75	2	50	5700

Sources of parameter values:

^aU.S. EPA. 2004b (Exhibit 3-3)

^bU.S. EPA. 2011e (Table 8-1)

^cIDEM. 2011. Best professional judgment.

^dU.S. EPA. 2011e (Table 5-1)

^eU.S. EPA. 2004b (Exhibit C-1)

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
ALAR	1596-84-5	380 C	960 C	56000 C	0.16 C	37 C		4.8 C	24 C	
Acephate	30560-19-1	340 N	2000 C	4200 N	0.28 N	63 N				
Acetaldehyde	75-07-0	120 N	370 N	620 N	0.077 N	19 N		9.4 N	39 N	
Acetochlor	34256-82-1	1700 N	12000 N	20000 N	4.3 N	270 N				
Acetone	67-64-1	85000 N	100000 L	100000 L	49 N	12000 N		32000 N	140000 N	
Acetone Cyanohydrin	75-86-5	280 N	2100 N	3600 N	0.14 N	34 N		63 N	260 N	
Acetonitrile	75-05-8	1200 N	3700 N	6200 N	0.54 N	130 N		63 N	260 N	
Acetophenone	98-86-2	2500 S	2500 S	2500 S	9.1 N	1500 N				
Acetylaminofluorene, 2-	53-96-3	1.8 C	4.5 C	260 C	0.013 C	0.14 C		0.019 C	0.094 C	
Acrolein	107-02-8	0.21 N	0.65 N	1.1 N	0.00017 N	0.041 N		0.021 N	0.088 N	
Acrylamide	79-06-1	3.2 C	34 C	2000 C	0.0018 C	0.43 C		0.096 C	1.2 C	
Acrylic Acid	79-10-7	42000 N	100000 L	100000 L	31 N	7700 N		1 N	4.4 N	
Acrylonitrile	107-13-1	3.4 C	12 C	120 N	0.002 C	0.45 C		0.36 C	1.8 C	
Adiponitrile	111-69-3	100000 L	100000 L	100000 L				6.3 N	26 N	
Alachlor	15972-60-8	120 C	310 C	10000 N	0.033 M	2 M				
Aldicarb	116-06-3	85 N	620 N	1000 N	0.075 N	15 N				
Aldicarb Sulfone	1646-88-4	85 N	620 N	1000 N	0.07 N	16 N				
Aldrin	309-00-2	0.41 C	1 C	31 N	0.0069 C	0.0021 C		0.005 C	0.025 C	
Allyl	74223-64-6	21000 N	100000 L	100000 L	29 N	3800 N				
Allyl Alcohol	107-18-6	420 N	3100 N	5100 N	0.32 N	78 N		0.1 N	0.44 N	
Allyl Chloride	107-05-1	2.5 N	7.5 N	13 N	0.013 N	2.1 N		1 N	4.4 N	
Aluminum	7429-90-5	100000 L	100000 L	100000 L	1000000 R	16000 N		5.2 N	22 N	
Aluminum Phosphide	20859-73-8	43 N	410 N	690 N		6.2 N				
Amdro	67485-29-4	25 N	180 N	310 N	34000 N	4.7 N				
Ametryn	834-12-8	770 N	5500 N	9300 N	2.5 N	120 N				
Aminobiphenyl, 4-	92-67-1	0.32 C	0.82 C	49 C	0.0027 C	0.026 C		0.0041 C	0.02 C	
Aminophenol, m-	591-27-5	6900 N	49000 N	82000 N	9.1 N	1200 N				
Aminophenol, p-	123-30-8	1700 N	12000 N	20000 N	2.4 N	310 N				
Amitraz	33089-61-1	210 N	1500 N	2600 N	61 N	5.9 N				
Ammonia	7664-41-7							100 N	440 N	
Ammonium Sulfamate	7773-06-0	22000 N	100000 L	100000 L		3100 N				
Aniline	62-53-3	600 N	3000 C	7300 N	0.75 N	110 N		1 N	4.4 N	
Anthraquinone, 9,10-	84-65-1	170 C	430 C	2000 N	2.5 C	12 C				
Antimony (metallic)	7440-36-0	43 N	410 N	690 N	5.4 N	6 N				
Antimony Pentoxide	1314-60-9	55 N	510 N	860 N		7.5 N				
Antimony Potassium Tartrate	11071-15-1	98 N	920 N	1500 N		13 N				
Antimony Tetroxide	1332-81-6	43 N	410 N	690 N		6 N				
Antimony Trioxide	1309-64-4	100000 L	100000 L	100000 L				0.21 N	0.88 N	
Apollo	74115-24-5	1100 N	8000 N	13000 N	220 N	180 N				
Aramite	140-57-8	270 C	690 C	39000 C	6.1 C	27 C		3.4 C	17 C	
Arsenic, Inorganic	7440-38-2	5.5 C	16 C	430 N	5.9 M	10 M		0.0057 C	0.029 C	
Arsine	7784-42-1	0.38 N	3.6 N	6.1 N		0.054 N		0.052 N	0.22 N	
Assure	76578-14-8	770 N	5500 N	9300 N	29 N	93 N				
Asulam	3337-71-1	4300 N	31000 N	52000 N	4 N	780 N				
Atrazine	1912-24-9	29 C	75 C	4200 C	0.039 M	3 M				
Auramine	492-80-8	7.7 C	20 C	1200 C	0.12 C	0.67 C		0.097 C	0.49 C	
Avermectin B1	65195-55-3	34 N	250 N	420 N	220 N	6.3 N				
Azobenzene	103-33-3	71 C	230 C	11000 C	0.15 C	1 C		0.78 C	4 C	
Barium	7440-39-3	21000 N	100000 L	100000 L	1700 M	2000 M		0.52 N	2.2 N	

Appendix A: Screening Levels

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Baygon	114-26-1	340 N	2500 N	4200 N	0.39 N	61 N				
Bayleton	43121-43-3	2500 N	18000 N	31000 N	6.9 N	430 N				
Baythroid	68359-37-5	2100 N	15000 N	26000 N	450 N	87 N				
Benefin	1861-40-1	25000 N	100000 L	100000 L	790 N	1200 N				
Benomyl	17804-35-2	4300 N	31000 N	52000 N	13 N	750 N				
Bentazon	25057-89-0	2500 N	18000 N	31000 N	1.9 N	440 N				
Benzaldehyde	100-52-7	1200 S	1200 S	1200 S	6.7 N	1500 N				
Benzene	71-43-2	15 C	54 C	750 N	0.051 M	5 M	24 C	120 C	3.1 C	16 C
Benzenediamine-2-methyl sulfate, 1,4-	6369-59-1	17 N	120 N	200 N		3.1 N				
Benzenethiol	108-98-5	110 N	1000 N	1300 S	0.17 N	13 N				
Benzidine	92-87-5	0.007 C	0.075 C	4.2 C	0.000047 C	0.00092 C			0.00014 C	0.0018 C
Benzoic Acid	65-85-0	100000 L	100000 L	100000 L	270 N	58000 N				
Benzotrichloride	98-07-7	0.69 C	2.2 C	93 C	0.0011 C	0.026 C				
Benzyl Alcohol	100-51-6	8500 N	62000 N	100000 L	7.3 N	1500 N				
Benzyl Chloride	100-44-7	14 C	49 C	190 N	0.017 C	0.77 C			0.5 C	2.5 C
Beryllium and compounds	7440-41-7	220 N	2000 N	3300 N	63 M	4 M			0.01 C	0.051 C
Bidrin	141-66-2	8.5 N	62 N	100 N	0.0075 N	1.6 N				
BifenoX	42576-02-3	770 N	5500 N	9300 N	11 N	75 N				
Biphenthrin	82657-04-3	1300 N	9200 N	15000 N	21000 N	230 N				
Biphenyl, 1,1'-	92-52-4	71 N	210 N	210 S	0.17 N	0.83 N			0.42 N	1.8 N
Bis(2-chloro-1-methylethyl) ether	108-60-1	64 C	220 C	1000 S	0.023 C	3.1 C			2.4 C	12 C
Bis(2-chloroethoxy)methane	111-91-1	250 N	1800 N	3100 N	0.22 N	47 N				
Bis(2-chloroethyl)ether	111-44-4	2.9 C	10 C	750 C	0.00063 C	0.12 C			0.074 C	0.37 C
Bis(2-ethylhexyl)phthalate	117-81-7	490 C	1200 C	20000 N	29 M	6 M			10 C	51 C
Bis(chloromethyl)ether	542-88-1	0.0011 C	0.0039 C	0.5 C	2.9E-06 C	0.00062 C			0.00039 C	0.002 C
Bisphenol A	80-05-7	4300 N	31000 N	52000 N	880 N	580 N				
Boron And Borates Only	7440-42-8	22000 N	100000 L	100000 L	200 N	3100 N			21 N	88 N
Boron Trifluoride	7637-07-2	4300 N	41000 N	69000 N		620 N			14 N	57 N
Bromate	15541-45-4	13 C	41 C	1700 C	1.6 M	10 M				
Bromo-2-chloroethane, 1-	107-04-0	0.34 C	1.2 C	140 C	0.00037 C	0.065 C			0.041 C	0.2 C
Bromobenzene	108-86-1	420 N	680 S	680 S	0.73 N	54 N			63 N	260 N
Bromochloromethane	74-97-5	220 N	680 N	1100 N	0.41 N	83 N			42 N	180 N
Bromodichloromethane	75-27-4	3.8 C	14 C	930 S	0.43 M	80 M			0.66 C	3.3 C
Bromoform	75-25-2	870 C	2200 C	20000 N	0.42 M	80 M			22 C	110 C
Bromomethane	74-83-9	10 N	32 N	54 N	0.035 N	7 N			5.2 N	22 N
Bromophos	2104-96-3	430 N	3100 N	5200 N	2.2 N	26 N				
Bromoxynil	1689-84-5	1700 N	12000 N	20000 N	5.3 N	310 N				
Bromoxynil Octanoate	1689-99-2	1700 N	12000 N	20000 N	17 N	100 N				
Butadiene, 1,3-	106-99-0	0.76 C	2.6 C	14 N	0.0017 C	0.16 C			0.81 C	4.1 C
Butanol, N-	71-36-3	8500 N	62000 N	100000 L	6.2 N	1500 N				
Butyl Benzyl Phthlate	85-68-7	3600 C	9100 C	100000 L	41 C	140 C				
Butyl alcohol, sec-	78-92-2	100000 L	100000 L	100000 L	130 N	31000 N			31000 N	130000 N
Butylate	2008-41-5	4300 N	31000 N	52000 N	6.6 N	340 N				
Butylated hydroxyanisole	25013-16-5	34000 C	86000 C	100000 L	130 C	3400 C			430 C	2200 C
Butylbenzene, n-	104-51-8	110 S	110 S	110 S	50 N	780 N				
Butylphthalyl Butylglycolate	85-70-1	85000 N	100000 L	100000 L	7300 N	16000 N				
Cacodylic Acid	75-60-5	1700 N	12000 N	20000 N		310 N				
Cadmium (Diet)	7440-43-9	98 N	800 N	1300 N						
Cadmium (Water)	7440-43-9				7.5 M	5 M			0.014 C	0.068 C

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Caprolactam	105-60-2	43000 N	100000 L	100000 L	38 N	7700 N				
Captafol	2425-06-1	45 C	110 C	2000 N	0.12 C	3.5 C			0.57 C	2.9 C
Captan	133-06-2	2900 C	7500 C	100000 L	3.8 C	270 C			37 C	190 C
Carbaryl	63-25-2	8500 N	62000 N	100000 L	25 N	1400 N				
Carbofuran	1563-66-2	430 N	3100 N	5200 N	0.31 M	40 M				
Carbon Disulfide	75-15-0	740 S	740 S	740 S	4.2 N	720 N			730 N	3100 N
Carbon Tetrachloride	56-23-5	8.5 C	30 C	460 S	0.039 M	5 M	5.7 C	28 C	4.1 C	20 C
Carbosulfan	55285-14-8	850 N	6200 N	10000 N	77 N	160 N				
Carboxin	5234-68-4	8500 N	62000 N	100000 L	16 N	1500 N				
Ceric oxide	1306-38-3	100000 L	100000 L	100000 L					0.94 N	3.9 N
Chloral Hydrate	302-17-0	8500 N	62000 N	100000 L	6.1 N	1500 N				
Chloramben	133-90-4	1300 N	9200 N	15000 N	1.1 N	230 N				
Chloranil	118-75-2	17 C	43 C	2500 C	0.028 C	1.7 C				
Chlordane	12789-03-6	22 C	65 C	680 N	2.7 M	2 M			0.24 C	1.2 C
Chlordecone (Kepone)	143-50-0	0.69 C	1.7 C	100 C	0.021 C	0.03 C			0.0053 C	0.027 C
Chlorfenvinphos	470-90-6	60 N	430 N	730 N	0.47 N	8.6 N				
Chlorimuron, Ethyl-	90982-32-4	1700 N	12000 N	20000 N	2.1 N	300 N				
Chlorine	7782-50-5	11000 N	91000 N	100000 L	16 N	1600 N			0.15 N	0.64 N
Chlorine Dioxide	10049-04-4	3200 N	30000 N	51000 N		470 N			0.21 N	0.88 N
Chlorite (Sodium Salt)	7758-19-2	3200 N	31000 N	52000 N		1000 M				
Chloro-1,1-difluoroethane, 1-	75-68-3	1200 S	1200 S	1200 S	990 N	100000 N			52000 N	220000 N
Chloro-1,3-butadiene, 2-	126-99-8	0.13 C	0.47 C	65 C	0.0017 C	0.16 C			0.081 C	0.41 C
Chloro-2-methylaniline HCl, 4-	3165-93-3	15 C	37 C	2200 C	0.015 C	1.3 C				
Chloro-2-methylaniline, 4-	95-69-2	69 C	170 C	3100 N	0.076 C	6.7 C			0.32 C	1.6 C
Chloroacetaldehyde, 2-	107-20-0	25 C	64 C	3800 C	0.01 C	2.5 C				
Chloroacetic Acid	79-11-8	170 N	1200 N	2000 N	0.24 M	60 M				
Chloroacetophenone, 2-	532-27-4	60000 N	100000 L	100000 L					0.031 N	0.13 N
Chloroaniline, p-	106-47-8	34 C	86 C	4200 N	0.027 C	3.2 C				
Chlorobenzene	108-90-7	410 N	760 S	760 S	1.4 M	100 M			52 N	220 N
Chlorobenzilate	510-15-6	62 C	160 C	9100 C	0.18 C	2.7 C			0.78 C	4 C
Chlorobenzoic Acid, p-	74-11-3	2500 N	18000 N	31000 N	2 N	390 N				
Chlorobenzotrifluoride, 4-	98-56-6	120 S	120 S	120 S	1.8 N	26 N			310 N	1300 N
Chlorobutane, 1-	109-69-3	730 S	730 S	730 S	3.9 N	480 N				
Chlorodifluoromethane	75-45-6	1700 S	1700 S	1700 S	810 N	100000 N			52000 N	220000 N
Chloroform	67-66-3	4.1 C	15 C	1800 N	0.44 M	80 M			1.1 C	5.3 C
Chloromethane	74-87-3	170 N	500 N	840 N	0.98 N	190 N			94 N	390 N
Chloromethyl Methyl Ether	107-30-2	0.27 C	0.94 C	110 C	0.00024 C	0.056 C			0.035 C	0.18 C
Chloronaphthalene, Beta-	91-58-7	180 S	180 S	180 S	57 N	550 N				
Chloronitrobenzene, o-	88-73-3	22 C	57 C	3000 N	0.038 C	2 C			0.01 N	0.044 N
Chloronitrobenzene, p-	100-00-5	85 N	620 N	1000 N	0.26 N	14 N			0.63 N	2.6 N
Chlorophenol, 2-	95-57-8	550 N	5100 N	8600 N	1.2 N	71 N				
Chloropicrin	76-06-2	2.9 N	8.8 N	15 N	0.0049 N	0.83 N			0.42 N	1.8 N
Chlorothalonil	1897-45-6	1300 N	5600 C	15000 N	8.7 C	190 C			27 C	140 C
Chlorotoluene, o-	95-49-8	910 S	910 S	910 S	3.5 N	180 N				
Chlorotoluene, p-	106-43-4	250 S	250 S	250 S	3.7 N	190 N				
Chlorozotocin	54749-90-5	0.028 C	0.072 C	4.2 C	0.000012 C	0.0028 C			0.00035 C	0.0018 C
Chlorpropham	101-21-3	17000 N	100000 L	100000 L	40 N	2200 N				
Chlorpyrifos	2921-88-2	85 N	620 N	1000 N	1.8 N	6.2 N				
Chlorpyrifos Methyl	5598-13-0	850 N	6200 N	10000 N	8.2 N	89 N				

Appendix A: Screening Levels

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Chlorsulfuron	64902-72-3	4300 N	31000 N	52000 N	13 N	770 N				
Chlorthiophos	60238-56-4	69 N	490 N	820 N	1 N	2 N				
Chromium(III), Insoluble Salts	16065-83-1	100000 L	100000 L	100000 L	R	N				
Chromium(VI)	18540-29-9	4.1 C	56 C	2400 C	0.12 C	0.31 C		0.00011 C	0.0015 C	
Chromium, Total	7440-47-3				1000000 R	100 M				
Cobalt	7440-48-4	32 N	300 N	520 N	4.3 N	4.7 N		0.0027 C	0.014 C	
Coke Oven Emissions	8007-45-2							0.015 C	0.2 C	
Copper	7440-50-8	4300 N	41000 N	69000 N	920 M	1300 M				
Cresol, m-	108-39-4	4300 N	31000 N	52000 N	12 N	720 N		630 N	2600 N	
Cresol, o-	95-48-7	4300 N	31000 N	52000 N	12 N	720 N		630 N	2600 N	
Cresol, p-	106-44-5	430 N	3100 N	5200 N	1.2 N	72 N		630 N	2600 N	
Cresol, p-chloro-m-	59-50-7	8500 N	62000 N	100000 L	26 N	1100 N				
Cresols	1319-77-3	11000 N	50000 S	50000 S	11 N	670 N		630 N	2600 N	
Crotonaldehyde, trans-	123-73-9	4.8 C	15 C	630 C	0.0014 C	0.35 C				
Cumene	98-82-8	270 S	270 S	270 S	13 N	390 N		420 N	1800 N	
Cupferron	135-20-6	31 C	78 C	4600 C	0.11 C	3.1 C		0.39 C	1.9 C	
Cyanazine	21725-46-2	8.1 C	21 C	1200 C	0.0071 C	0.76 C				
Cyanides										
-Calcium Cyanide	592-01-8	4300 N	41000 N	69000 N		620 N				
-Copper Cyanide	544-92-3	550 N	5100 N	8600 N		78 N				
-Cyanide (CN-)	57-12-5	2200 N	20000 N	34000 N	40 M	200 M				
-Cyanogen	460-19-5	4300 N	41000 N	69000 N	130 N	620 N				
-Cyanogen Bromide	506-68-3	9800 N	92000 N	100000 L		1400 N				
-Cyanogen Chloride	506-77-4	5500 N	51000 N	86000 N	160 N	780 N				
-Hydrogen Cyanide	74-90-8	66 N	610 N	1000 N	0.28 N	1.4 N		0.83 N	3.5 N	
-Potassium Cyanide	151-50-8	5500 N	51000 N	86000 N		770 N				
-Potassium Silver Cyanide	506-61-6	22000 N	100000 L	100000 L		2400 N				
-Silver Cyanide	506-64-9	11000 N	100000 N	100000 L		1300 N				
-Sodium Cyanide	143-33-9	4300 N	41000 N	69000 N		200 M				
-Thiocyanate	463-56-9	22 N	200 N	340 N	0.013 N	3.1 N				
-Zinc Cyanide	557-21-1	5500 N	51000 N	86000 N		780 N				
Cyclohexane	110-82-7	120 S	120 S	120 S	270 N	13000 N		6300 N	26000 N	
Cyclohexane, 1,2,3,4,5-pentabromo-6-chloro-	87-84-3	290 C	750 C	42000 C	2.4 C	21 C				
Cyclohexanone	108-94-1	100000 L	100000 L	100000 L	360 N	77000 N		730 N	3100 N	
Cyclohexylamine	108-91-8	17000 N	100000 L	100000 L	16 N	3000 N				
Cyhalothrin/karate	68085-85-8	430 N	3100 N	5200 N	1100 N	78 N				
Cypermethrin	52315-07-8	850 N	6200 N	10000 N	510 N	160 N				
Cyromazine	66215-27-8	640 N	4600 N	7900 N	0.62 N	120 N				
DDD	72-54-8	28 C	72 C	4200 C	13 C	2.8 C		0.35 C	1.8 C	
DDE, p,p'-	72-55-9	20 C	51 C	3000 C	9.4 C	2 C		0.25 C	1.3 C	
DDT	50-29-3	24 C	70 C	720 N	13 C	2 C		0.25 C	1.3 C	
Dacthal	1861-32-1	850 N	6200 N	10000 N	2.3 N	93 N				
Dalapon	75-99-0	2500 N	18000 N	31000 N	0.83 M	200 M				
Decabromodiphenyl ether, 2,2',3,3',4,4',5,5',6,6'- (BDE-209)	1163-19-5	600 N	4300 N	7300 N	1200 N	110 N				
Demeton	8065-48-3	3.4 N	25 N	42 N		0.52 N				
Di(2-ethylhexyl)adipate	103-23-1	5700 C	14000 C	100000 L	580 M	400 M				
Diallate	2303-16-4	110 C	280 C	16000 C	0.14 C	4.6 C				
Diazinon	333-41-5	60 N	430 N	730 N	0.99 N	7.9 N				
Dibromo-3-chloropropane, 1,2-	96-12-8	0.076 C	0.69 C	44 N	0.0017 M	0.2 M		0.0016 C	0.02 C	

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Dibromobenzene, 1,4-	106-37-6	850 N	6200 N	10000 N	1.9 N	98 N				
Dibromochloromethane	124-48-1	9.5 C	33 C	800 S	0.43 M	80 M			0.9 C	4.5 C
Dibromoethane, 1,2-	106-93-4	0.48 C	1.7 C	180 C	0.00028 M	0.05 M			0.041 C	0.2 C
Dibromomethane (Methylene Bromide)	74-95-3	35 N	110 N	180 N	0.039 N	7.9 N			4.2 N	18 N
Dibutyl Phthalate	84-74-2	8500 N	62000 N	100000 L	34 N	670 N				
Dibutyltin Compounds	NA	25 N	180 N	310 N		4.7 N				
Dicamba	1918-00-9	2500 N	18000 N	31000 N	2.3 N	440 N				
Dichloro-2-butene, 1,4-	764-41-0	0.097 C	0.35 C	49 C	0.00011 C	0.012 C			0.0058 C	0.029 C
Dichloro-2-butene, cis-1,4-	1476-11-5	0.097 C	0.35 C	49 C	0.00011 C	0.012 C			0.0058 C	0.029 C
Dichloro-2-butene, trans-1,4-	110-57-6	0.097 C	0.35 C	49 C	0.00011 C	0.012 C			0.0058 C	0.029 C
Dichloroacetic Acid	79-43-6	140 C	340 C	4200 N	0.25 M	60 M				
Dichlorobenzene, 1,2-	95-50-1	380 S	380 S	380 S	12 M	600 M			210 N	880 N
Dichlorobenzene, 1,4-	106-46-7	34 C	120 C	17000 C	1.4 M	75 M			2.2 C	11 C
Dichlorobenzidine, 3,3'-	91-94-1	15 C	38 C	2200 C	0.14 C	1.1 C			0.072 C	0.36 C
Dichlorobenzophenone, 4,4'-	90-98-2	770 N	5500 N	9300 N	17 N	140 N				
Dichlorodifluoromethane	75-71-8	130 N	400 N	670 N	5.7 N	190 N			100 N	440 N
Dichloroethane, 1,1-	75-34-3	46 C	170 C	1700 S	0.14 C	24 C	110 C	550 C	15 C	77 C
Dichloroethane, 1,2-	107-06-2	6 C	22 C	250 N	0.028 M	5 M	43 C	210 C	0.94 C	4.7 C
Dichloroethylene, 1,1-	75-35-4	340 N	1100 N	1200 S	0.05 M	7 M	300 N	1300 N	210 N	880 N
Dichloroethylene, 1,2- (Mixed Isomers)	540-59-0	980 N	1300 S	1300 S	0.76 N	130 N				
Dichloroethylene, 1,2-cis-	156-59-2	220 N	2000 N	2400 S	0.41 M	70 M				
Dichloroethylene, 1,2-trans-	156-60-5	210 N	690 N	1200 N	0.59 M	100 M			63 N	260 N
Dichlorophenol, 2,4-	120-83-2	250 N	1800 N	3100 N	0.83 N	35 N				
Dichlorophenoxy Acetic Acid, 2,4-	94-75-7	970 N	7700 N	13000 N	0.36 M	70 M				
Dichlorophenoxy)butyric Acid, 4-(2,4-	94-82-6	690 N	4900 N	8200 N	0.72 N	91 N				
Dichloropropane, 1,2-	78-87-5	13 C	47 C	120 N	0.033 M	5 M			2.4 C	12 C
Dichloropropane, 1,3-	142-28-9	1500 S	1500 S	1500 S	2 N	290 N				
Dichloropropanol, 2,3-	616-23-9	250 N	1800 N	3100 N	0.2 N	47 N				
Dichloropropene, 1,3-	542-75-6	24 C	83 C	570 N	0.029 C	4.1 C			6.1 C	31 C
Dichlorvos	62-73-7	24 C	59 C	520 N	0.014 C	2.3 C			0.29 C	1.5 C
Dicyclopentadiene	77-73-6	43 N	130 N	130 S	0.83 N	12 N			7.3 N	31 N
Dieldrin	60-57-1	0.42 C	1.1 C	52 N	0.012 C	0.015 C			0.0053 C	0.027 C
Diesel Engine Exhaust	NA								0.081 C	0.41 C
Diethanolamine	111-42-2	10000 L	10000 L	10000 L					3.1 N	13 N
Diethyl Phthalate	84-66-2	69000 N	100000 L	100000 L	90 N	11000 N				
Diethylene Glycol Monobutyl Ether	112-34-5	2500 N	18000 N	30000 N	2.1 N	470 N			0.1 N	0.44 N
Diethylene Glycol Monoethyl Ether	111-90-0	5000 N	36000 N	61000 N	3.8 N	940 N			0.31 N	1.3 N
Diethylformamide	617-84-5	85 N	620 N	1000 N	0.065 N	16 N				
Diethylstilbestrol	56-53-1	0.02 C	0.049 C	2.9 C	0.0047 C	0.00043 C			0.00024 C	0.0012 C
Difenzoquat	43222-48-6	6900 N	49000 N	82000 N		1200 N				
Diflubenzuron	35367-38-5	1700 N	12000 N	20000 N	5 N	220 N				
Difluoroethane, 1,1-	75-37-6	1400 S	1400 S	1400 S	560 N	83000 N			42000 N	180000 N
Dihydrosafrole	94-58-6	150 C	390 C	23000 C	0.36 C	15 C			1.9 C	9.4 C
Diisopropyl Ether	108-20-3	2300 S	2300 S	2300 S	7.6 N	1500 N			730 N	3100 N
Diisopropyl Methylphosphonate	1445-75-6	530 S	530 S	530 S	6.8 N	1200 N				
Dimethipin	55290-64-7	1700 N	12000 N	20000 N	1.4 N	310 N				
Dimethoate	60-51-5	17 N	120 N	200 N	0.014 N	3.1 N				
Dimethoxybenzidine, 3,3'-	119-90-4	490 C	1200 C	70000 C	1.1 C	47 C				
Dimethyl methylphosphonate	756-79-6	4100 C	10000 C	62000 N	1.6 C	390 C				

Appendix A: Screening Levels

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Dimethylamino azobenzene [p-]	60-11-7	1.5 C	3.7 C	220 C	0.0037 C	0.043 C			0.019 C	0.094 C
Dimethylaniline HCl, 2,4-	21436-96-4	12 C	30 C	1700 C	0.013 C	1.1 C				
Dimethylaniline, 2,4-	95-68-1	34 C	86 C	2000 N	0.036 C	3.2 C				
Dimethylaniline, N,N-	121-69-7	220 N	830 S	830 S	0.19 N	27 N				
Dimethylbenzidine, 3,3'-	119-93-7	0.62 C	1.6 C	91 C	0.0074 C	0.056 C				
Dimethylformamide	68-12-2	8500 N	62000 N	100000 L	6.5 N	1600 N			31 N	130 N
Dimethylhydrazine, 1,1-	57-14-7	8.5 N	61 N	100 N	0.0072 N	1.6 N			0.0021 N	0.0088 N
Dimethylhydrazine, 1,2-	540-73-8	0.012 C	0.031 C	1.8 C	5.5E-06 C	0.0012 C			0.00015 C	0.00077 C
Dimethylphenol, 2,4-	105-67-9	1700 N	12000 N	20000 N	6.4 N	270 N				
Dimethylphenol, 2,6-	576-26-1	52 N	370 N	620 N	0.2 N	8.1 N				
Dimethylphenol, 3,4-	95-65-8	85 N	620 N	1000 N	0.33 N	14 N				
Dimethylterephthalate	120-61-6	5.5 S	5.5 S	5.5 S	7.3 N	1400 N				
Dimethylvinylchloride	513-37-1	150 C	380 C	22000 C	0.18 C	15 C			1.9 C	9.4 C
Dinitro-o-cresol, 4,6-	534-52-1	6.9 N	49 N	82 N	0.041 N	1.2 N				
Dinitro-o-cyclohexyl Phenol, 4,6-	131-89-5	170 N	1200 N	2000 N	11 N	17 N				
Dinitrobenzene, 1,2-	528-29-0	8.5 N	62 N	100 N	0.028 N	1.5 N				
Dinitrobenzene, 1,3-	99-65-0	8.5 N	62 N	100 N	0.027 N	1.5 N				
Dinitrobenzene, 1,4-	100-25-4	8.5 N	62 N	100 N	0.027 N	1.5 N				
Dinitrophenol, 2,4-	51-28-5	170 N	1200 N	2000 N	0.67 N	30 N				
Dinitrotoluene Mixture, 2,4/2,6-	25321-14-6	10 C	25 C	1500 C	0.025 C	0.92 C				
Dinitrotoluene, 2,4-	121-14-2	22 C	55 C	2000 N	0.054 C	2 C			0.27 C	1.4 C
Dinitrotoluene, 2,6-	606-20-2	85 N	620 N	1000 N	0.41 N	15 N				
Dinitrotoluene, 2-Amino-4,6-	35572-78-2	210 N	2000 N	3200 N	0.46 N	30 N				
Dinitrotoluene, 4-Amino-2,6-	19406-51-0	210 N	1900 N	3200 N	0.46 N	30 N				
Dinoseb	88-85-7	85 N	620 N	1000 N	1.2 M	7 M				
Dioxane, 1,4-	123-91-1	69 C	170 C	10000 C	0.028 C	6.7 C			3.2 C	16 C
Dioxins										
-Hexachlorodibenzo-p-dioxin, Mixture	NA	0.0013 C	0.0039 C	0.18 C	0.0031 C	0.00011 C			0.000019 C	0.000094 C
-TCDD, 2,3,7,8-	1746-01-6	6E-05 C	0.0002 C	0.0014 N	0.0003 M	0.00003 M			6.4E-07 C	3.2E-06 C
Diphenamid	957-51-7	2500 N	18000 N	31000 N	92 N	470 N				
Diphenyl Sulfone	127-63-9	69 N	490 N	820 N	0.53 N	11 N				
Diphenylamine	122-39-4	2100 N	15000 N	26000 N	8.9 N	240 N				
Diphenylhydrazine, 1,2-	122-66-7	8.5 C	22 C	1300 C	0.043 C	0.67 C			0.11 C	0.56 C
Diquat	85-00-7	180 N	1400 N	2200 N	7.5 M	20 M				
Direct Black 38	1937-37-7	0.92 C	2.3 C	140 C	880 C	0.091 C			0.012 C	0.058 C
Direct Blue 6	2602-46-2	0.92 C	2.3 C	140 C	2900 C	0.091 C			0.012 C	0.058 C
Direct Brown 95	16071-86-6	1 C	2.6 C	150 C		0.1 C			0.013 C	0.065 C
Disulfoton	298-04-4	3.4 N	25 N	42 N	0.014 N	0.38 N				
Dithiane, 1,4-	505-29-3	850 N	6200 N	10000 N	1.5 N	150 N				
Diuron	330-54-1	170 N	1200 N	2000 N	0.23 N	28 N				
Dodine	2439-10-3	340 N	2500 N	4200 N	6.4 N	62 N				
EPTC	759-94-4	410 S	410 S	410 S	3.1 N	290 N				
Endosulfan	115-29-7	520 N	3700 N	6200 N	21 N	78 N				
Endothall	145-73-3	1700 N	12000 N	20000 N	0.48 M	100 M				
Endrin	72-20-8	25 N	180 N	310 N	1.6 M	2 M				
Epichlorohydrin	106-89-8	28 N	88 N	150 N	0.0088 N	2 N			1 N	4.4 N
Epoxybutane, 1,2-	106-88-7	240 N	720 N	1200 N	0.19 N	42 N			21 N	88 N
Ethephon	16672-87-0	430 N	3100 N	5200 N	0.33 N	78 N				
Ethion	563-12-2	43 N	310 N	520 N	0.13 N	3.2 N				

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Ethoxyethanol Acetate, 2-	111-15-9	8500 N	62000 N	100000 L	6.3 N	1500 N			63 N	260 N
Ethoxyethanol, 2-	110-80-5	34000 N	100000 L	100000 L	25 N	6200 N			210 N	880 N
Ethyl Acetate	141-78-6	11000 S	11000 S	11000 S	59 N	14000 N				
Ethyl Acrylate	140-88-5	180 C	600 C	2500 S	0.062 C	14 C				
Ethyl Chloride	75-00-3	2100 S	2100 S	2100 S	120 N	21000 N			10000 N	44000 N
Ethyl Ether	60-29-7	10000 S	10000 S	10000 S	14 N	3100 N				
Ethyl Methacrylate	97-63-2	1100 S	1100 S	1100 S	2 N	420 N			310 N	1300 N
Ethyl-p-nitrophenyl Phosphonate	2104-64-5	0.85 N	6.2 N	10 N	0.041 N	0.066 N				
Ethylbenzene	100-41-4	76 C	270 C	480 S	16 M	700 M			9.7 C	49 C
Ethylene Cyanohydrin	109-78-4	2500 N	18000 N	31000 N	1.9 N	470 N				
Ethylene Diamine	107-15-3	7700 N	55000 N	93000 N	6.4 N	1400 N				
Ethylene Glycol	107-21-1	100000 L	100000 L	100000 L	130 N	31000 N			420 N	1800 N
Ethylene Glycol Monobutyl Ether	111-76-2	8500 N	62000 N	100000 L	6.2 N	1500 N			1700 N	7000 N
Ethylene Oxide	75-21-8	2.4 C	8.3 C	950 C	0.0018 C	0.44 C			0.28 C	1.4 C
Ethylene Thiourea	96-45-7	6.9 N	49 N	82 N	0.0054 N	1.2 N			1.9 C	9.4 C
Ethyleneimine	151-56-4	0.11 C	0.27 C	15 C	0.000044 C	0.01 C			0.0013 C	0.0065 C
Ethylphthalyl Ethyl Glycolate	84-72-0	100000 L	100000 L	100000 L	2000 N	45000 N				
Express	101200-48-0	690 N	4900 N	8200 N	1 N	130 N				
Fenamiphos	22224-92-6	21 N	150 N	260 N	0.068 N	3.4 N				
Fenpropathrin	39515-41-8	2100 N	15000 N	26000 N	42 N	46 N				
Fluometuron	2164-17-2	1100 N	8000 N	13000 N	2.9 N	190 N				
Fluoride	16984-48-8	4300 N	41000 N	69000 N		620 N			14 N	57 N
Fluorine (Soluble Fluoride)	7782-41-4	6600 N	61000 N	100000 L	12000 M	4000 M			14 N	57 N
Fluridone	59756-60-4	6900 N	49000 N	82000 N	2500 N	1100 N				
Flurprimidol	56425-91-3	1700 N	12000 N	20000 N	24 N	260 N				
Flutolanil	66332-96-5	5200 N	37000 N	62000 N	77 N	720 N				
Fluvalinate	69409-94-5	850 N	6200 N	10000 N	4700 N	160 N				
Folpet	133-07-3	2000 C	4900 C	100000 L	0.8 C	170 C				
Fomesafen	72178-02-0	36 C	91 C	5300 C	0.22 C	3.4 C				
Fonofos	944-22-9	170 N	1200 N	2000 N	0.69 N	18 N				
Formaldehyde	50-00-0	17000 N	100000 L	100000 L	13 N	3100 N			1.9 C	9.4 C
Formic Acid	64-18-6	69000 N	100000 L	100000 L	57 N	14000 N			0.31 N	1.3 N
Fosetyl-AL	39148-24-8	100000 L	100000 L	100000 L		47000 N				
Furans										
-Dibenzofuran	132-64-9	110 N	170 S	170 S	2.1 N	5.8 N				
-Furan	110-00-9	110 N	1000 N	1700 N	0.11 N	15 N				
Furazolidone	67-45-8	1.8 C	4.5 C	260 C	0.0069 C	0.18 C				
Furfural	98-01-1	250 N	1800 N	3100 N	0.2 N	46 N			52 N	220 N
Furium	531-82-8	4.5 C	11 C	670 C	0.012 C	0.44 C			0.057 C	0.29 C
Furmecyclox	60568-05-0	220 C	570 C	33000 C	0.2 C	9.6 C			2.8 C	14 C
Glufosinate, Ammonium	77182-82-2	34 N	250 N	420 N	0.028 N	6.3 N				
Glutaraldehyde	111-30-8	100000 L	100000 L	100000 L					0.083 N	0.35 N
Glycidyl	765-34-4	34 N	250 N	420 N	0.025 N	6.3 N			1 N	4.4 N
Glyphosate	1071-83-6	8500 N	62000 N	100000 L	2.8 M	700 M				
Goal	42874-03-3	250 N	1800 N	3100 N	38 N	24 N				
Guthion	86-50-0	250 N	1800 N	3100 N	0.26 N	43 N			10 N	44 N
Haloxypop, Methyl	69806-40-2	4.3 N	31 N	52 N	0.13 N	0.58 N				
Harmony	79277-27-3	1100 N	8000 N	13000 N	1.2 N	200 N				
Heptachlor	76-44-8	1.5 C	3.8 C	220 C	0.66 M	0.4 M			0.019 C	0.094 C

Appendix A: Screening Levels

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Heptachlor Epoxide	1024-57-3	0.74 C	1.9 C	13 N	0.082 M	0.2 M			0.0094 C	0.047 C
Hexabromobenzene	87-82-1	170 N	1200 N	2000 N	3.6 N	31 N				
Hexabromodiphenyl ether, 2,2',4,4',5,5'- (BDE-153)	68631-49-2	17 N	120 N	200 N		3.1 N				
Hexachlorobenzene	118-74-1	4.2 C	11 C	630 C	0.25 M	1 M			0.053 C	0.27 C
Hexachlorobutadiene	87-68-3	85 N	220 C	1000 N	0.1 C	2.6 C			1.1 C	5.6 C
Hexachlorocyclohexane, Alpha-	319-84-6	1.1 C	2.7 C	160 C	0.0072 C	0.062 C			0.014 C	0.068 C
Hexachlorocyclohexane, Beta-	319-85-7	3.8 C	9.6 C	560 C	0.026 C	0.22 C			0.046 C	0.23 C
Hexachlorocyclohexane, Gamma- (Lindane)	58-89-9	7.3 C	21 C	410 N	0.023 M	0.2 M			0.078 C	0.4 C
Hexachlorocyclohexane, Technical	608-73-1	3.8 C	9.6 C	560 C	0.026 C	0.22 C			0.048 C	0.24 C
Hexachlorocyclopentadiene	77-47-4	520 N	3700 N	6200 N	3.1 M	50 M			0.21 N	0.88 N
Hexachloroethane	67-72-1	60 N	430 C	730 N	0.062 N	5.1 N			2.2 C	11 C
Hexachlorophene	70-30-4	25 N	180 N	310 N	130 N	4.7 N				
Hexahydro-1,3,5-trinitro-1,3,5-triazine (RDX)	121-82-4	78 C	240 C	4700 N	0.046 C	6.1 C				
Hexamethylene Diisocyanate, 1,6-	822-06-0	4.8 N	14 N	24 N	0.0041 N	0.021 N			0.01 N	0.044 N
Hexane, N-	110-54-3	140 S	140 S	140 S	34 N	250 N			730 N	3100 N
Hexanedioic Acid	124-04-9	100000 L	100000 L	100000 L	150 N	31000 N				
Hexanone, 2-	591-78-6	290 N	1400 N	2300 N	0.16 N	34 N			31 N	130 N
Hexazinone	51235-04-2	2800 N	20000 N	34000 N	4.6 N	500 N				
Hydrazine	302-01-2	2.9 C	9.5 C	400 C		0.22 C			0.005 C	0.025 C
Hydrazine Sulfate	10034-93-2	2.9 C	9.5 C	400 C		0.22 C			0.005 C	0.025 C
Hydrogen Chloride	7647-01-0	100000 L	100000 L	100000 L					21 N	88 N
Hydrogen Fluoride	7664-39-3	4300 N	41000 N	69000 N		620 N			15 N	61 N
Hydrogen Sulfide	7783-06-4	100000 L	100000 L	100000 L					2.1 N	8.8 N
Hydroquinone	123-31-9	110 C	290 C	17000 C	0.15 C	11 C				
Imazalil	35554-44-0	1100 N	8000 N	13000 N	48 N	140 N				
Imazaquin	81335-37-7	21000 N	100000 L	100000 L	380 N	3800 N				
Iodine	7553-56-2	1100 N	10000 N	17000 N		160 N				
Iprodione	36734-19-7	3400 N	25000 N	42000 N	3.5 N	570 N				
Iron	7439-89-6	77000 N	100000 L	100000 L	5600 N	11000 N				
Isobutyl Alcohol	78-83-1	10000 S	10000 S	10000 S	19 N	4600 N				
Isophorone	78-59-1	7100 C	18000 C	100000 L	4.4 C	670 C			2100 N	8800 N
Isopropalin	33820-53-0	1300 N	9200 N	15000 N	110 N	230 N				
Isopropanol	67-63-0	100000 L	100000 L	100000 L					7300 N	31000 N
Isopropyl Methyl Phosphonic Acid	1832-54-8	8500 N	62000 N	100000 L	6.9 N	1600 N				
Isoxaben	82558-50-7	4300 N	31000 N	52000 N	31 N	560 N				
JP-7	NA	100000 L	100000 L	100000 L		630 N			310 N	1300 N
Kerb	23950-58-5	6400 N	46000 N	79000 N	18 N	900 N				
Lactofen	77501-63-4	170 N	1200 N	2000 N	18 N	19 N				
Lead Compounds										
-Lead acetate	301-04-2	24 C	62 C	3500 C		2.4 C			0.3 C	1.5 C
-Lead and Compounds	7439-92-1	400 N	1300 N	970	270 M	15 M				
-Lead subacetate	1335-32-6	180 C	450 C	26000 C		18 C			2.2 C	11 C
-Tetraethyl Lead	78-00-2	0.0085 N	0.062 N	0.1 N	0.000069 N	0.00099 N				
Linuron	330-55-2	170 N	1200 N	2000 N	0.46 N	26 N				
Lithium	7439-93-2	220 N	2000 N	3400 N	190 N	31 N				
Londax	83055-99-6	17000 N	100000 L	100000 L	16 N	3100 N				
MCPA	94-74-6	43 N	310 N	520 N	0.03 N	5.7 N				
MCPB	94-81-5	850 N	6200 N	10000 N	1.3 N	160 N				
MCPD	93-65-2	85 N	620 N	1000 N	0.071 N	12 N				

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Malathion	121-75-5	1700 N	12000 N	20000 N	1.6 N	300 N				
Maleic Anhydride	108-31-6	8500 N	61000 N	100000 N	6.1 N	1500 N			0.73 N	3.1 N
Maleic Hydrazide	123-33-1	43000 N	100000 L	100000 L	32 N	7800 N				
Malononitrile	109-77-3	8.5 N	62 N	100 N	0.0066 N	1.6 N				
Mancozeb	8018-01-7	2500 N	18000 N	31000 N	13 N	470 N				
Maneb	12427-38-2	430 N	3100 N	5200 N	2.2 N	78 N				
Manganese (Diet)	7439-96-5									
Manganese (Non-diet)	7439-96-5	2500 N	23000 N	39000 N	420 N	320 N			0.052 N	0.22 N
Meposfolan	950-10-7	7.7 N	55 N	93 N	0.041 N	1.4 N				
Mepiquat Chloride	24307-26-4	2500 N	18000 N	31000 N	3.1 N	470 N				
Mercury Compounds										
-Mercuric Chloride (and other Mercury salts)	7487-94-7	32 N	310 N	520 N	2.1 M	2 M			0.031 N	0.13 N
-Mercury (elemental)	7439-97-6	3.1 S	3.1 S	3.1 S	2.1 M	2 M			0.31 N	1.3 N
-Methyl Mercury	22967-92-6	11 N	100 N	170 N		1.6 N				
-Phenylmercuric Acetate	62-38-4	6.9 N	49 N	82 N	0.0075 N	1.2 N				
Merphos	150-50-5	2.5 N	18 N	31 N	0.92 N	0.47 N				
Merphos Oxide	78-48-8	2.5 N	18 N	31 N	0.006 N	0.061 N				
Metaxyl	57837-19-1	5200 N	37000 N	62000 N	5.1 N	920 N				
Methacrylonitrile	126-98-7	4.5 N	18 N	30 N	0.0034 N	0.75 N			0.73 N	3.1 N
Methamidophos	10265-92-6	4.3 N	31 N	52 N	0.0033 N	0.78 N				
Methanol	67-56-1	43000 N	100000 L	100000 L	32 N	7800 N			4200 N	18000 N
Methidathion	950-37-8	85 N	620 N	1000 N	0.073 N	15 N				
Methomyl	16752-77-5	2100 N	15000 N	26000 N	1.7 N	390 N				
Methoxy-5-nitroaniline, 2-	99-59-2	140 C	350 C	20000 C	0.089 C	13 C			1.7 C	8.8 C
Methoxychlor	72-43-5	430 N	3100 N	5200 N	43 M	40 M				
Methoxyethanol Acetate, 2-	110-49-6	690 N	4900 N	8200 N	0.53 N	130 N			1 N	4.4 N
Methoxyethanol, 2-	109-86-4	430 N	3100 N	5200 N	0.32 N	78 N			21 N	88 N
Methyl Acetate	79-20-9	29000 S	29000 S	29000 S	66 N	16000 N				
Methyl Acrylate	96-33-3	3200 N	6800 S	6800 S	2 N	460 N				
Methyl Ethyl Ketone (2-Butanone)	78-93-3	28000 S	28000 S	28000 S	21 N	4900 N			5200 N	22000 N
Methyl Hydrazine	60-34-4	85 N	610 N	1000 N	0.073 N	16 N			0.021 N	0.088 N
Methyl Isobutyl Ketone (4-methyl-2-pentanone)	108-10-1	3400 S	3400 S	3400 S	4.5 N	1000 N			3100 N	13000 N
Methyl Isocyanate	624-83-9	100000 L	100000 L	100000 L					1 N	4.4 N
Methyl Methacrylate	80-62-6	2400 S	2400 S	2400 S	6.1 N	1400 N			730 N	3100 N
Methyl Parathion	298-00-0	21 N	150 N	260 N	0.11 N	3.4 N				
Methyl Phosphonic Acid	993-13-5	5200 N	37000 N	62000 N	3.8 N	940 N				
Methyl Styrene (Mixed Isomers)	25013-15-4	350 N	380 S	380 S	0.99 N	31 N			42 N	180 N
Methyl methanesulfonate	66-27-3	69 C	170 C	10000 C	0.028 C	6.8 C			0.87 C	4.4 C
Methyl tert-Butyl Ether (MTBE)	1634-04-4	600 C	2200 C	8900 S	0.54 C	120 C			94 C	470 C
Methyl-1,4-benzenediamine dihydrochloride, 2-	615-45-2	17 N	120 N	200 N	0.037 N	3.1 N				
Methyl-5-Nitroaniline, 2-	99-55-8	760 C	1900 C	20000 N	0.78 C	70 C				
Methyl-N-nitro-N-nitrosoguanidine, N-	70-25-7	0.83 C	2.1 C	120 C	0.00056 C	0.081 C			0.01 C	0.051 C
Methylaniline Hydrochloride, 2-	636-21-5	52 C	130 C	7700 C	0.043 C	5 C			0.66 C	3.3 C
Methylarsonic acid	124-58-3	850 N	6200 N	10000 N		160 N				
Methylbenzene,1-4-diamine monohydrochloride, 2-	74612-12-7	17 N	120 N	200 N		3.1 N				
Methylbenzene-1,4-diamine sulfate, 2-	615-50-9	17 N	120 N	200 N		3.1 N				
Methylcholanthrene, 3-	56-49-5	0.073 C	0.78 C	46 C	0.38 C	0.0098 C			0.0015 C	0.019 C
Methylene Chloride	75-09-2	150 C	530 C	3300 S	0.025 M	5 M			52 C	260 C
Methylene-bis(2-chloroaniline), 4,4'-	101-14-4	17 C	170 C	2000 N	0.32 C	1.4 C			0.022 C	0.29 C

Appendix A: Screening Levels

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Methylene-bis(N,N-dimethyl) Aniline, 4,4'-	101-61-1	150 C	370 C	22000 C	0.66 C	6 C		1.9 C	9.4 C	
Methylenebisbenzenamine, 4,4'-	101-77-9	4.2 C	11 C	630 C	0.037 C	0.41 C		0.053 C	0.27 C	
Methylenediphenyl Diisocyanate	101-68-8	100000 L	100000 L	100000 L				0.63 N	2.6 N	
Methylstyrene, Alpha-	98-83-9	500 S	500 S	500 S	19 N	580 N				
Metolachlor	51218-45-2	13000 N	92000 N	100000 L	49 N	2100 N				
Metribuzin	21087-64-9	2100 N	15000 N	26000 N	2.3 N	380 N				
Mineral oils	8012-95-1	100000 L	100000 L	100000 L	36000 N	47000 N				
Mirex	2385-85-5	0.38 C	0.96 C	56 C	0.53 C	0.037 C		0.0048 C	0.024 C	
Molinate	2212-67-1	170 N	1200 N	2000 N	0.26 N	23 N				
Molybdenum	7439-98-7	550 N	5100 N	8600 N	32 N	78 N				
Monochloramine	10599-90-3	11000 N	100000 N	100000 L		1600 N				
Monomethylaniline	100-61-8	170 N	1200 N	2000 N	0.22 N	30 N				
N,N'-Diphenyl-1,4-benzenediamine	74-31-7	25 N	180 N	310 N	5.6 N	2.7 N				
Naled	300-76-5	170 N	1200 N	2000 N	0.28 N	31 N				
Naphtha, High Flash Aromatic (HFAN)	64724-95-6	3200 N	31000 N	52000 N		140 N		100 N	440 N	
Naphthylamine, 2-	91-59-8	3.8 C	9.6 C	560 C	0.034 C	0.33 C				
Napropamide	15299-99-7	8500 N	62000 N	100000 L	170 N	1300 N				
Nickel Carbonyl	13463-39-3	5200 N	44000 N	73000 N		670 N		0.052 N	0.22 N	
Nickel Oxide	1313-99-1	5300 N	47000 N	79000 N		780 N		0.1 N	0.44 N	
Nickel Refinery Dust	NA	5200 N	44000 N	73000 N		760 N		0.052 N	0.22 N	
Nickel Soluble Salts	7440-02-0	2100 N	20000 N	32000 N	17000 N	300 N		0.094 C	0.39 N	
Nickel Subsulfide	12035-72-2	5.3 C	17 C	720 C		0.39 C		0.051 C	0.22 N	
Nitrate	14797-55-8	100000 L	100000 L	100000 L		10000 M				
Nitrite	14797-65-0	11000 N	100000 N	100000 L		1000 M				
Nitroaniline, 2-	88-74-4	850 N	6000 N	9900 N	1.3 N	150 N		0.052 N	0.22 N	
Nitroaniline, 4-	100-01-6	340 C	860 C	4200 N	0.28 C	33 C		6.3 N	26 N	
Nitrobenzene	98-95-3	67 C	240 C	2000 N	0.016 C	1.2 C		0.61 C	3.1 C	
Nitrocellulose	9004-70-0	100000 L	100000 L	100000 L	210000 N	47000000 N				
Nitrofurantoin	67-20-9	6000 N	43000 N	73000 N	9.5 N	1100 N				
Nitrofurazone	59-87-0	5.2 C	13 C	770 C	0.0094 C	0.52 C		0.066 C	0.33 C	
Nitroglycerin	55-63-0	8.5 N	62 N	100 N	0.013 N	1.5 N				
Nitroguanidine	556-88-7	8500 N	62000 N	100000 L	7.7 N	1600 N				
Nitromethane	75-52-5	69 C	250 C	2700 N	0.024 C	5.4 C		2.7 C	14 C	
Nitropropane, 2-	79-46-9	0.18 C	0.64 C	89 C	0.000094 C	0.018 C		0.009 C	0.045 C	
Nitroso-N-ethylurea, N-	759-73-9	0.06 C	0.64 C	38 C	0.000038 C	0.0079 C		0.0012 C	0.016 C	
Nitroso-N-methylurea, N-	684-93-5	0.013 C	0.14 C	8.4 C	0.000008 C	0.0018 C		0.00028 C	0.0036 C	
Nitroso-di-N-butylamine, N-	924-16-3	1.2 C	4 C	200 C	0.00097 C	0.024 C		0.015 C	0.077 C	
Nitroso-di-N-propylamine, N-	621-64-7	0.97 C	2.5 C	140 C	0.0014 C	0.093 C		0.012 C	0.061 C	
Nitrosodiethanolamine, N-	1116-54-7	2.4 C	6.2 C	350 C	0.00097 C	0.24 C		0.03 C	0.15 C	
Nitrosodiethylamine, N-	55-18-5	0.011 C	0.11 C	6.7 C	0.00001 C	0.0014 C		0.00022 C	0.0029 C	
Nitrosodimethylamine, N-	62-75-9	0.032 C	0.34 C	8.2 N	0.000021 C	0.0042 C		0.00069 C	0.0088 C	
Nitrosodiphenylamine, N-	86-30-6	1400 C	3500 C	100000 L	11 C	100 C		9.4 C	47 C	
Nitrosomethylethylamine, N-	10595-95-6	0.31 C	0.78 C	46 C	0.00017 C	0.03 C		0.0039 C	0.019 C	
Nitrosomorpholine [N-]	59-89-2	1 C	2.6 C	150 C	0.00049 C	0.1 C		0.013 C	0.065 C	
Nitrosopiperidine [N-]	100-75-4	0.73 C	1.8 C	110 C	0.00076 C	0.071 C		0.009 C	0.045 C	
Nitrosopyrrolidine, N-	930-55-2	3.2 C	8.2 C	490 C	0.0025 C	0.32 C		0.04 C	0.2 C	
Nitrotoluene, m-	99-08-1	8.5 N	62 N	100 N	0.024 N	1.3 N				
Nitrotoluene, o-	88-72-2	41 C	130 C	1500 S	0.051 C	2.7 C				
Nitrotoluene, p-	99-99-0	340 N	1100 C	4200 N	0.69 C	37 C				

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Nonane, n-	111-84-2	6.9 S	6.9 S	6.9 S	1.3 N	4.6 N			210 N	880 N
Norflurazon	27314-13-2	3400 N	25000 N	42000 N	77 N	600 N				
Nustar	85509-19-9	60 N	430 N	730 N	27 N	8.3 N				
Octabromodiphenyl Ether	32536-52-0	250 N	1800 N	3100 N	190 N	47 N				
Octahydro-1,3,5,7-tetranitro-1,3,5,7-tetra (HMX)	2691-41-0	5300 N	49000 N	83000 N	20 N	780 N				
Octamethylpyrophosphoramidate	152-16-9	170 N	1200 N	2000 N	0.15 N	31 N				
Oryzalin	19044-88-3	4300 N	31000 N	52000 N	23 N	620 N				
Oxadiazon	19666-30-9	430 N	3100 N	5200 N	7.1 N	35 N				
Oxamyl	23135-22-0	2100 N	15000 N	26000 N	0.88 M	200 M				
Paclobutrazol	76738-62-0	1100 N	8000 N	13000 N	7 N	170 N				
Paraquat Dichloride	1910-42-5	380 N	2800 N	4700 N	19 N	70 N				
Parathion	56-38-2	520 N	3700 N	6200 N	6.6 N	65 N				
Pebulate	1114-71-2	4300 N	31000 N	52000 N	6.7 N	420 N				
Pendimethalin	40487-42-1	3400 N	25000 N	42000 N	30 N	130 N				
Pentabromodiphenyl Ether	32534-81-9	170 N	1200 N	2000 N	27 N	31 N				
Pentabromodiphenyl ether, 2,2',4,4',5- (BDE-99)	60348-60-9	8.5 N	62 N	100 N	1.4 N	1.6 N				
Pentachlorobenzene	608-93-5	69 N	490 N	820 N	0.35 N	2.3 N				
Pentachloroethane	76-01-7	76 C	190 C	11000 C	0.054 C	5.6 C				
Pentachloronitrobenzene	82-68-8	27 C	66 C	3100 N	0.24 C	1 C				
Pentachlorophenol	87-86-5	12 C	27 C	2000 C	0.2 M	1 M		4.8 C	24 C	
Pentaerythritol tetranitrate (PETN)	78-11-5	170 N	1200 N	2000 N	0.9 N	30 N				
Pentane, n-	109-66-0	390 S	390 S	390 S	200 N	2100 N		1000 N	4400 N	
Perchlorates										
-Ammonium Perchlorate	7790-98-9	77 N	720 N	1200 N		11 N				
-Lithium Perchlorate	7791-03-9	77 N	720 N	1200 N		11 N				
-Perchlorate and Perchlorate Salts	14797-73-0	77 N	720 N	1200 N		15 M				
-Potassium Perchlorate	7778-74-7	77 N	720 N	1200 N		11 N				
-Sodium Perchlorate	7601-89-0	77 N	720 N	1200 N		11 N				
Permethrin	52645-53-1	4300 N	31000 N	52000 N	3700 N	780 N				
Phenacetin	62-44-2	3100 C	7800 C	100000 L	1.7 C	300 C		39 C	190 C	
Phenmedipham	13684-63-4	21000 N	100000 L	100000 L	320 N	3000 N				
Phenol	108-95-2	25000 N	100000 L	100000 L	52 N	4500 N		210 N	880 N	
Phenothiazine	92-84-2	43 N	310 N	520 N	0.2 N	3.2 N				
Phenylenediamine, m-	108-45-2	520 N	3700 N	6200 N	0.5 N	94 N				
Phenylenediamine, o-	95-54-5	140 C	370 C	21000 C	0.075 C	14 C				
Phenylenediamine, p-	106-50-3	17000 N	100000 L	100000 L	16 N	3000 N				
Phenylphenol, 2-	90-43-7	3500 C	8900 C	100000 L	71 C	260 C				
Phorate	298-02-2	17 N	120 N	200 N	0.052 N	2.3 N				
Phosgene	75-44-5	0.46 N	1.4 N	2.4 N				0.31 N	1.3 N	
Phosmet	732-11-6	1700 N	12000 N	20000 N	1.3 N	290 N				
Phosphates, Inorganic										
-Aluminum metaphosphate	13776-88-0	100000 L	100000 L	100000 L		760000 N				
-Ammonium polyphosphate	68333-79-9	100000 L	100000 L	100000 L		760000 N				
-Calcium pyrophosphate	7790-76-3	100000 L	100000 L	100000 L		760000 N				
-Diammonium phosphate	7783-28-0	100000 L	100000 L	100000 L		760000 N				
-Dicalcium phosphate	7757-93-9	100000 L	100000 L	100000 L		760000 N				
-Dimagnesium phosphate	7782-75-4	100000 L	100000 L	100000 L		760000 N				
-Dipotassium phosphate	7758-11-4	100000 L	100000 L	100000 L		760000 N				
-Disodium phosphate	7558-79-4	100000 L	100000 L	100000 L		760000 N				

Appendix A: Screening Levels

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
-Monoaluminum phosphate	13530-50-2	100000 L	100000 L	100000 L		760000 N				
-Monoammonium phosphate	7722-76-1	100000 L	100000 L	100000 L		760000 N				
-Monocalcium phosphate	7758-23-8	100000 L	100000 L	100000 L		760000 N				
-Monomagnesium phosphate	7757-86-0	100000 L	100000 L	100000 L		760000 N				
-Monopotassium phosphate	7778-77-0	100000 L	100000 L	100000 L		760000 N				
-Monosodium phosphate	7558-80-7	100000 L	100000 L	100000 L		760000 N				
-Polyphosphoric acid	8017-16-1	100000 L	100000 L	100000 L		760000 N				
-Potassium triphosphate	13845-36-8	100000 L	100000 L	100000 L		760000 N				
-Sodium acid pyrophosphate	7758-16-9	100000 L	100000 L	100000 L		760000 N				
-Sodium aluminum phosphate (acidic)	7785-88-8	100000 L	100000 L	100000 L		760000 N				
-Sodium aluminum phosphate (anhydrous)	10279-59-1	100000 L	100000 L	100000 L		760000 N				
-Sodium aluminum phosphate (tetrahydrate)	10305-76-7	100000 L	100000 L	100000 L		760000 N				
-Sodium hexametaphosphate	10124-56-8	100000 L	100000 L	100000 L		760000 N				
-Sodium polyphosphate	68915-31-1	100000 L	100000 L	100000 L		760000 N				
-Sodium trimetaphosphate	7785-84-4	100000 L	100000 L	100000 L		760000 N				
-Sodium triphosphate	7758-29-4	100000 L	100000 L	100000 L		760000 N				
-Tetrapotassium phosphate	7320-34-5	100000 L	100000 L	100000 L		760000 N				
-Tetrasodium pyrophosphate	7722-88-5	100000 L	100000 L	100000 L		760000 N				
-Trialuminum sodium tetra decahydrogenoctaorthophosphate (dihydrate)	15136-87-5	100000 L	100000 L	100000 L		760000 N				
-Tricalcium phosphate	7758-87-4	100000 L	100000 L	100000 L		760000 N				
-Trimagnesium phosphate	7757-87-1	100000 L	100000 L	100000 L		760000 N				
-Tripotassium phosphate	7778-53-2	100000 L	100000 L	100000 L		760000 N				
-Trisodium phosphate	7601-54-9	100000 L	100000 L	100000 L		760000 N				
Phosphine	7803-51-2	32 N	310 N	520 N		4.7 N		0.31 N	1.3 N	
Phosphoric Acid	7664-38-2	100000 L	100000 L	100000 L		760000 N		10 N	44 N	
Phosphorus, White	7723-14-0	2.2 N	20 N	34 N	0.023 N	0.31 N				
Phthalic Acid, P-	100-21-0	85000 N	100000 L	100000 L	110 N	15000 N				
Phthalic Anhydride	85-44-9	100000 L	100000 L	100000 L	130 N	30000 N		21 N	88 N	
Picloram	1918-02-1	6000 N	43000 N	73000 N	2.8 M	500 M				
Picramic Acid (2-Amino-4,6-dinitrophenol)	96-91-3	8.5 N	62 N	100 N	0.02 N	1.5 N				
Pirimiphos, Methyl	29232-93-7	850 N	6200 N	10000 N	1.7 N	91 N				
Polybrominated Biphenyls	59536-65-1	0.22 C	0.57 C	7.3 N		0.022 C		0.0028 C	0.014 C	
Polychlorinated Biphenyls (PCBs)										
-Aroclor 1016	12674-11-2	5.5 N	37 N	63 N	2.1 N	1.1 N		1.2 C	6.1 C	
-Aroclor 1221	11104-28-2	2 C	5.4 C	390 C	0.015 C	0.043 C		0.043 C	0.21 C	
-Aroclor 1232	11141-16-5	2 C	5.4 C	73 S	0.015 C	0.043 C		0.043 C	0.21 C	
-Aroclor 1242	53469-21-9	3.1 C	7.4 C	460 C	1.1 C	0.34 C		0.043 C	0.21 C	
-Aroclor 1248	12672-29-6	3.1 C	7.4 C	460 C	1 C	0.34 C		0.043 C	0.21 C	
-Aroclor 1254	11097-69-1	1.5 N	7.4 C	18 N	1.6 N	0.31 N		0.043 C	0.21 C	
-Aroclor 1260	11096-82-5	3.1 C	7.4 C	460 C	4.8 C	0.34 C		0.043 C	0.21 C	
-Heptachlorobiphenyl, 2,3,3',4,4',5,5'- (PCB 189)	39635-31-9	1.5 C	3.8 C	30 N	2.4 C	0.17 C		0.021 C	0.11 C	
-Hexachlorobiphenyl, 2,3',4,4',5,5'- (PCB 167)	52663-72-6	1.5 C	3.8 C	30 N	1.4 C	0.17 C		0.021 C	0.11 C	
-Hexachlorobiphenyl, 2,3,3',4,4',5'- (PCB 157)	69782-90-7	1.5 C	3.8 C	30 N	1.5 C	0.17 C		0.021 C	0.11 C	
-Hexachlorobiphenyl, 2,3,3',4,4',5- (PCB 156)	38380-08-4	1.5 C	3.8 C	30 N	1.5 C	0.17 C		0.021 C	0.11 C	
-Hexachlorobiphenyl, 3,3',4,4',5,5'- (PCB 169)	32774-16-6	0.0015 C	0.0038 C	0.03 N	0.0014 C	0.00017 C		0.000021 C	0.00011 C	
-Pentachlorobiphenyl, 2',3,4,4',5- (PCB 123)	65510-44-3	1.5 C	3.8 C	30 N	0.89 C	0.17 C		0.021 C	0.11 C	
-Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	31508-00-6	1.5 C	3.8 C	30 N	0.87 C	0.17 C		0.021 C	0.11 C	
-Pentachlorobiphenyl, 2,3,3',4,4'- (PCB 105)	32598-14-4	1.5 C	3.8 C	30 N	0.89 C	0.17 C		0.021 C	0.11 C	
-Pentachlorobiphenyl, 2,3,4,4',5- (PCB 114)	74472-37-0	1.5 C	3.8 C	30 N	0.89 C	0.17 C		0.021 C	0.11 C	

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
-Pentachlorobiphenyl, 3,3',4,4',5-	57465-28-8	0.0005 C	0.0011 C	0.0088 N	0.00027 C	0.000052 C			6.4E-06 C	0.000032 C
-Polychlorinated Biphenyls (high risk)	1336-36-3	3.1 C	7.4 C	460 C					0.043 C	0.21 C
-Polychlorinated Biphenyls (low risk)	1336-36-3				1.6 M	0.5 M			0.24 C	1.2 C
-Polychlorinated Biphenyls (lowest risk)	1336-36-3								1.2 C	6.1 C
-Tetrachlorobiphenyl, 3,3',4,4'- (PCB 77)	32598-13-3	0.48 C	1.1 C	8.8 N	0.16 C	0.052 C			0.0064 C	0.032 C
-Tetrachlorobiphenyl, 3,4,4',5- (PCB 81)	70362-50-4	0.15 C	0.38 C	3 N	0.053 C	0.017 C			0.0021 C	0.011 C
Polymeric Methylene Diphenyl Diisocyanate (PMDI)	9016-87-9	100000 L	100000 L	100000 L					0.63 N	2.6 N
Polynuclear Aromatic Hydrocarbons (PAHs)										
-Acenaphthene	83-32-9	4800 N	33000 N	55000 N	82 N	400 N				
-Anthracene	120-12-7	24000 N	100000 L	100000 L	860 N	1300 N				
-Benz[a]anthracene	56-55-3	2.1 C	21 C	1300 C	2.1 C	0.29 C			0.087 C	1.1 C
-Benzo(j)fluoranthene	205-82-3	5.3 C	13 C	800 C	13 C	0.56 C			0.22 C	1.1 C
-Benzo[a]pyrene	50-32-8	0.21 C	2.1 C	130 C	4.7 M	0.2 M			0.0087 C	0.11 C
-Benzo[b]fluoranthene	205-99-2	2.1 C	21 C	1300 C	7 C	0.29 C			0.087 C	1.1 C
-Benzo[k]fluoranthene	207-08-9	21 C	210 C	13000 C	68 C	2.9 C			0.087 C	1.1 C
-Chrysene	218-01-9	210 C	2100 C	100000 L	210 C	29 C			0.87 C	11 C
-Dibenz[a,h]anthracene	53-70-3	0.21 C	2.1 C	130 C	2.2 C	0.029 C			0.008 C	0.1 C
-Dibenzo[a,e]pyrene	192-65-4	0.53 C	1.3 C	80 C	15 C	0.056 C			0.022 C	0.11 C
-Dimethylbenz(a)anthracene, 7,12-	57-97-6	0.006 C	0.062 C	3.7 C	0.017 C	0.00086 C			0.00014 C	0.0017 C
-Fluoranthene	206-44-0	3200 N	22000 N	37000 N	1400 N	630 N				
-Fluorene	86-73-7	3200 N	22000 N	37000 N	81 N	220 N				
-Indeno[1,2,3-cd]pyrene	193-39-5	2.1 C	21 C	1300 C	23 C	0.29 C			0.087 C	1.1 C
-Methylnaphthalene, 1-	90-12-0	310 C	390 S	390 S	1 C	9.7 C				
-Methylnaphthalene, 2-	91-57-6	370 S	370 S	370 S	2.8 N	27 N				
-Naphthalene	91-20-3	50 C	180 C	1000 N	0.092 C	1.4 C	91 C	460 C	0.72 C	3.6 C
-Nitropyrene, 4-	57835-92-4	5.3 C	13 C	800 C	0.55 C	0.16 C			0.22 C	1.1 C
-Pyrene	129-00-0	2400 N	17000 N	28000 N	190 N	87 N				
Prochloraz	67747-09-5	45 C	110 C	6700 C	0.32 C	3.2 C				
Profluralin	26399-36-0	520 N	3700 N	6200 N	23 N	19 N				
Prometon	1610-18-0	1300 N	9200 N	15000 N	1.8 N	190 N				
Prometryn	7287-19-6	340 N	2500 N	4200 N	1.4 N	45 N				
Propachlor	1918-16-7	1100 N	8000 N	13000 N	2.3 N	190 N				
Propanil	709-98-8	430 N	3100 N	5200 N	0.7 N	63 N				
Propargite	2312-35-8	1700 N	12000 N	20000 N	180 N	120 N				
Propargyl Alcohol	107-19-7	170 N	1200 N	2000 N	0.13 N	31 N				
Propazine	139-40-2	1700 N	12000 N	20000 N	4.6 N	260 N				
Propham	122-42-9	1700 N	12000 N	20000 N	3.4 N	270 N				
Propiconazole	60207-90-1	1100 N	8000 N	13000 N	11 N	160 N				
Propionaldehyde	123-38-6	110 N	340 N	570 N	0.069 N	17 N			8.3 N	35 N
Propyl benzene	103-65-1	260 S	260 S	260 S	20 N	530 N			1000 N	4400 N
Propylene	115-07-1	100000 L	100000 L	100000 L					3100 N	13000 N
Propylene Glycol	57-55-6	100000 L	100000 L	100000 L	1300 N	310000 N				
Propylene Glycol Dinitrate	6423-43-4	80 N	240 N	400 N	0.0037 N	0.57 N			0.28 N	1.2 N
Propylene Glycol Monoethyl Ether	1569-02-4	60000 N	100000 L	100000 L	45 N	11000 N				
Propylene Glycol Monomethyl Ether	107-98-2	60000 N	100000 L	100000 L	44 N	11000 N			2100 N	8800 N
Propylene Oxide	75-56-9	28 C	90 C	2500 N	0.0097 C	2.3 C			6.6 C	33 C
Pursuit	81335-77-5	21000 N	100000 L	100000 L	68 N	3900 N				
Pydrin	51630-58-1	2100 N	15000 N	26000 N	4900 N	390 N				
Pyridine	110-86-1	110 N	1000 N	1700 N	0.1 N	15 N				

Appendix A: Screening Levels

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Quinalphos	13593-03-8	43 N	310 N	520 N	0.65 N	3.8 N				
Quinoline	91-22-5	2.2 C	5.7 C	330 C	0.014 C	0.21 C				
Refractory Ceramic Fibers	NA	100000 L	100000 L	100000 L				31 N	130 N	
Resmethrin	10453-86-8	2500 N	18000 N	31000 N	600 N	48 N				
Ronnel	299-84-3	4300 N	31000 N	52000 N	55 N	300 N				
Rotenone	83-79-4	340 N	2500 N	4200 N	490 N	47 N				
Safrole	94-59-7	7.3 C	78 C	4600 C	0.0076 C	0.62 C		0.15 C	1.9 C	
Savey	78587-05-0	2100 N	15000 N	26000 N	7.2 N	81 N				
Selenious Acid	7783-00-8	550 N	5100 N	8600 N		78 N				
Selenium	7782-49-2	550 N	5100 N	8600 N	5.3 M	50 M		21 N	88 N	
Selenium Sulfide	7446-34-6	550 N	5100 N	8600 N		78 N		21 N	88 N	
Sethoxydim	74051-80-2	7700 N	55000 N	93000 N	140 N	780 N				
Silica (crystalline, respirable)	7631-86-9	100000 L	100000 L	100000 L				3.1 N	13 N	
Silver	7440-22-4	550 N	5100 N	8600 N	12 N	71 N				
Simazine	122-34-9	57 C	140 C	5200 N	0.039 M	4 M				
Sodium Acifluorfen	62476-59-9	1100 N	8000 N	13000 N	32 N	200 N				
Sodium Azide	26628-22-8	430 N	4100 N	6900 N		62 N				
Sodium Diethyldithiocarbamate	148-18-5	25 C	64 C	3800 C		2.5 C				
Sodium Fluoride	7681-49-4	5500 N	51000 N	86000 N		780 N		14 N	57 N	
Sodium Fluoroacetate	62-74-8	1.7 N	12 N	20 N	0.0013 N	0.31 N				
Sodium Metavanadate	13718-26-8	110 N	1000 N	1700 N		16 N				
Stirofos (Tetrachlorovinphos)	961-11-5	280 C	720 C	31000 N	1.4 C	24 C				
Strontium, Stable	7440-24-6	66000 N	100000 L	100000 L	6600 N	9300 N				
Strychnine	57-24-9	25 N	180 N	310 N	1 N	4.6 N				
Styrene	100-42-5	870 S	870 S	870 S	2.2 M	100 M		1000 N	4400 N	
Sulfonylbis(4-chlorobenzene), 1,1'-	80-07-9	69 N	490 N	820 N	1.5 N	13 N				
Sulfuric Acid	7664-93-9	100000 L	100000 L	100000 L				1 N	4.4 N	
Systhane	88671-89-0	2100 N	15000 N	26000 N	86 N	350 N				
TCMTB	21564-17-0	2500 N	18000 N	31000 N	51 N	370 N				
Tebuthiuron	34014-18-1	6000 N	43000 N	73000 N	6.3 N	1100 N				
Temephos	3383-96-8	1700 N	12000 N	20000 N	1200 N	310 N				
Terbacil	5902-51-2	1100 N	8000 N	13000 N	1.2 N	200 N				
Terbufos	13071-79-9	2.1 N	15 N	26 N	0.0079 N	0.18 N				
Terbutryn	886-50-0	85 N	620 N	1000 N	0.28 N	10 N				
Tetrabromodiphenyl ether, 2,2',4,4'- (BDE-47)	5436-43-1	8.5 N	62 N	100 N	0.85 N	1.6 N				
Tetrachlorobenzene, 1,2,4,5-	95-94-3	25 N	180 N	310 N	0.11 N	1.2 N				
Tetrachloroethane, 1,1,1,2-	630-20-6	27 C	93 C	680 S	0.038 C	5 C		3.3 C	17 C	
Tetrachloroethane, 1,1,1,2,2-	79-34-5	7.8 C	28 C	1900 S	0.0052 C	0.66 C	63 C	310 C	0.42 C	2.1 C
Tetrachloroethylene	127-18-4	7.7 C	26 C	170 S	0.045 M	5 M	11 C	55 C	4.1 C	21 C
Tetrachlorophenol, 2,3,4,6-	58-90-2	2500 N	18000 N	31000 N	21 N	170 N				
Tetrachlorotoluene, p- alpha, alpha, alpha-	5216-25-1	0.34 C	0.86 C	49 C	0.0023 C	0.034 C				
Tetraethyl Dithiopyrophosphate	3689-24-5	43 N	310 N	520 N	0.078 N	5.3 N				
Tetrafluoroethane, 1,1,1,2-	811-97-2	1100 S	1100 S	1100 S	1900 N	17000 N		83000 N	350000 N	
Tetryl (Trinitrophenylmethyl)nitramine)	479-45-8	340 N	2500 N	4200 N	12 N	63 N				
Thallium (Soluble Salts)	7440-28-0	1.1 N	10 N	17 N	2.9 M	2 M				
Thiobencarb	28249-77-6	850 N	6200 N	10000 N	8.3 N	120 N				
Thiodiglycol	111-48-8	7600 N	68000 N	100000 L	4.4 N	1100 N				
Thiofanox	39196-18-4	25 N	180 N	310 N	0.028 N	4.1 N				
Thiophanate, Methyl	23564-05-8	6900 N	49000 N	82000 N	21 N	1200 N				

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Thiram	137-26-8	430 N	3100 N	5200 N	2.2 N	76 N				
Tin	7440-31-5	66000 N	100000 L	100000 L	47000 N	9300 N				
Titanium Tetrachloride	7550-45-0	100000 L	100000 L	100000 L				0.1 N	0.44 N	
Toluene	108-88-3	820 S	820 S	820 S	14 M	1000 M		5200 N	22000 N	
Toluene-2,5-diamine	95-70-5	8.5 N	62 N	100 N	0.0099 N	1.6 N				
Toluidine, p-	106-49-0	36 C	91 C	5300 C	0.029 C	3.4 C				
Toxaphene	8001-35-2	6.2 C	16 C	910 C	9.3 M	3 M		0.076 C	0.38 C	
Tralometrin	66841-25-6	640 N	4600 N	7900 N	920 N	120 N				
Tri-n-butyltin	688-73-3	25 N	180 N	310 N	2 N	4.7 N				
Triallate	2303-17-5	1100 N	8000 N	13000 N	3.9 N	87 N				
Triasulfuron	82097-50-5	850 N	6200 N	10000 N	3.4 N	160 N				
Tribromobenzene, 1,2,4-	615-54-3	430 N	3100 N	5200 N	2.2 N	78 N				
Tributyl Phosphate	126-73-8	760 C	1900 C	10000 N	4.4 C	45 C				
Tributyltin Compounds	NA	25 N	180 N	310 N		4.7 N				
Tributyltin Oxide	56-35-9	25 N	180 N	310 N	4600 N	4.4 N				
Trichloro-1,2,2-trifluoroethane, 1,1,2-	76-13-1	910 S	910 S	910 S	2600 N	53000 N		31000 N	130000 N	
Trichloroacetic Acid	76-03-9	97 C	250 C	14000 C	0.25 M	60 M				
Trichloroaniline HCl, 2,4,6-	33663-50-2	240 C	590 C	35000 C	1.3 C	23 C				
Trichloroaniline, 2,4,6-	634-93-5	2.5 N	18 N	31 N	0.054 N	0.3 N				
Trichlorobenzene, 1,2,3-	87-61-6	69 N	150 S	150 S	0.31 N	5.2 N				
Trichlorobenzene, 1,2,4-	120-82-1	87 N	270 N	400 S	4.1 M	70 M		2.1 N	8.8 N	
Trichloroethane, 1,1,1-	71-55-6	640 S	640 S	640 S	1.4 M	200 M	13000 N	54000 N	5200 N	22000 N
Trichloroethane, 1,1,2-	79-00-5	2.2 N	6.8 N	11 N	0.032 M	5 M	11 N	46 N	0.21 N	0.88 N
Trichloroethylene	79-01-6	6.2 N	20 N	34 N	0.036 M	5 M	9.1 N	38 N	2.1 N	8.8 N
Trichlorofluoromethane	75-69-4	1100 N	1200 S	1200 S	14 N	1100 N			730 N	3100 N
Trichlorophenol, 2,4,5-	95-95-4	8500 N	62000 N	100000 L	67 N	890 N				
Trichlorophenol, 2,4,6-	88-06-2	85 N	620 N	1000 N	0.68 N	9 N			7.8 C	40 C
Trichlorophenoxyacetic Acid, 2,4,5-	93-76-5	850 N	6200 N	10000 N	0.99 N	120 N				
Trichlorophenoxypropionic acid, -2,4,5	93-72-1	690 N	4900 N	8200 N	0.55 M	50 M				
Trichloropropane, 1,1,2-	598-77-6	550 N	1300 S	1300 S	0.61 N	78 N				
Trichloropropane, 1,2,3-	96-18-4	0.07 C	0.95 C	37 N	0.000056 C	0.0065 C			0.31 N	1.3 N
Trichloropropene, 1,2,3-	96-19-5	1.1 N	3.3 N	5.5 N	0.0061 N	0.62 N			0.31 N	1.3 N
Tridiphane	58138-08-2	250 N	1800 N	3100 N	6.7 N	47 N				
Triethylamine	121-44-8	170 N	520 N	880 N	0.091 N	15 N			7.3 N	31 N
Trifluralin	1582-09-8	640 N	2200 C	7900 N	15 C	22 C				
Trimethyl Phosphate	512-56-1	340 C	860 C	10000 N	0.15 C	34 C				
Trimethylbenzene, 1,2,3-	526-73-8	74 N	220 N	290 S	0.29 N	10 N			5.2 N	22 N
Trimethylbenzene, 1,2,4-	95-63-6	87 N	220 S	220 S	0.44 N	15 N			7.3 N	31 N
Trimethylbenzene, 1,3,5-	108-67-8	180 S	180 S	180 S	2.5 N	87 N				
Trinitrobenzene, 1,3,5-	99-35-4	3100 N	27000 N	46000 N	33 N	460 N				
Trinitrotoluene, 2,4,6-	118-96-7	50 N	420 N	710 N	0.89 N	7.6 N				
Triphenylphosphine Oxide	791-28-6	1700 N	12000 N	20000 N	23 N	280 N				
Tris(2-chloroethyl)phosphate	115-96-8	340 C	860 C	7300 N	0.64 C	33 C				
Tris(2-ethylhexyl)phosphate	78-42-2	2100 C	5400 C	100000 L	21000 C	210 C				
Uranium (Soluble Salts)	NA	320 N	3100 N	5200 N	270 M	30 M			0.31 N	1.3 N
Urethane	51-79-6	1.7 C	17 C	1000 C	0.00094 C	0.21 C			0.033 C	0.42 C
Vanadium Pentoxide	1314-62-1	920 N	7500 N	13000 N		110 N			0.0029 C	0.015 C
Vanadium and Compounds	NA	550 N	5200 N	8800 N	1600 N	78 N				
Vernolate	1929-77-7	85 N	620 N	1000 N	0.13 N	8.3 N				

Appendix A: Screening Levels

Table A-6: Screening Level Summary Table - 2012

Chemical		Soil Exposure			Ground Water		Vapor Exposure			
		Direct Contact			Soil MTG	Tap	Ground Water		Indoor Air	
		Residential (mg/kg)	Com/Ind (mg/kg)	Excavation (mg/kg)	Residential (mg/kg)	Residential (ug/L)	Residential (ug/L)	Com/Ind (ug/L)	Residential (ug/m ³)	Com/Ind (ug/m ³)
Name	CASRN									
Vinclozolin	50471-44-8	2100 N	15000 N	26000 N	5.2 N	340 N				
Vinyl Acetate	108-05-4	1400 N	2800 S	2800 S	1.7 N	410 N			210 N	880 N
Vinyl Bromide	593-60-2	1.5 C	5.6 C	32 N	0.0086 C	1.5 C			0.76 C	3.8 C
Vinyl Chloride	75-01-4	0.84 C	17 C	660 N	0.014 M	2 M	2 C	35 C	1.6 C	28 C
Warfarin	81-81-2	25 N	180 N	310 N	0.093 N	4.4 N				
Xylene, P-	106-42-3	390 S	390 S	390 S	3.7 N	190 N			100 N	440 N
Xylene, m-	108-38-3	390 S	390 S	390 S	3.7 N	190 N			100 N	440 N
Xylene, o-	95-47-6	430 S	430 S	430 S	3.7 N	190 N			100 N	440 N
Xylenes	1330-20-7	260 S	260 S	260 S	200 M	10000 M			100 N	440 N
Zinc Phosphide	1314-84-7	32 N	310 N	520 N		4.7 N				
Zinc and Compounds	7440-66-6	32000 N	100000 L	100000 L		4700 N				
Zineb	12122-67-7	4300 N	31000 N	52000 N	45 N	780 N				

C = Carcinogenic endpoint

L = Capped at 100,000 mg/kg (soil direct contact only)

M = Set to maximum contaminant limit (MCL; ground water only) or based on MCL (migration to ground water)

N = Noncarcinogenic endpoint

R = Capped at 1,000,000 mg/kg (migration to ground water only)

S = Capped at soil saturation limit

Table A-7: Recreational Soil Direct Contact Screening Levels - 2012

Chemical		Trail (mg/kg)	Athletic Field (mg/kg)	Community Park (mg/kg)
Name	CASRN			
Arsenic, Inorganic	7440-38-2	500	80	30
Benzene	71-43-2	1800*	1070	420
Benzo(a)pyrene	50-32-8	5	3	1
Ethylbenzene	100-41-4	480*	480*	480*
Lead and Compounds	7439-92-1	400	400	400
Toluene	108-88-3	820*	820*	820*
Xylenes	1330-20-7	260*	260*	260*

*Soil saturation limit

Acronyms

AA	Ambient air
ARAR	Applicable or relevant and appropriate requirement
ASTM	ASTM International, formerly American Society for Testing and Materials
BTEX	Benzene, toluene, ethylbenzene, and xylenes
BTV	Background threshold value
CAS	Chemical Abstracts Service
CASRN	Chemical Abstracts Service Registry Number
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CERCLIS	Comprehensive Environmental Response, Compensation, and Liability Information System
CFR	Code of Federal Regulations
CSA	Crawl space air
CSM	Conceptual site model
CVI	Chlorinated vapor intrusion
CVOC	Chlorinated volatile organic compound
DAF	Dilution attenuation factor
DNAPL	Dense non-aqueous phase liquid
DQO	Data quality objective
EC	Engineering control
EPA	Environmental Protection Agency
EPC	Exposure point concentration
EQL	Estimated quantitation limit
ERA	Ecological risk assessment
ERC	Environmental restrictive covenant
ERO	Environmental restrictive ordinance
ESA	Ecologically susceptible area
eV	Electron volt
FA	Financial assurance
FID	Flame ionization detector
F _{oc}	Fraction of organic carbon
GC/MS	Gas chromatography/mass spectroscopy
GIS	Geographic information system
GW	Ground water
GWSL	Ground water screening level
IA	Indoor air
IAb	Indoor air background
IASL	Indoor air screening level
IBP	Indiana Brownfields Program
IC	Indiana Code
IC	Institutional control
ICP	Inductively coupled plasma
IDEM	Indiana Department of Environmental Management
IEUBK	Integrated Exposure Uptake Biokinetic Model

IUR	Inhalation unit risk
LNAPL	Light non-aqueous phase liquid
LOC	Letter of credit
LOE	Line of evidence
LUST	Leaking underground storage tank
MCL	Maximum contaminant level
MDDR	Minimum data documentation requirements
MS/MSD	Matrix spike/matrix spike duplicate
NAPL	Non-aqueous phase liquid
NIOSH	National Institute for Occupational Safety and Health
OLQ	Office of Land Quality
PAH	Polyaromatic hydrocarbon
PCB	Polychlorinated biphenyl
PID	Photoionization detector
POC	Point of compliance
PPB	Parts per billion
PPM	Parts per million
PVI	Petroleum vapor intrusion
QA/QC	Quality assurance/quality control
QAPP	Quality assurance project plan
RCG	Remediation Closure Guide
RCRA	Resource Conservation and Recovery Act
RfC	Reference concentration
RfD	Reference dose
RME	Reasonable maximum exposure
RMSD	Root mean squared deviation
RO	Remediation objective
SAP	Sampling and analysis plan
SCP	State Cleanup Program
SF	Slope factor
SGe	Soil gas, exterior
SGss	Soil gas, subslab
SIM	Selective ion monitoring
SPLP	Synthetic precipitation leaching procedure
TAL	Target analyte list
TCL	Target compound list
TSD	Treatment, storage, disposal
UCL	Upper confidence limit
U.S. EPA	United States Environmental Protection Agency
USGS	United States Geological Survey
VI	Vapor intrusion
VOC	Volatile organic compound
VRP	Voluntary remediation program
WHPA	Wellhead protection area

Glossary

Absorption	Taking up by capillary, osmotic, chemical, or solvent action; as a sponge (or soil) absorbs water.
Absorption route	The way a toxicant comes into contact with an organism, typically by means of dermal contact, ingestion, or inhalation [formerly exposure route]
Activity restriction	A formal restriction that limits specific activities that could result in exposure to chemicals at levels unsafe for human health or the environment. This restriction is implemented through an environmental restrictive covenant.
Acute hazard	Environmental exposure conditions that pose an imminent threat to human health or the environment.
Adsorption	Adhesion of molecules of gases, or of ions or molecules in solutions, to the surfaces of solid bodies with which they are in contact.
All Appropriate Inquiry	Investigation into the previous ownership and uses of the property consistent with good commercial or customary practice as defined in 42 USC §9601(35)(b) that will qualify a party to a commercial real estate transaction for one of the threshold criteria for satisfying the landowner liability protections in CERCLA liability [42 USC §9601(35)(A) & (B), §9607(b)(3), §9607(q), and §9607(r)], assuming compliance with other elements of the defense.
Anthropogenic background	Natural and human-made substances present in the environment as a result of human activities not specifically related to the site in question.
Aquifer	A consolidated or unconsolidated geologic formation or group of formations or a portion of a formation, that is hydraulically interconnected and that has the ability to receive, store, or transmit water to wells, springs, or other surface water bodies.
Background reference area	The area where background samples are collected for comparison with samples collected on the site.
Background threshold value	An upper limit estimate of the background chemical concentration used to represent environmental chemicals that are not specifically related to the site being investigated.

Background well	A ground water monitoring well placed upgradient of the area of concern and out of the zone of influence of the source.
Blank	A sample analyzed to determine if all or a portion of an analyte detected in an environmental sample is the result of external contamination due to handling or other factors in the field or the laboratory; in such cases, the detected concentration of the analyte may not actually represent site conditions.
Calibration	Routine quality control procedures performed daily or more frequently to verify the accuracy of analytical instruments or measuring equipment.
Chain of custody	An unbroken trail of accountability that ensures the physical security of samples, data, and records.
Chemical Abstracts Service (CAS) Number	A unique numerical identifier that specifies a particular substance no matter what chemical name or synonym is used.
Closure	IDEM's written recognition that a party has demonstrated attainment of remediation objectives in a particular area. The written instrument for this decision varies by remedial program (see the <i>Remediation Program Guide</i>). Under the Resource Conservation and Recovery Act, closure refers to a series of formal procedures required to end the operation of a permitted treatment, storage, or disposal unit.
Cohesive soil	Clay, or soil with high clay content, that does not crumble, can be excavated with vertical side slopes, and is plastic when moist. Cohesive soils include clayey silt, sandy clay, silty clay, clay, and organic clay.
Commercial/industrial exposure	Human contact with contaminated environmental media at a frequency and duration likely to occur at a commercial or industrial property.
Commercial/industrial land use	Property used in conjunction with a business (and not used for human habitation), or vacant land not intended for future human habitation.
Composite sample	A sample that consists of portions of several samples from a given area; the portions are thoroughly homogenized to represent the area sampled. Composite samples are not appropriate for volatile substances.
Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA)	Legislation that established the federal Superfund for response to uncontrolled releases of hazardous substances that may endanger public health or the environment.

Conceptual Site Model	A comprehensive description of a site and the processes by which contamination may move from source(s) to receptor(s).
Conditional closure	A closure that relies on a continuing activity and/or activity restriction to adequately address risk from a release.
Contaminant	For purposes of the <i>Remediation Closure Guide (RCG)</i> , a chemical present at a concentration that exceeds the chemical's remediation objective.
Contract Laboratory Program	U.S. EPA program that establishes laboratory specifications, analytical methods, and quality assurance/quality control protocols required for Superfund and related activities.
Control sample	A sample introduced into a data collection process to monitor the performance of the system.
Critical effect	The first adverse effect, or its known precursor, that occurs to the most sensitive species as the dose increases during toxicity testing of a chemical.
Critical effects category	A group of organs or tissues with a common function or means of absorption, grouped together for the purpose of determining additivity of chemicals by critical effect.
Data quality objectives	Qualitative and quantitative statements that clarify a study's technical and quality objectives, define the appropriate type of data, and specify tolerable levels of potential decision error that will be used as the basis for establishing the quality and quantity of data needed to support decisions.
Dermal contact	Skin contact with any contaminated medium.
Dilution attenuation factor	The ratio of contaminant concentration in soil leachate to the concentration in ground water at the downgradient edge of the contaminated area (standard value equals twenty). This factor accounts for the reduction in contaminant concentration that results from adsorption, chemical transformation, biological degradation, and dilution due to mixing of the leachate with ambient ground water.
Dose-response relationship	The association between the amount of exposure to an agent and the likelihood and severity of adverse health effects.
Dry soil bulk density	The weight per unit volume of oven dry soil, determined by dividing the weight of the oven dry soil by the volume of the same oven dry soil.

Duplicate	A split sample or an independent second sample collected from, and representative of, the same sample location for the purpose of documenting precision.
Ecologically susceptible area	Habitats where it is appropriate to consider the effects of chemicals on nonhuman receptors.
Engineering controls	Physical barriers designed and maintained to prevent humans or other receptors from being exposed to contaminated environmental media.
Environment	The complex of physical, chemical, and biologic factors that include land, fish, wildlife, biota, air, water, ground water, drinking water supplies, and other similar natural resources as provided by IC 13-11-2-137 that act upon an organism or ecological community.
Environmental media	Material found in the outdoor, natural, physical environment through which chemicals can move and contact organisms.
Environmental restrictive covenant (ERC)	A legal and administrative measure to protect human health and the environment at sites where contamination is left in place. ERCs limit human exposure by restricting activity, use, and access to properties with contamination. Restrictive covenants can be enforced by the state against current and future property owners.
Environmental restrictive ordinance (ERO)	An ordinance adopted by a municipal corporation that limits, regulates, or prohibits withdrawal, human consumption, and any other use of ground water.
Environmental site assessment	The process by which a person or entity seeks to determine if a particular parcel of real property (including improvements) is subject to recognized environmental conditions. At the option of the user, an environmental site assessment may include more inquiry than that constituting all appropriate inquiry or, if the user is not concerned about qualifying for landowner liability protections, less inquiry than that constituting all appropriate inquiry. An environmental site assessment is both different from and less rigorous than an environmental compliance audit.
Equipment rinsate blank	A sample of analyte-free media that has been used to rinse sampling equipment. It is collected after completion of decontamination and prior to sampling. This blank is useful in documenting adequate decontamination of sampling equipment.

Estimated quantitation limit	The lowest concentration that can be reliably achieved within specified limits of precision and accuracy under routine laboratory operating conditions. Use of the word “estimated” emphasizes sample matrix dependence.
Excavation worker exposure	Worker exposure that could potentially result from trenching or excavation activities at a site. This term replaces the terminology “construction worker exposure” used in earlier guidance.
Exceedance	A chemical concentration that is greater than a remediation objective.
Exposure	An organism’s contact with a chemical, physical, or biological agent. Exposure is quantified as the concentration of the agent in the contact medium integrated over the duration of that contact.
Exposure control area	An area over which a remedy reduces exposure to an acceptable level. An exposure control area can be, but often is not, the same as an area of property control; it may involve multiple properties and multiple owners.
Exposure duration	The total amount of time over which an exposure occurs, typically expressed in years.
Exposure frequency	The number of days per year that an exposure occurs.
Exposure pathway	The course a chemical takes from a source to the point of contact with an exposed organism.
Exposure point concentration	A quantitative measure of potential contaminants in environmental media for the purpose of exposure assessment. Replaces the term “potential exposure concentration” (PEC).
Exposure scenario	The setting or circumstances under which which exposure to contamination does or can occur.
Exposure time	The number of hours per day that an exposure occurs.
Extent of contamination	The vertical and horizontal distribution of chemicals whose concentrations exceed remediation objectives.
Field blank	Analyte-free reagent water taken to the sampling site, transferred into a sample container on site, and then analyzed by the laboratory for the same parameters as the investigative samples. This sample is used to check for procedural contamination of samples.

Field duplicate	A split sample or an independent sample collected as closely as possible from the same location or source and at the same time. This duplicate sample is stored in a separate container and analyzed separately to document the precision of the sampling process.
Fill	Artificially deposited soil, rock, and/or waste material.
Fraction of organic carbon	The portion of organic matter in soil that is available to adsorb organic chemicals.
Free product	A substance that is present as a nonaqueous phase liquid.
Future land use	Projected site use or purpose in a time subsequent to the present.
Ground water	Water occurring beneath the surface of the ground, regardless of location or form (IC 25-39-2-10).
Hazard index	The sum of individual hazard quotients for multiple substances.
Hazard quotient	The ratio of a single substance exposure level over a specified period of time relative to a level that is considered protective, or the ratio of the exposure level to the remediation objective.
Health protective level	Chemical concentration calculated to be protective.
Holding time	Elapsed time, expressed in days from the date of sampling to the date of analysis, that a properly preserved sample may be stored before analysis.
Hydraulic conductivity	The extent to which a given substance allows water to flow through it.
Inhalation unit risk	An estimate of the increased cancer risk per concentration over a lifetime of exposure. Expressed in units of $(\mu\text{g}/\text{m}^3)^{-1}$.
Institutional controls	Administratively or legally enforceable measures that limit human exposure to chemicals at concentrations that exceed residential remediation objectives.
Interference	An element, chemical, or other matrix effect present in a sample that interferes with the detection of a target analyte. Interference may lead to inaccurate analytical results.
Judgmental sampling	A method of selecting sample locations based on the professional judgment of the sampler. The history of the site, current site conditions, and terrain should guide these decisions.

Karst terrain	Areas where karst topography, with its characteristic surface and subterranean features, is developed as the result of dissolution of limestone, dolomite, or other soluble rock. Characteristic features present in karst terrains include but are not limited to sinkholes, sinking streams, caves, large springs, and blind valleys.
Limiting factor	A constraint on a screening level based on a chemical property (e.g., soil saturation limit) or policy decision (e.g., maximum contaminant levels).
Matrix	The substance containing the analyte of interest. Examples include soil, sediment, sludge, ground water, surface water, drinking water, and air. Sometimes matrix types are simplified to consider only three main types: soil, water, and air.
Matrix spike	An aliquot of sample spiked with a known concentration of target analytes to document method bias in a particular matrix. The spiking occurs prior to sample preparation and analysis.
Matrix spike duplicate	A split sample, both portions of which are spiked with identical concentrations of target analytes to determine method bias and precision in a particular sample matrix.
Maximum contaminant level	Maximum concentration of a chemical allowed in drinking water systems by the National Primary Drinking Water regulations [40 CFR 141.22 (inorganic chemicals) and 141.61 (organic chemicals)].
Messenger well	Plume trend monitoring well located in the internal area of the plume, downgradient from the source, and within a two-year ground water time-of-travel distance.
Method detection limit (MDL)	The minimum concentration of an analyte that can be measured and reported with 99 percent confidence. MDLs are matrix specific.
Micrograms per kilogram (µg/kg)	An expression of concentration as mass of analyte per unit mass of sample. Equivalent to parts per billion. Used for soil, sediment, and waste samples.
Micrograms per liter (µg/l)	An expression of concentration as mass of analyte per unit volume of same. Roughly equivalent to parts per billion. Used for liquid samples.
Migration to ground water	The soil exposure pathway that considers vertical chemical leaching from soil into ground water.
Monitoring well	A well installed to obtain hydrogeological information or to monitor the quality or quantity of ground water.

Naturally occurring background	Substances present in the environment in forms that have not been influenced by human activity.
Nature of contamination	Site-related contaminants found during site characterization and their respective concentrations.
Off-site source	An identifiable location outside the site of interest that contributed contamination to the site.
Particulate emission factor	The rate at which chemicals move from soil into particulates in air.
Perimeter of compliance (POC)	When there is human or ecological exposure within the contaminant plume area, the POC is established as the location where exposure occurs. When there is neither human nor ecological exposure within the contaminant plume area, the POC is defined as the perimeter that is representative of the point at which ground water chemical concentrations are equal to or less than land use-specific remediation objectives. The POC referred to in the <i>RCG</i> is not to be confused with the “point of compliance” defined in the hazardous waste regulations, 40 CFR 264.
Perimeter of compliance well	A ground water monitoring well used for plume stability monitoring purposes that is located in an area of the plume downgradient of source area wells where dissolved contaminant concentrations are expected to exceed estimated quantitation limits for at least 75 percent of the monitoring events and where chemical concentrations approximate the remediation objective.
Petroleum	As per IC 13-11-2-160, petroleum is used for the following purposes: (1) IC 13-23, (2) IC 13-24-1, (3) IC 13-25-5. Those uses include petroleum and crude oil, or any part of petroleum or crude oil, that is liquid at standard temperature (60°F) and pressure (14.7 pounds per square inch absolute).
Playground	Areas that contain play equipment such as see-saws, merry-go-rounds, swing sets, slides, climbers, walking bridges, jungle gyms, chin-up bars, sandboxes, spring riders, monkey bars, overhead ladders, trapeze and trapeze rings, and/or playhouses.
Potential contaminant	A chemical present at a concentration that may or may not exceed its remediation objective.

Preferential pathway	The route of least resistance for fluid flow, including vapors. A more permeable feature than surrounding materials. The pathway may extend vertically or horizontally and be derived naturally or from human activities. The feature may also be oriented such that fluid flows in an unexpected direction. Generally limited in width from microscopic to a few tens of feet but often extensive in length. Examples include sediment grain size changes from fine to coarse, buried stream channels, fractured or dissolved bedrock, desiccation fractures in sediments, improperly sealed wells, field tiles, buried utility lines, and building foundations.
Property control	Control over land use or activities on a parcel of land, either through ownership or agreements with the owner(s), for the purpose of reducing or controlling exposure to contaminants.
ProUCL	A software program used to calculate, among other things, the upper confidence limit of various sample sets. ProUCL is available for free download on the U.S. EPA website.
Quality assurance project plan	A formal technical document describing detailed quality assurance/quality control and other technical procedures to ensure that the quality of environmental data will satisfy stated performance criteria for the data collection activity.
Quality control	A systematic approach that measures the attributes and performance of a process, item, or service against defined standards to verify that they are met.
Quantitation limit	The lowest concentration that can be reliably measured within specified limits of precision and accuracy under routine laboratory operating conditions.
Receptor	A human and/or ecological entity exposed to a stressor.
Recreational land use	Applies to areas and facilities where leisure time activities take place. Examples include parks, trails, walkways, sports complexes and open areas where people gather to enjoy recreational activities.
Reference concentration	An estimate of a lifetime continuous air concentration expected to occur without harmful effect. Expressed in units of mg/m^3 .
Reference dose	An estimate of lifetime daily oral dose expected to occur without harmful effects. Expressed in units of $\text{mg}/\text{kg}\text{-day}$.
Release	This term has program specific definitions under IC 13-11-2-184.

Remedial action	Activities consistent with the definition in IC 13-11-2-185.
Remediation objective	An environmental concentration of a chemical such that an equal or lower concentration will not result in unacceptable risk to receptors. Examples include screening levels, site-specific levels, and background concentrations.
Remedy	One or more measures taken to reduce risks to human health and/or the environment arising from a contaminant release. Measures may include contaminant treatment, contaminant removal, institutional controls, or engineered controls, alone or in combination.
Residential exposure	Human contact with contaminated environmental media at a frequency and duration likely to occur at a residence.
Residential land use	Any property used as a place of residence or any property that is within the commercial/ industrial category, but used in part for residential activities, such as a daycare center. Agriculture is considered a residential land use.
Resource Conservation and Recovery Act	Federal legislation that established cradle-to-grave accountability for hazardous wastes, from the point of generation to the point of disposal.
Risk	The probability of deleterious health or environmental effects.
Risk assessment	The collection and analysis of data that characterize the nature and magnitude of risk posed by a specific toxic agent.
Risk management	The process of evaluating and selecting responses to environmental risk.
Sample	In environmental field work, a single item or specimen from a larger whole or group, such as any single sample or any medium. In statistics, a set of representative individual specimens whose properties are studied to gain information about the whole population.
Sampling and analysis plan	A site-specific plan detailing sampling rationale, protocols, and analyses. The protocols provide for documentation of all field work.
Screening level ecological assessment	A desktop review and site inspection to determine if ecologically susceptible areas (ESAs) are present at or near the site, and whether a release could have occurred within or migrated to ESAs, resulting in a completed exposure pathway.

Screening level	A chemical-specific concentration level that IDEM has determined to be sufficiently protective at any site, provided it is applied under appropriate land use scenarios.
Sediment	Particulate matter typically consisting of mixtures of clay, silt, sand, organic matter, and various minerals that usually lie below water.
Semivolatile organic compound	Organic compound that volatilizes slowly under standard conditions.
Sentinel well	A ground water monitoring well located hydraulically down gradient of POC wells and along the centerline of the plume.
Site	The geographical area where an evaluation of potential environmental contaminants is desired. This may consist of an entire facility and surrounding property or a single area of concern within a facility or property, depending upon the applicable regulatory program. For purposes of IC 13-25-5, site means a parcel of real property for which an application has been submitted under IC 13-25-5-2.
Site characterization	The process of determining the nature and extent of potential contaminants in environmental media.
Site-specific level	A chemical specific concentration calculated using standard equations and one or more site-specific parameter values.
Slope factor	An upper bound estimate of the increased cancer risk per dose over a lifetime of exposure. Expressed in units of $(\text{mg}/\text{kg}\text{-day})^{-1}$.
Soil direct contact	A grouping of soil exposure pathways that assumes human exposure to soil chemicals through simultaneous skin contact, ingestion, and dust and volatile inhalation.
Soil horizon	A horizontal layer of soil with physical or chemical characteristics that separate it from layers above and below. Soil scientists generally name these horizons (from top to bottom) O, A, B, C, and R, and often subdivide them to reflect more specific characteristics within each layer. Considered together, these horizons constitute a soil profile.
Soil porosity	A measurement of the void areas between soil particles that may be filled with gas or water.
Soil saturation limit	The chemical concentration in soil at which the absorptive limits of the soil particles, the solubility limits of the soil pore water, and saturation of soil pore air have been reached.

Soil to ground water partitioning equation	The methodology for calculating screening levels for chemical migration from soil to ground water. The equation quantifies chemical concentrations in soil that have the potential to contaminate ground water (also referred to as the migration to ground water model).
Solubility limit	The maximum concentration of a chemical that will dissolve in water.
Source area	The horizontal and vertical geographical area where a chemical enters the environment.
Stability monitoring	A method that uses quantitative and temporal evaluation of ground water data to demonstrate that a ground water plume is not increasing in size or concentration and is not migrating.
Storativity	The volume of water an aquifer releases from or takes into storage per unit of surface area of the aquifer per unit change in head.
Stratum	A single layer of rock or soil regardless of thickness with internally consistent characteristics that distinguish it from contiguous layers. Each layer is generally one of a number of parallel layers that lie upon one another, laid down by natural forces. (plural: <i>strata</i>)
Surface water	<p>Aqueous media including but not limited to rivers, streams, wetlands, reservoirs, lakes, and ponds.</p> <p>Surface waters of the state include rivers, streams, creeks, free-flowing underground streams, reservoirs, lakes, and wetlands, (see 327 IAC 2-1-9[42] and 327 IAC 2-1.5-2[79]). All surface waters of the state must comply with all water quality standards contained under 327 IAC 2, including use designations, numeric and narrative water quality criteria, and the antidegradation standard.</p>
Susceptible areas	Areas for which standard models and screening levels do not apply. Susceptible areas include preferential pathways, wellhead protection areas, and ecologically susceptible areas.
SW-846	Standard methods of analysis, sampling, and quality assurance/quality control specified in U.S. EPA (2009h), as updated.
Synthetic precipitation leaching procedure	An analytical method designed to determine the mobility of analytes present in liquids, soils, and wastes in accordance with SW-846 Method 1312, as updated.

Systematic sampling	A method of placing sample locations at fixed intervals beginning at a random starting point, or according to a predefined pattern.
Target risk	A value that is combined with exposure and toxicity information to calculate a risk-based concentration for a specific application (for example, a preliminary remediation objective).
Threshold dose	The lowest amount or exposure level of a substance, below which adverse effects are not observed.
Transmissivity	A measure of the amount of water that can be transmitted horizontally by the full, saturated thickness of an aquifer with a hydraulic gradient of 1. Transmissivity is determined by multiplying the hydraulic conductivity of the aquifer by its saturated thickness.
Trip blank	A sample of analyte free media taken from the laboratory to the sampling site and returned to the laboratory unopened. A trip blank is used to document contamination from volatiles attributable to shipping and field handling procedures.
Unconditional closure	A closure that adequately addresses risk from a release without relying on any continuing activity and/or activity restriction.
Vapor intrusion	A process by which chemical vapors from a contaminant in soil or ground water migrate into a structure and adversely affect indoor air quality.
Volatile organic compound	Compounds that tend to evaporate at low to moderate temperatures (usually less than 200°F) due to their low vapor pressure.
Volatilization factor (soil to air)	The rate of change between the concentration of a chemical constituent in the soil and the flux of the volatilized constituent in the air.
Wellhead protection area	The surface and subsurface area, delineated by fixed radius, hydrogeological mapping, analytical, semi-analytical, or numerical flow/solute transport methods, that contributes water to a community public water supply system production well or wellfield and through which chemicals are likely to move and reach the well within a specified period.

References

- American Cancer Society. 2010. [*Cancer Facts & Figures 2010*](#).
- API. 2007. [*Technical Protocol for Evaluating the Natural Attenuation of MTBE*](#). API Publication 4761. Prepared by P. Zeeb and T. H. Wiedenmeier.
- ASTM. 2002. [*Standard Guide for Environmental Risk Assessments: Phase II Environmental Site Assessment Process*](#). E 1903-02. ASTM International.
- ASTM. 2003. [*Standard Guide for Developing Conceptual Site Models for Contaminated Sites*](#). E 1689-95 (Reapproved 2008). ASTM International.
- ASTM. 2005. [*Standard Practice of Environmental Site Assessments: Phase I Environmental Site Assessment Process*](#). E 1527-05. ASTM International.
- ASTM. 2006. [*Standard Guide for Selection of Purging and Sampling Devices for Ground-Water Monitoring Wells*](#). ASTM D6634-01. ASTM International.
- ASTM. 2008. [*Standard Guide for Comparing Ground-Water Flow Model Simulations to Site-Specific Information*](#). D5496-93. ASTM International.
- ASTM 2009. Various ASTM International analytical methods are available on the [ASTM International](#) website.
- Buchman, M. F. 2008. [*NOAA Screening Quick Reference Tables*](#). NOAA OR&R Report 08-1, Seattle WA, Office of Response and Restoration Division, National Oceanic and Atmospheric Administration.
- CalDTSC/RWQCB. 2003. [*Advisory - Active Soil Gas Investigations*](#). State of California Department of Toxic Substances Control and California Regional Water Quality Control Board, Los Angeles Region. January 28.
- Commonwealth of Massachusetts. 2002. [*Indoor Air Sampling and Evaluation Guide*](#). Office of Research and Standards, Department of Environmental Protection, WEC Policy #02-430.
- Davis, B. E. and the Federal Interagency Sedimentation Project. 2005. [*A Guide to the Proper Selection and Use of Federally Approved Sediment and Water-Quality Samplers*](#). United States Geological Survey Open-File Report 2005-1087.
- Davis, R. 2009. "Update on Recent Studies and Proposed Screening Criteria for the Vapor Intrusion Pathway", [*LUSTLine Bulletin*](#) 61:11-14.
- DiGiulio, D. et al. 2006. [*Comparison of Geoprobe PRT and AMS GVP Soil-Gas Sampling Systems with Dedicated Vapor Probes in Sandy Soils at the Raymark Superfund Site*](#). U.S. EPA EPA/600/R-06-111.
- Hartman, Blayne. 2006. "How to Collect Reliable Soil-Gas Data for Risk-Based Applications – Specifically Vapor Intrusion. Part 4 – Updates of Soil-Gas Collection and Analytical Procedures". [*LUSTLine Bulletin*](#) 53:14-19.
- Howard, P. H. 1990. *Handbook of Environmental Fate and Transport Exposure Data for Organic Chemicals: Volume II Solvents*. Lewis Publishers. ISBN 0-87371-204-8.
- Howard, P. H. 1991. *Handbook of Environmental Degradation Rates*. Lewis Publishers.

- IDEM. 1999. [*Guidance to the Performance and Presentation of Analytical Chemistry Data*](#). Non-Rule Policy Document WASTE-0032. Indiana Department of Environmental Management.
- IDEM. 2002. [*Contained-in Policy Guidance for RCRA*](#). Non-Rule Policy Document WASTE-0052. Indiana Department of Environmental Management.
- IDEM. 2003. [*Minimum Data Documentation Requirements*](#). Indiana Department of Environmental Management.
- IDEM. 2004. [*Monitored Natural Attenuation for Petroleum Contaminated Sites*](#). Non-Rule Policy Document WASTE-0054. Indiana Department of Environmental Management.
- IDEM. 2005. [*Sampling and Analysis of Ground Water for Metals at Remediation Sites*](#). Non-Rule Policy Document WASTE-0057. Indiana Department of Environmental Management.
- IDEM. 2007. [*Determining the Fraction of Organic Carbon, RISC Nondefault Option*](#). Indiana Department of Environmental Management, Office of Land Quality. OLQ-General ID-0119.
- IDEM. 2008. [*Supplemental Guidance for Sampling Soil and Waste Samples for Volatile Organic Compounds \(VOCs\)*](#). Indiana Department of Environmental Management.
- IDEM. 2008b. [*IDEM Office of Land Quality Spatial Data Collection Standards*](#). Indiana Department of Environmental Management.
- IDEM. 2009a. [*Analytical Data Deliverable Requirements: Supplemental Guidance*](#). Indiana Department of Environmental Management, Office of Land Quality, Chemistry Services Section.
- IDEM. 2009b. [*Drilling Procedures and Monitoring Well Construction Guidelines*](#). Non-Rule Policy Document WASTE-053-NPD. Indiana Department of Environmental Management.
- IDEM. 2009c. [*The Micro-Purge Sampling Option*](#). Technical Guidance Document produced by the Technology Evaluation Work Group of Indiana Department of Environmental Management, Office of Land Quality. Revised November 3, 2009.
- IDEM. 2009d. [*The Non-Purge Sampling Option*](#). Technical Guidance Document produced by the Technology Evaluation Work Group of Indiana Department of Environmental Management, Office of Land Quality. Revised November 3, 2009.
- ITRC. 2004. [*Technical and Regulatory Guidance for Using Polyethylene Diffusion Bag Samplers to Monitor Volatile Organic Compounds in Groundwater*](#). Interstate Technology and Regulatory Council.
- ITRC. 2007a. [*Protocol for use of Five Passive Samplers to Sample for a Variety of Contaminants in Groundwater*](#). Interstate Technology and Regulatory Council.
- Luo, H. et al. 2009. “[*Spatial Variability of Soil-Gas Concentrations near and beneath a Building Overlying Shallow Petroleum Hydrocarbon-Impacted Soils*](#)”, *Ground Water Monitoring and Remediation* 29(1):81-91.
- MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. “[*Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems*](#)”, *Archives of Environmental Contamination and Toxicology* 39:20-31.

-
- Mace, R. E., S. Fisher, D. M. Welsh, and S. P. Parra. 1997. *Extent, Mass, and Duration of Hydrocarbon Plumes from Leaking Petroleum Storage Tank Sites in Texas*. Bureau of Economic Geology, The University of Texas, Austin.
- McHugh, T., R. Davis, G. DeVauall, H. Hopkins, J. Menatti, and T. Peargin. 2010. "Evaluation of Vapor Attenuation at Petroleum Hydrocarbon Sites: Considerations for Site Screening and Investigation", *Soil and Sediment Contamination: An International Journal* 19(6):725-745.
- Newell, C. J., L. P. Hopkins, and P. B. Bedient. 1990. "[A Hydrogeologic Database for Groundwater Modeling](#)", *Ground Water* 28(5):703-714 (September/October).
- Newell, C. J. and J. A. Connor. 1998. [Characteristics of Dissolved Petroleum Hydrocarbon Plumes: Results from Four Studies](#). American Petroleum Institute, Soil/Groundwater Technical Task Force.
- Nielsen, David M. 2005. *Practical Handbook of Environmental Site Characterization and Ground-Water Monitoring, 2nd Edition*. CRC Press. ISBN 1566705894.
- NIOSH. 2009. [National Institute for Occupational Safety and Health](#). Follow the link for information on various analytical methods.
- NYDoH. 2006. [Guidance for Evaluating Soil Vapor Intrusion in the State of New York](#). New York State Department of Health.
- Ohio EPA. 2008. [Ecological Risk Assessment Guidance Document](#).
- Puls, R. W. and M. J. Barcelona. 1996. [Low-Flow \(Minimal Drawdown\) Ground-Water Sampling Procedures](#). EPA/540/S-95/504.
- Rice, D. W., R. D. Grose, J. C. Michaelson, B. Dooher, D. H. MacQueen, S. J. Cullen, W. E. Kastenber, L. G. Everett, and M. A. Marino. 1995. [California Leaking Underground Fuel Tank \(LUFT\) Historical Case Analyses](#). Lawrence Livermore National Laboratory, Livermore, California. (UCRL-AR-122207).
- SMO. 2009. *Standard Methods for the Examination of Water and Wastewater*. Standard Methods Organization. Analytical method descriptions available for sale on the [Standard Methods Organization website](#).
- Tillman, F.D., Jr. and J.W. Weaver. 2007. "Temporal moisture content variability beneath and external to a building and the potential effects on vapor intrusion risk assessment.", *Science of the Total Environment* 379(2007):1-15.
- USDOE. 1997. [Preliminary Remediation Goals for Ecological Endpoints](#). ES/ER/TM-162/R2.
- U.S. EPA. 1989a. [Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual \(Part A\)](#). EPA/540/1-89/002.
- U.S. EPA. 1991a. [Description and Sampling of Contaminated Soils](#). EPA/625/12-91/002.
- U.S. EPA. 1991c. [Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual \(Part B, Development of Risk-based Preliminary Remediation Goals\)](#). EPA/540/R-92/003.
- U.S. EPA. 1991d. [Risk Management Guidance for Superfund: Volume I - Human Health Evaluation Manual \(Part C, Risk Evaluation for Remedial Alternatives\)](#). Publication 9285.7-01C

- U.S. EPA. 1991e. [*Risk Assessment Guidance for Superfund: Volume I - Human Health Evaluation Manual \(Supplemental Guidance: Standard Default Exposure Factors Interim Final\)*](#). OSWER Directive 9285.6-03.
- U.S. EPA. 1991f. [*Role of the Baseline Risk Assessment in Superfund Remedy Selection Decisions*](#). OSWER Directive 9355.0-30.
- U.S. EPA. 1991g. [*Wildlife Exposure Factors Handbook*](#). Office of Research and Development. EPA 600-R-93-187.
- U.S. EPA. 1992. [*Guidelines for Exposure Assessment*](#). EPA/600/Z-92/001.
- U.S. EPA. 1993. [*Data Quality Objectives Process for Superfund: Interim Final Guidance*](#). EPA/540/R-93/071.
- U.S. EPA. 1994a. [*Exposure Assessment Guidance for RCRA Hazardous Waste Combustion Facilities \(Draft\)*](#). EPA 530-R-94-021.
- U.S. EPA. 1995b. [*Land Use in the CERCLA Remedy Selection Process*](#). OSWER Directive 9355.7-04.
- U.S. EPA. 1996a. [*Soil Screening Guidance: Technical Background Document*](#). EPA/540/R-95/128.
- U.S. EPA. 1996b. [*Soil Screening Guidance: User's Guide*](#). EPA/540/R-96/018.
- U.S. EPA. 1997b. [*Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments \(Interim Final\)*](#). Office of Solid Waste and Emergency Response. EPA 540-R-97-006.
- U.S. EPA. 1997e. [*The EPA Quality System*](#). EPA QA/Q-0, Final.
- U.S. EPA. 1997f. [*Preliminary Remediation Goals for Ecological Endpoints*](#). ES/ER/TM-162/R2.
- U.S. EPA. 1998a. [*Guidelines for Ecological Risk Assessment*](#). EPA 630-R-95-002F.
- U.S. EPA. 1999b. [*Ecological Risk Assessment and Risk Management Principles for Superfund Sites*](#). OSWER Directive 9285.7-28 P.
- U.S. EPA. 1999c. [*Use of Monitored Natural Attenuation at Superfund, RCRA Corrective Action, and Underground Storage Tank Sites*](#). U.S. EPA Directive 9200.4-17P.
- U.S. EPA. 1999d. [*USEPA Contract Laboratory Program National Functional Guidelines for Organic Data Review*](#). EPA-540/R-99/008.
- U.S. EPA. 2000b. [*Bioaccumulation Testing and Interpretation for the Purpose of Sediment Quality Assessment Status and Needs*](#). EPA-823-R-00-001.
- U.S. EPA. 2000c. [*Guidance for Data Quality Assessment: Practical Methods for Data Analysis*](#). EPA QA/G-9. QA00 Update. EPA/600/R-96/084.
- U.S. EPA. 2001a. [*Fact Sheet: Correcting Henry's Law Constant for Soil Temperature*](#).
- U.S. EPA. 2001b. [*Methods for Collection, Storage, and Manipulation of Sediments for Chemical and Toxicological Analyses: Technical Manual*](#). EPA-823-B-01-002.
- U.S. EPA. 2001c. [*USEPA Contract Laboratory Program National Functional Guidelines for Low Concentration Organic Data Review*](#). EPA/540/R-00/006.

-
- U.S. EPA. 2002a. [*Draft Guidance for Evaluating the Vapor Intrusion to Indoor Air Pathway from Groundwater to Soils*](#). EPA 530-D-02-004.
- U.S. EPA. 2002b. [*Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers*](#). EPA 542-S-02-001.
- U.S. EPA. 2002c. [*Guidance for Quality Assurance Project Plans*](#). EPA QA/G-5. EPA/240/R-02/009.
- U.S. EPA. 2002d. [*Guidance on Choosing a Sampling Design for Experimental Data Collection*](#). EPA 240-R-02-005.
- U.S. EPA. 2002e. [*Guidance on Environmental Data Verification and Data Validation*](#). EPA QA/G-8. EPA/240/R-02/004.
- U.S. EPA. 2002f. [*Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites*](#). Office of Solid Waste and Emergency Response. 9355.4-24.
- U.S. EPA. 2002g. [*Guidance for Comparing Background and Chemical Concentrations in Soil for CERCLA Sites*](#). EPA 540-R-01-003. OSWER 9285.7-41.
- U.S. EPA. 2003a. [*Literature Review and Report: Surface-Sediment Sampling Technologies*](#). Available on the U.S. EPA website.
- U.S. EPA. 2003b. [*Recommendations of the Technical Review Workgroup for Lead for an Approach to Assessing Risks Associated with Adult Exposures to Lead in Soil*](#). EPA-540-R-03-001.
- U.S. EPA. 2003c. [*US EPA Region 5 RCRA Ecological Screening Levels*](#).
- U.S. EPA. 2004a. [*Performance Monitoring of MNA Remedies for VOCs in Ground Water*](#). EPA/600/R-04/027.
- U.S. EPA. 2004b. [*Risk Assessment Guidance for Superfund Volume I - Human Health Evaluation Manual \(Part E, Supplemental Guidance for Dermal Risk Assessment\) Final*](#). EPA/540/R/99/005.
- U.S. EPA. 2004d. [*USEPA Contract Laboratory Program National Functional Guidelines for Inorganic Data Review*](#). EPA/540/R-04/004.
- U.S. EPA. 2005. [*Guidelines for Carcinogen Risk Assessment*](#). EPA/630/P-03/001F.
- U.S. EPA. 2005b. [*Groundwater Sampling and Monitoring with Direct Push Technologies*](#). EPA 540-R-04-005.
- U.S. EPA. 2005d. [*USEPA Contract Laboratory Program National Functional Guidelines for Chlorinated Dioxin/Furan Data Review*](#). EPA/540/R-05/001.
- U.S. EPA. 2006a. [*Assessment of Vapor Intrusion in Homes Near the Raymark Superfund Site Using Basement and Sub-Slab Air Samples*](#). Office of Research and Development, EPA/600/R-05/147.
- U.S. EPA. 2006b. [*Guidance on Systematic Planning Using the Data Quality Objectives Process*](#). EPA QA/G-4. EPA/240/B-06/001.
- U.S. EPA. 2006d. [*Data Quality Assessment: Statistical Methods for Practitioners*](#). EPA QA/G-95. Office of Environmental Information. EPA/240/B-06/003.

- U.S. EPA. 2007. [*ProUCL Version 4.00.02 User Guide*](#). EPA 600-R-07-038.
- U.S. EPA. 2009a. [*Air Toxics Monitoring Methods*](#).
- U.S. EPA. 2009b. [*Clean Water Act Analytical Methods*](#).
- U.S. EPA. 2009c. [*Contract Laboratory Program Analytical Services and Methods*](#).
- U.S. EPA. 2009d. [*Estimation Programs Interface Suite*](#), version 4.00.
- U.S. EPA. 2009g. [*Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual \(Part F, Supplemental Guidance for Inhalation Risk Assessment\) Final*](#). EPA-540-R-070-002.
- U.S. EPA. 2009h. [*Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*](#). EPA SW-846.
- U.S. EPA. 2010b. [*Conceptual Model Scenarios for the Vapor Intrusion Pathway*](#). EPA 530-R-10-003.
- U.S. EPA. 2010d. [*Institutional Controls: A Guide to Planning, Implementing, Maintaining, and Enforcing Institutional Controls at Contaminated Sites*](#). EPA 540-R-09-001. OSWER 9335.0-89.
- U.S. EPA. 2011. [*Regional Screening Level User's Guide*](#).
- U.S. EPA. 2011b. [*Regional Screening Level \(RSL\) Summary Table*](#).
- U.S. EPA. 2011c. [*Background Indoor Air Concentrations of Volatile Organic Compounds in North American Residences: A Compilation of Statistics for Assessing Vapor Intrusion*](#). EPA 530-R-10-001.
- U.S. EPA 2011d. [*Petroleum Hydrocarbons and Chlorinated Hydrocarbons Differ in their Potential for Vapor Intrusion*](#). Office of Underground Storage Tanks.
- U.S. EPA. 2011e. [*Exposure Factors Handbook: 2011 Edition*](#). EPA/600/R-09/052F.
- USGS. 2009. [*National Field Manual for the Collection of Water-Quality Data*](#). United States Geological Survey.
- Wiedemeier, T. H., H. S. Rifai, C. J. Newell, and J. T. Wilson. 1999. *Natural Attenuation of Fuel Hydrocarbons and Chlorinated Solvents in the Subsurface*. John Wiley and Sons, New York.
- Wolter, S. A., G. Lindsey, J. Drew, S. Hurst, and S. Galloway. 2001. [*Summary Report Indiana Trails Study: A Study of Trails in 6 Indiana Cities*](#). Eppley Institute for Parks and Public Lands, Indiana University, and Center for Urban Policy & the Environment, Indiana University Purdue University Indianapolis.

Uniform Resource Locators for Remediation Closure Guide References

This section provides written uniform resource locators for each reference that appears on the world wide web.

American Cancer Society. 2010.

<http://www.cancer.org/acs/groups/content/@epidemiologysurveillance/documents/document/acspc-026238.pdf>.

API. 2007. <http://www.api.org/ehs/groundwater/oxygenates/upload/4761new.pdf>.

ASTM. 2002. <http://www.astm.org/Standards/E1903.htm>.

ASTM. 2003. <http://www.astm.org/Standards/E1689.htm>.

ASTM. 2005. <http://www.astm.org/Standards/E1527.htm>.

ASTM. 2006. <http://www.astm.org/Standards/D6634.htm>.

ASTM. 2008. <http://www.astm.org/Standards/D5490.htm>.

ASTM 2009. <http://www.astm.org/>.

Buchman, M. F. 2008. http://response.restoration.noaa.gov/book_shelf/122_NEW-SQuiRTs.pdf.

CalDTSC/RWQCB. 2003.

http://www.dtsc.ca.gov/LawsRegsPolicies/Policies/SiteCleanup/upload/SMBR_ADV_activesoil_gasinvst.pdf.

Commonwealth of Massachusetts. 2002. <http://www.mass.gov/dep/cleanup/laws/02-430.pdf>.

Davis, B. E. and the Federal Interagency Sedimentation Project. 2005.

http://water.usgs.gov/osw/pubs/OFR_2005_1087/OFR_2005-1087.pdf.

Davis, R. 2009. http://www.neiwpcc.org/lustline/lustline_pdf/lustline_61.pdf.

DiGiulio, D. et al. 2006. <http://www.epa.gov/nrmrl/pubs/600r06111/600r06111.pdf>.

Hartman, Blayne. 2006. http://www.neiwpcc.org/lustline/lustline_pdf/lustline_53.pdf.

IDEM. 1999. http://www.in.gov/idem/files/nrpd_waste-0032.pdf.

IDEM. 2002. http://www.in.gov/idem/files/nrpd_waste-0052.pdf.

IDEM. 2003. <http://www.in.gov/idem/5058.htm>.

IDEM. 2004. <http://www.in.gov/idem/4807.htm>.

IDEM. 2005. <http://www.in.gov/idem/4806.htm>.

IDEM. 2007. http://www.in.gov/idem/files/Foc_Guidance_070925_Final.pdf.

IDEM. 2008. <http://www.in.gov/idem/files/la-074-gg.pdf>.

IDEM. 2009a. http://www.in.gov/idem/files/solid_waste_haz_waste_deliverables.doc.

- IDEM. 2009b. http://www.in.gov/idem/files/nrpd_waste-0053.pdf.
- IDEM. 2009c. http://www.in.gov/idem/files/remediation_tech_guidance_micro-purge.pdf.
- IDEM. 2009d. http://www.in.gov/idem/files/remediation_tech_guidance_non-purge.pdf.
- ITRC. 2004. <http://www.itrcweb.org/Documents/DSP-3.pdf>.
- ITRC. 2007a. <http://www.itrcweb.org/Documents/DSP-5.pdf>.
- Luo, H. et al. 2009. <http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6592.2008.01217.x/full>.
- MacDonald, D.D., C.G. Ingersoll, and T.A. Berger. 2000. http://www.swrcb.ca.gov/water_issues/programs/tmdl/docs/303d_policydocs/241.pdf.
- Newell, C. J., L. P. Hopkins, and P. B. Bedient. 1990. <http://onlinelibrary.wiley.com/doi/10.1111/j.1745-6584.1990.tb01986.x/abstract>.
- Newell, C. J. and J. A. Connor. 1998. <http://www.api.org/ehs/groundwater/bulletins/index.cfm>
- NIOSH. 2009. <http://www.cdc.gov/niosh/>.
- NYDoH. 2006. http://www.health.state.ny.us/environmental/investigations/soil_gas/svi_guidance/docs/svi_main.pdf.
- Ohio EPA. 2008. <http://www.epa.ohio.gov/portals/30/rules/RR-031.pdf>.
- Puls, R. W. and M. J. Barcelona. 1996. <http://www.epa.gov/tio/tsp/download/lwflw2a.pdf>.
- Rice, D. W., R. D. Grose, J. C. Michaelson, B. Dooher, D. H. MacQueen, S. J. Cullen, W. E. Kastenbergl, L. G. Everett, and M. A. Marino. 1995. <http://www.swrcb.ca.gov/ust/cleanup/docs/llnlplum.pdf>.
- SMO. 2009. <http://standardmethods.org/>.
- USDOE. 1997. <http://www.esd.ornl.gov/programs/ecorisk/documents/tm162r2.pdf>.
- U.S. EPA. 1989a. <http://epa-prgs.ornl.gov/radionuclides/HHEMA.pdf>.
- U.S. EPA. 1991a. <http://nepis.epa.gov/Exe/ZyNET.exe/300043U0.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1991+Thru+1994&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C91thru94%5CTxt%5C00000002%5C300043U0.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL>.
- U.S. EPA. 1991c. <http://epa-prgs.ornl.gov/radionuclides/HHEMB.pdf>.
- U.S. EPA. 1991d. <http://rais.ornl.gov/documents/HHEMC.pdf>.
- U.S. EPA. 1991e. <http://www.epa.gov/oswer/riskassessment/pdf/OSWERdirective9285.6-03.pdf>.
- U.S. EPA. 1991f. <http://www.epa.gov/oswer/riskassessment/pdf/baseline.pdf>.

- U.S. EPA. 1991g. <http://www.epa.gov/ncea/pdfs/introduc.pdf>.
- U.S. EPA. 1992. http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=429103.
- U.S. EPA. 1995b. <http://www.epa.gov/superfund/community/relocation/landuse.pdf>.
- U.S. EPA. 1996a. <http://www.epa.gov/superfund/health/conmedia/soil/toc.htm#top>.
- U.S. EPA. 1996b. <http://www.epa.gov/superfund/health/conmedia/soil/pdfs/ssg496.pdf>.
- U.S. EPA. 1997b. <http://www.epa.gov/superfund/health/conmedia/soil/pdfs/ssg496.pdf>.
- U.S. EPA. 1997f. <http://www.esd.ornl.gov/programs/ecorisk/documents/tm162r2.pdf>.
- U.S. EPA. 1998a. http://oaspub.epa.gov/eims/eimscomm.getfile?p_download_id=36512
- U.S. EPA. 1999b. <http://www.epa.gov/oswer/riskassessment/pdf/final10-7.pdf>.
- U.S. EPA. 1999c. <http://www.clu-in.org/download/reg/d9200417.pdf>.
- U.S. EPA. 1999d. <http://www.epa.gov/superfund/programs/clp/download/fgorg.pdf>.
- U.S. EPA. 2000b. http://water.epa.gov/polwaste/sediments/cs/biotesting_index.cfm.
- U.S. EPA. 2000c. http://www.clu-in.org/conf/tio/pasi_121603/g9-final.pdf.
- U.S. EPA. 2001a. <http://www.epa.gov/oswer/riskassessment/airmodel/pdf/factsheet.pdf>.
- U.S. EPA. 2001b. <http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/91c82f66c6b878db85256d83004fda8b!OpenDocument>.
- U.S. EPA. 2002a. <http://www.epa.gov/osw/hazard/correctiveaction/eis/vapor/complete.pdf>.
- U.S. EPA. 2002b. http://www.epa.gov/tio/tsp/download/gw_sampling_guide.pdf.
- U.S. EPA. 2002c. <http://www.epa.gov/quality/qs-docs/g5-final.pdf>.
- U.S. EPA. 2002d. <http://www.epa.gov/quality/qs-docs/g5s-final.pdf>.
- U.S. EPA. 2002e. <http://www.epa.gov/quality/qs-docs/g8-final.pdf>.
- U.S. EPA. 2002f. http://www.epa.gov/superfund/health/conmedia/soil/pdfs/ssg_main.pdf.
- U.S. EPA. 2002g. <http://www.epa.gov/oswer/riskassessment/pdf/background.pdf>.
- U.S. EPA. 2003a. <http://www.epa.gov/esd/cmb/research/bs123.pdf>.
- U.S. EPA. 2003b. <http://www.epa.gov/superfund/lead/products/adultpb.pdf>.
- U.S. EPA. 2003c. <http://www.epa.gov/reg5rcra/ca/ESL.pdf>.
- U.S. EPA. 2004a http://costperformance.org/monitoring/pdf/perf_monitor_mna_remedies.pdf.
- U.S. EPA. 2004b. http://www.epa.gov/oswer/riskassessment/ragse/pdf/part_e_final_revision_10-03-07.pdf.
- U.S. EPA. 2004d. <http://www.epa.gov/superfund/programs/clp/download/inorgfg10-08-04.pdf>.
- U.S. EPA. 2005. http://www.epa.gov/raf/publications/pdfs/CANCER_GUIDELINES_FINAL_3-25-05.PDF
- U.S. EPA. 2005b. <http://www.clu-in.org/download/char/540r04005.pdf>.

- U.S. EPA. 2005d. <http://www.epa.gov/superfund/programs/clp/download/dlm/dlm2nfg.pdf>.
- U.S. EPA. 2006a. <http://www.epa.gov/nrmrl/pubs/600R05147/600R05147.pdf>.
- U.S. EPA. 2006b. <http://www.epa.gov/quality/qs-docs/g4-final.pdf>.
- U.S. EPA. 2006d. <http://www.epa.gov/quality/qs-docs/g9s-final.pdf>.
- U.S. EPA. 2007. http://www.epa.gov/esd/tsc/ProUCL_v4.00.02/ProUCL_v4.00.02_User_Guide.pdf.
- U.S. EPA. 2009a. <http://www.epa.gov/ttnamti1/airtox.html>.
- U.S. EPA. 2009b. <http://water.epa.gov/scitech/methods/cwa/index.cfm>.
- U.S. EPA. 2009c. <http://www.epa.gov/superfund/programs/clp/analytic.htm>.
- U.S. EPA. 2009d. <http://www.epa.gov/opptintr/exposure/pubs/episuite.htm>.
- U.S. EPA. 2009g. http://www.epa.gov/oswer/riskassessment/ragsf/pdf/partf_200901_final.pdf.
- U.S. EPA. 2009h. <http://www.epa.gov/epawaste/hazard/testmethods/sw846/index.htm>.
- U.S. EPA. 2010a. https://iavi.rti.org/attachments/WorkshopsAndConferences/05_EPA_Background.pdf.
- U.S. EPA. 2010b. https://iavi.rti.org/attachments/WorkshopsAndConferences/06_Abreu_AEHS_CMS-%20Part_1_final_optA.pdf.
- U.S. EPA. 2010d. <http://epa.gov/superfund/policy/ic/pdfs/PIME-IC-Guidance-Interim.pdf>.
- U.S. EPA. 2011. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/usersguide.htm.
- U.S. EPA. 2011b. http://www.epa.gov/reg3hwmd/risk/human/rb-concentration_table/Generic_Tables/pdf/master_sl_table_run_JUN2011.pdf.
- U.S. EPA. 2011c. <http://www.epa.gov/oswer/vaporintrusion/documents/oswer-vapor-intrusion-background-Report-062411.pdf>
- U.S. EPA. 2011d. <http://www.epa.gov/oust/cat/pvi/pvicvi.pdf>
- U.S. EPA. 2011e. <http://www.epa.gov/ncea/efh/pdfs/efh-complete.pdf>
- USGS. 2009. <http://water.usgs.gov/owq/FieldManual/>.
- Wolter, et al. 2001. <http://www.in.gov/indot/files/z-CompleteDocument.pdf>

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