MERLA Groundwater and Soil Investigation Guidance

1.0 Purpose

This Groundwater and Soil Investigation Guidance document provides a framework for investigating contaminated groundwater and soil at Minnesota Pollution Control Agency (MPCA) remediation sites with releases that fall under the Minnesota Environmental Response and Liability Act ("MERLA", Minn. Stat. ch. 115B). This guidance is applicable to the MPCA Remediation Division programs listed in the box to the right. For sites enrolled in the Voluntary Investigation and Cleanup (VIC) Program , see also the Brownfield Program's Phase II Investigation guidance document on the MPCA's Brownfield redevelopment webpage. Agricultural groundwater investigations are not included in this guidance since they are conducted by the Minnesota Department of Agriculture. Petroleum release investigations are also not included in this guidance as they are conducted under the MPCA's Petroleum Remediation Program (Petroleum cleanup guidance).

This guidance applies to the following Remediation Division MERLA programs:

- Site Assessment
- Superfund
- Voluntary Investigation and Cleanup (VIC)
- Resource Conservation and Recovery Act (RCRA) Remediation Program
- Closed Landfill Program (CLP)

The intended audience of this guidance document is environmental professionals who are planning investigations to determine whether groundwater and soil have been impacted and, if so, investigate the magnitude and extent of contamination and risk to human health and the environment. Groundwater and soil investigations are only one component of a complete site investigation. A companion document, MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33), provides an overview of the different remediation phases that comprise a site investigation under MERLA. Although this guidance focuses on groundwater and soil, it is common to have multiple media investigated and reported on at once. Guidance for evaluating other types of media (surface water, soil vapor, and sediment) may be found on the MPCA's Cleanup guidance webpage.

This document provides guidance regarding the following:

- Conducting a desktop pre-investigation and information assessment
- Scoping and developing an initial groundwater and soil screening investigation
- Evaluating and reporting the data from the initial groundwater and soil investigations
- Scoping and conducting a groundwater and soil Remedial Investigation (RI)
- Aquifer characterization
- Plume delineation
- Updating contaminant fate and transport assumptions
- Preparing and updating a Conceptual Site Model (CSM)

- Applicable state and federal regulations and guidance

An investigating party must evaluate groundwater or soil at a site where a release or threatened release of hazardous substances, pollutants, or contaminants has reached or has the potential to reach groundwater or soil (Minn. Stat. 115B.02). Hazardous substances include but are not limited to those within the scope of MERLA (Minn. Stat. 115B.02) and the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA – 40 Code of Federal Regulations [CFR] Part 300.5).

When conducting a site investigation under MERLA or a Facility Assessment under the Resource Conservation and Recovery Act (RCRA), the Responsible Party is required to evaluate all media, including groundwater and soil. A voluntary party enrolled in the VIC Program must evaluate groundwater or soil if their planned actions at a site create an exposure pathway to either media or if they are requesting an assurance letter for either media. In some cases, a voluntary party is eligible to obtain an assurance letter for groundwater impacts without conducting a new groundwater evaluation if previous investigations have identified groundwater impacts and MPCA determines the data is useable for liability assurance purposes. See MPCA's Brownfield Program Services (c-brwnfld4-01) for a description of VIC assurance letters and requirements. For additional guidance for sites enrolled in the VIC Program, see the MPCA's Brownfield redevelopment webpage.

In addition to this Groundwater and Soil Investigation Guidance document, each of the MERLA remediation programs may have program-specific guidance or site-specific requirements that affect the scope of a groundwater or soil investigation. Refer to program-specific guidance, if available, and confer with the MPCA project manager if questions arise for an active MPCA remediation site.

Groundwater

This guidance document does not discuss surface water. The MPCA has separate and more specific guidance for evaluating impacts and the risk to surface water which can be found in Surface Water and Sediment Evaluation at Remediation Sites guidance document (c-rem3-31). For information specific to assessing surface water, see Minnesota administrative rule Minn. R. 7050 Waters of the State.

As illustrated above, groundwater investigations are conducted with a specific goal. Additional examples may include Phase I and Phase II Environmental Site Assessments (ESAs), which are conducted by voluntary parties for brownfields investigations and are generally conducted to obtain liability protection, identify potential groundwater contaminant sources, and define exposure risks for a property prior to development. Preliminary Assessments (PAs) are conducted to identify sites with significant releases that need to be addressed by state or federal remediation programs to support listing on the National Priorities List. The RCRA Facility Assessments (RFAs) are conducted to gather information on releases at RCRA facilities. The regulatory program or programs and investigation goals should be clear before investigation planning processes to ensure scope and analysis and planned for accordingly

Soil

This guidance document is not meant to be a comprehensive manual of field screening or sampling technologies. Instead, it highlights commonly used methods and provides guidance for collecting suitable soil data so that risk can be evaluated, and reasonable and protective soil response actions can be designed.

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2.0 Pre-investigation phase

Before conducting a groundwater or soil investigation, a pre-investigation review should be completed to identify potential contaminant releases, potential pathways into the environment, and sources of contamination. This process, known in Phase I terminology as identifying a Recognized Environmental Condition (REC), involves evaluating current and past land use, existing site conditions, and reports or referrals related to releases or threatened release of contaminants. If a REC related to groundwater or soil is encountered, hydrogeologic or geologic conditions are assessed to determine the potential for groundwater or soil contamination.

During the pre-investigation phase, the review should identify potential contaminant release sources and provide information on current and past land use and hydrogeologic/geologic conditions needed to evaluate the potential for groundwater/soil contamination and contaminant of potential concern (COPCs). The information from the pre-investigation should also identify potential off-site sources of groundwater/soil contamination. It often includes the following activities:

- Collect and review desktop information
  - Groundwater e.g.: maps, hydrogeologic atlas, geologic information, aerial photographs, city directory listings, fire insurance maps, topographic maps, geographic information systems [GIS] information, chain of title documents, plat maps.
  - Soil e.g.: regional geologic records, reports or referrals related to releases or threatened release of contaminants, aerial photographs, city directory listings, fire insurance maps, topographic maps, geographic information systems [GIS] information, chain of title documents, plat maps.
- Collect and review regulatory listings and conduct file searches (e.g., regulatory files available with United States Environmental Protection Agency (EPA) and/or MPCA, records and permits on file with local government units, information from public health agencies, files and plans available on site/in-house). These listings are valuable as they often contain information on spills, incident reports, and referrals to the MPCA by the State Duty Officer or other agency programs. Many sites have been investigated earlier under the jurisdiction of other MPCA programs or independently outside of MPCA oversight.
- Conduct interviews with current/former property owners and/or building occupants.
- Complete a site visit to observe conditions at the property.
- Groundwater: Collect and review information from the County Well Index on the Minnesota Well Index website to gather hydrogeologic information such as local groundwater occurrence, lithology, depth to groundwater, surficial and bedrock geology, and identify nearby water wells. Guidance on conducting a water well receptor survey can be found in MPCA's Risk evaluation and site management decision at petroleum release site (c-prp4-02). It should be noted that contaminants on MERLA sites, such as chlorinated solvents, per- and polyfluoroalkyl substances (PFAS), and 1,4-dioxane, behave differently in groundwater than many petroleum-related contaminants and receptor survey search radii may need to be expanded as appropriate.

While the various MERLA programs refer to this phase differently, the goal is the same – to inform the need for, scope, and design of an initial environmental investigation at the site. For more detailed information about the pre-investigation phase, see the MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33).

2.1 Contaminants of potential concern (COPCs)

COPCs are identified during the pre-investigation phase by evaluating historic and/or current property use, site-specific operations, chemical use, waste generation, safety data sheets, and other site-specific sources of information. A site's current and historical use of COPCs and the proximity to other off-site COPC sources should be evaluated to guide subsequent site investigations. For a general resource, see the MPCA's Typical contaminants based on site use and processes (c-rem3-35) fact sheet for common site uses and related categories of potential contaminants. The table is not intended to be all inclusive, and it may not be relevant for every site. The EPA also maintains a list of Typical Wastes Generated By Industry Sectors.

To determine the COPCs, previous analytical data should be evaluated for evidence of compounds not expected to be present at the site. Previous data should also be evaluated for evidence of compounds that are expected to be present at the site but were not directly detected (e.g., a COPC found in one medium, but not sampled for in another).

Data that could potentially be used by the MPCA or other agencies for decision making, even if work is not being done directly for the MPCA, should have approved work plans or SAPs to ensure minimum data quality standards are being followed. Accredited laboratories and certified methods should be used, and data should be evaluated, at a minimum, using MPCA's Laboratory data review checklist (p-eao2-11b) in accordance with MPCA's Laboratory data checklist guidance (p-eao2-11a) and Laboratory quality control and data policy (p-eao2-09a). Additional information about data quality can be found at the MPCA's Science and data website.

The rationale for identifying COPCs (or for not identifying COPCs) should be clearly documented. An understanding of Minnesota's regulatory screening criteria at this early stage can be particularly helpful for determining COPCs that are applicable to a site. This ensures potential risks are understood allowing for a comprehensive understanding of potential contaminants and the necessary precautions, ultimately leading to a more thorough site investigation.

When identifying COPCs, consideration must be given to the possible existence of contaminants created through the degradation of "parent" compounds. Some of these parent compounds break down to other "daughter" compounds (breakdown products) under vadose zone and aquifer conditions and may be more toxic or mobile than their parent compounds. The table below is a listing of some parent compounds and their common breakdown products. Parent compounds and their breakdown products may or may not be a part of the same analyte suite.

Common contaminant breakdown products

Parent compound	Breakdown products
Tetrachloroethylene	Trichloroethylene, dichloroethene, vinyl chloride, ethene
Trichloroethylene	Dichloroethylene, vinyl chloride, ethene
Pentachlorophenol	Mono-, di-, and trichlorophenols anisoles
Chlorinated volatiles and semi-volatiles	Dioxins, furans
Nitrate	Nitrite, ammonia, nitrogen
Sulfate	Sulfide, sulfite

A complete understanding of site contaminants will allow for an assessment of the potential concerns associated with each COPC. This information is needed for prioritizing contaminants based on their level of risk to human health and the environment. An effective COPC assessment allows projects to allocate resources efficiently and optimize the overall remediation strategy.

2.2 Conceptual site model (CSM)

The CSM provides a framework for understanding and visualizing the information associated with a site. A CSM presents the current understanding of a property based on the collective body of information. A CSM addresses the following topics:

- Potential release areas and sources
- COPCs
- Anticipated hydrogeologic conditions
- Contaminant fate and transport
- Potential receptors and exposure pathways

Information gathered during the pre-investigation phase is used to develop a preliminary CSM. The preliminary CSM is used as a foundation for compiling existing information, building stakeholder consensus, and identifying data for a comprehensive overview of a site in the early stages of assessment. It may not be possible to create a complete CSM based on the existing data available prior to beginning an assessment or investigation, however the CSM is necessary to understand the site, identify data needs and priorities, and develop an investigation strategy. Preparation of a preliminary CSM at this early stage can lead to a more focused and efficient investigation. As new information becomes available, the CSM should be updated to incorporate the new data. As each phase of the groundwater investigation is completed, the CSM should be updated to reflect new information.

The CSM should also establish appropriate risk-based groundwater screening values based on the current and/or planned property use. See Section 4.0 for a description of the risk-based groundwater screening values used by the MERLA programs. See MPCA's MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33) for more information on developing and updating the CSM.

2.3 Outcome and reporting

The inset below provides typical documentation within the pre-investigation phase:

MERLA Remediation phase	Site assessment	Superfund	VIC
Pre-Investigation	• Site Summary Report • Investigation Summary Report • Listing on PLP** • Enrollment in Superfund**	• Phase I Environmental Site Assessment (ESA) • Listing on the PLP** • Enrollment in Superfund**	• Phase I ESA

** Item is not considered a document, but rather an event.*
***Item is an event that may occur during any remediation phase.*
Note: Sites in the Site Assessment use document titles and terminology that differ from EPA Site Assessment terminology under CERCLA. Refer to EPA/CERCLA guidance/MERLA RBSE for additional information. Discuss reporting requirements with the MPCA project manager to clarify what is required for a particular site.

Depending on the regulatory program, the report title and requirements can vary.

- If the final deliverable is intended for Site Assessment, it may take the form of a Site Summary Report.
- If the final deliverable is intended for Superfund or VIC, it may take the form of a Phase I ESA and must be prepared in compliance with the current ASTM® E1527 Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process and the MPCA's guidance Phase I ESA Report for Brownfield Program enrollment (c-brwnfld4-03). Superfund and VIC can be flexible in considering Limited Phase I ESAs or the incorporation of groundwater information review within other report submissions, such as within a Phase II Work Plan or an Investigation Work Plan
- If the final report is intended for the RCRA Remediation Program, typically consisting of an RFA, it must comply with EPA PB87-107769. See EPA's RCRA Facility Assessment Guidance.
- If the final report is intended to for federal remediation sites, typically consisting of a CERCLA Preliminary Assessment (PA), it must comply with EPA 9345.0-01A. See EPA's Guidance for Performing Preliminary Assessments Under CERCLA.

The resultant report typically identifies RECs and/or COPCs at the site and makes a recommendation for follow-up sampling to address those concerns. There are two potential conclusions from the hydrogeologic information review: (1) Sufficient information is collected to indicate no release has occurred or is likely to occur, therefore no additional groundwater investigation is necessary, or (2) the potential for groundwater contamination has been identified; therefore, a groundwater screening investigation is recommended.

When reviewing information specific to groundwater, the resultant report should discuss the following items:

- Historical and current chemical storage, use, management, and waste generation and disposal practices, and any potential sources of hazardous substances contaminants, or pollutants.
- Existing environmental site data, if available.

- Geologic information (i.e., soil composition, soil/bedrock type, or physical properties of soil).
- Groundwater: Hydrogeologic information (i.e., depth to groundwater, groundwater flow direction).
- Land uses and operations and whether they have created or have the potential to create a release.
- Known hazardous substance releases.
- Potentially complete exposure pathways and affected media, if available.
- Likelihood of a release to occur or that has occurred that may impact media.
- A survey of receptors
- Critical locations where groundwater or soil sampling is warranted based on current and historical site information and the location of potential receptors.

3.0 Site investigation phase

Groundwater or soil investigations are required at any site where a release or potential release of hazardous substances to the environment has been identified. It is intended to determine the extent and magnitude of contaminated groundwater and evaluate the associated human health and ecological risks.

The links below provide additional information about the site investigation phase:

- ITRC's Integrated DNAPL Site Characterization and Tools Selection
- ASTM E1903-19 Standard Practice for Environmental Site Assessments: Phase II ESA Process
- EPA's Guidance for Performing Site Inspections (SI) under CERCLA
- EPA's Guidance for Conducting Remedial Investigations and Feasibility Studies (RI/FS) Under CERCLA
- EPA's RCRA Facility Investigation (RFI) Guidance

Note that if a release is identified that has not been previously reported, it should be reported to the State Duty Officer immediately in accordance with Minn. Stat. Sec. 115.061.

Groundwater

Because all groundwater, as per Minnesota Rule 7060, is required to be protected as a potable water source, the groundwater contamination must be delineated to the most restrictive numeric risk-based values for potential contaminants and an assumed unrestricted property use scenario. For investigations conducted under RCRA and MERLA, groundwater contamination must be delineated to the applicable risk-based criteria (e.g., Minnesota Department of Health [MDH] Health Risk Limits [HRLs] or EPA Maximum Contaminant Level [MCL]) in all directions regardless of the presence or absence of receptors (see **Section 5.1**). Voluntary parties enrolled in VIC are not required to delineate groundwater contamination off-site. Generally, a minimum of three sampling locations are required for a screening investigation to evaluate possible presence of groundwater contamination and assess groundwater flow direction at each potential release point or source area. The number and location of sample locations are site-specific depending on the characteristics and size of the potential source and certainty of the location of the release. It may not be possible to obtain accurate groundwater elevation data from temporary monitoring wells or sampling points, so groundwater flow direction may be interpolated based on topography, surface water features, or data collected during the hydrogeologic information assessment.

3.1 Screening investigation versus remedial investigation

For groundwater and soil investigations conducted by a voluntary party for a site enrolled in VIC, the level of investigation necessary depends on the proposed actions and the type of assurance letter being requested. For groundwater and soil investigations led by a Responsible Party, including Cooperative Responsible Parties, the investigation must define the extent and magnitude of all contaminants associated with the release and assess the potential risk to receptors.

There are typically two types of site investigations:

- **Screening investigation:** The screening investigation (often known as a Phase II ESA) is conducted to confirm whether a release has occurred, identifies the presence or absence of COPCs, and can provide useful information for other facets of the investigation (e.g., the potential for soil contamination release to groundwater, the potential for groundwater or soil contamination to create vapor intrusion concerns). The report title for a screening investigation can vary based on the regulatory program; see Section 3.3 for terminology.
- **Groundwater:** This phase of the investigation is often completed using temporary monitoring wells instead of permanent monitoring wells. The initial investigation may include sampling of drinking water, irrigation, or public supply wells if they are readily accessible and deemed to be potentially at risk as determined during the pre-investigation phase. The initial groundwater screening investigation evaluates risk based on a limited assessment of current site conditions, and for MERLA and CERCLA sites helps determine whether an RI is necessary.
- **Soil:** Soil sampling during the screening investigation should focus on potential source areas where a release may have occurred. This may include *point sources of contamination* such as floor drains, chemical storage tanks, and operational areas, as well as potential *site-wide impacts* from historical fill. To evaluate risk to human health and the environment, both scenarios when present, should be addressed. The initial soil screening investigation evaluates risk based on a limited assessment of current site conditions, and for MERLA and CERCLA sites, helps determine whether an RI is necessary. Often in the case for a VIC site, a Phase II ESA may be adequate to complete the site investigation phase by identifying the nature of contamination, relevant exposure pathways, and unacceptable risks that warrant response actions relative to the proposed use or development of the property.
- **Remedial investigation:** An RI is initiated if the groundwater or soil screening investigation data suggest that groundwater or soil has been or may be impacted by a release of contamination. An RI is a comprehensive investigation of a site specifically geared towards developing a remediation plan for addressing identified contamination. Once a release has been confirmed, the RI is completed to fully define the nature and extent of contamination, migration pathways, potential receptors, and determine if unacceptable risk exists at a site. It determines where contamination is present and what areas need to be remediated. Samples may be collected to determine whether or not contaminants have been released to the environment and whether they have a potential to cause harm to human health or the environment.

3.2 Scoping and planning documents

Planning is important to ensure the effectiveness of a project and maintain processes consistent with MERLA requirements. When site work involves oversight with the MPCA, various planning documents should be submitted to the MPCA for review and approval.

Site investigations can be costly and difficult to coordinate with property owners and subcontractors. A thorough scoping and design planning stage is imperative before investigation activities begin to minimize any potential costly issues or delays. It is important to develop planning documents and update them accordingly for each stage of the site investigation to ensure a carefully designed and effectively executed plan. Complex projects with multiple stakeholders or in situations as warranted, may need site-specific planning documents.

3.2.1 Planning documents

For sites enrolled in Superfund or the RCRA Remediation Program, the MPCA requires review and approval of the proposed scope of work before the work is conducted to ensure that the planned sampling meets the needs of the program. For sites enrolled in VIC, regulatory review and approval are not required but are recommended when possible. Undertaking work with the appropriate MPCA-approved planning documents in place provides the investigating party with confidence that the MPCA is in general concurrence and that the amount of work is appropriate to meet the investigation objectives. Any work conducted without an MPCA-approved Work Plan may be at the investigating party’s own risk. Examples of planning documents include:

Investigation work plan: An Investigation Work Plan should be developed to organize and guide the data collection effort. The work plan outlines the overall strategy for assessing contamination at a site, including objectives, summary scope of work, analytical and drilling methods, safety, subcontractors, budget, and schedule. The Investigation Work Plan may include supporting elements such as the Sampling and Analysis Plan (SAP), the Quality Assurance Project Plan (QAPP), the data quality objectives (DQOs), and the Health and Safety Plan (HASP).

Sampling and analysis plan: The SAP provides the technical details for field work and specific procedures to address the project objectives including investigation and sampling strategy and rationale, detailed descriptions of all procedures, preservation and handling of samples, documentation of the selected MDH Accredited Lab and lab methods and detections limits, and quality assurance/quality control (QA/QC). SAPs should be developed to collect data at locations of concern related to storage or possible use or releases of contaminants (e.g., above or around a surface impoundment, near an area of soil staining, or in chemical storage or operational areas). They should be clear, concise, and easy to understand. The need for background sample locations should also be considered based on project or regulatory requirements. The need for background sample locations should also be considered based on project or regulatory requirements. Consult the MPCA QA/QC Coordinator for laboratory accreditation information or search the MDH Accredited Laboratories website for current Minnesota-accredited laboratories.

When analyzing environmental samples for PFAS, the analytical methods used must be consistent with MPCA's Guidance for PFAS Substances: Analytical (p-eao-2-28). Field sampling methods for PFAS must be consistent with MPCA's Guidance for PFAS substances: Sampling (p-eao-2-27). If you are unsure of what type of plan is required, contact the MPCA.

It is often helpful to include a table in the SAP like the example table below that describes the proposed sampling locations, rationale, depths, and analytes. The groundwater screening investigation should focus on the presence or absence of groundwater contaminants in suspected source areas. Subsequent sampling in the RI stage will focus on defining the extent and magnitude of contamination and establishing a permanent monitoring well network if appropriate.

Example groundwater sampling scope and rationale

Boring ID	Rationale	Matrix	Assumed depth (feet)	Analysis*
GW-01	Assess groundwater quality in outdoor material storage area	Groundwater	15 to 25	Volatile organic compounds (VOCs), dissolved RCRA metals
GW-02, GW-03	Assess groundwater quality near septic drain field	Groundwater	15 to 25	VOCs, dissolved RCRA metals
GW-04, GW-05	Assess groundwater quality in loading dock areas	Groundwater	15 to 25	VOCs, dissolved RCRA metals
GW-06	Assess groundwater quality in footprint of former industrial building	Groundwater	15 to 25	VOCs, dissolved RCRA metals
Res-01	Assess drinking water quality in private well located immediately adjacent to the potential source area	Drinking Water	Not Applicable	VOCs, total RCRA metals

*Evaluate analytical methods to ensure they are capable of achieving reporting limits (RLs) lower than applicable drinking water standards.

A SAP is a necessary planning document for work completed by the responsible party under Superfund and RCRA. The scope of the SAP submittal can vary widely depending on site-specific requirements and the regulatory program. For a groundwater or soil screening investigation completed by a voluntary party under VIC, SAPs are not required.

Quality assurance project plan (QAPP): A QAPP is a comprehensive QA/QC document that covers not only sampling and analysis, but the development, collection, and analysis of all other data. A QAPP describes the policy, organization, functional activities, and QA/QC protocols for a project. It ensures that the data collected are reliable, appropriate for their intended use, and defensible.

All organizations performing work for the MPCA and the EPA are required to develop and operate management processes and structures for ensuring data or information collected are of the needed and expected quality for their desired use. Federally funded sites typically require a project-specific QAPP and may have considerably different sampling & analysis requirements that are outlined in a Cooperative Agreement. Other complex projects with multiple stakeholders or situations may also warrant a site-specific QAPP. Prior to starting project work, identify if a not federally funded project needs a site-specific quality document or if the work can be completed under the MPCA Quality Assurance Program Plan (QAPrP).

The level of QC planning is often a reflection of the client needs and the end user of the data. For example, it may not be necessary for a VIC property's due diligence Phase II ESA to be conducted under a formal QAPP; however, groundwater sampling completed for the MPCA under the Superfund, Site Assessment, and RCRA programs would be governed by the MPCA's in-house quality documents including the MPCA Quality Management Plan, MPCA Superfund and Site Assessment Program QAPP, or the MPCA QAPrP. Work completed on state or federally listed Superfund sites most likely have project-specific QAPPs.

During a groundwater or soil screening investigation, the MPCA allows for the use of SAPs (rather than QAPPs) in most cases for initial groundwater investigations under the Superfund, Site Assessment, and RCRA programs. Neither SAPs nor QAPPs are required for VIC Phase II ESAs. Although QAPPs are not often prepared or required during the screening investigation phase of a project, industry standard QA/QC practices as described in the SAP must be followed to ensure that representative and defensible data are collected, or it may be rejected by the program. The SAP must describe the DQOs and QA/QC requirements.

Data quality objectives: DQOs are qualitative and quantitative statements that clearly state the objective of a proposed project, define the most appropriate type of data to collect, determine the appropriate conditions for data collection, and specify acceptable quality control limits that establish the quantity and quality of data needed for decision making. In other words, DQOs define the type and amount of data needed and specify the acceptable level of data quality. DQOs are necessary for ensuring that the data collected meet the expected quality for their intended application. The DQOs are based on the use of the data that will be generated. Different data uses may require different quantities of data and levels of quality. For additional information of the DQO process, refer to MPCA's [Data Quality Objectives (p-eao2-14)].

Health and safety plan: A HASP supports workers involved in field efforts, ensuring their safety and adherence to health protocols during the execution of the project.

Regardless of the specific sampling documents required for a site, review of the investigation results may identify the need for additional sampling, to fully define the extent and magnitude of contamination. Refer to [MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33)] for more details on planning documents and guidance and references. To determine the appropriate planning documents necessary, consult with the MPCA project manager.

3.2.2 Screening investigation scope of work

The scope of work for groundwater and soil screening sampling is prepared based on information collected during the pre-investigation phase. The goals of a screening investigation are to:

- Determine the presence or absence of groundwater or soil contamination
- Determine if a release of contaminants to groundwater or soil has occurred at the site

- To identify specific COPCs
- Provide a range of contaminant concentrations
- Provides adequate data to assess exposure pathways
- Identify hot spots
- Adequately represent site conditions
- Establish site hydrogeological conditions
- Determine if interim or emergency response actions are needed to address urgent risks to human health and the environment

Once the need for groundwater or soil sampling has been identified, it is important to clearly specify the data required and the rationale behind it. To ensure progress toward a meaningful release determination, it is critical to identify COPCs to target for sampling, develop a sampling design, and choose appropriate sampling locations, sampling methods/equipment, and analytical methods.

For most screening investigations, the first step of determining the COPCs will be based on available information regarding the type of release being investigated. This will often include reviewing historical and/or current property use to identify COPCs that may be present. A table of property uses and typical COPCs found in the Typical contaminants based on site use and processes (c-rem3-35) fact sheet provides a list of potential groundwater contamination sources and the typical COPCs associated with storage, possible use, and/or releases of each.

Groundwater or soil samples should be collected from each area of concern and analyzed for all COPCs, based on the site-specific operations, chemicals, and waste streams identified during the pre-investigation phase. I.e., collect data at locations of concern related to storage or possible use or releases of contaminants (e.g., above or around a surface impoundment, near an area of soil staining, or in chemical storage or operational areas). Specific sample locations and depths should consider the current and proposed use of the site and related potential exposure pathways. The scope of the sampling effort will also be influenced by the objectives of the investigation, including but not limited to the type of desired MPCA assurance letter or closure document.

Soil:

Soil sampling during the initial soil investigation should focus on potential source areas where a release may have occurred. This may include *point sources of contamination* such as floor drains, chemical storage tanks, and operational areas, as well as potential *site-wide impacts* from historical fill. To fully evaluate risk to human health and the environment, both scenarios, when present, should be addressed.

The outcome of the initial soil investigation will be either a determination that no additional assessment is needed, or a recommendation to collect additional soil data (and/or samples of other environmental media) to address information gaps and allow a complete evaluation of risk at the site.

3.2.3 Remedial investigation scope of work

The scope of work for the RI is driven by the data gaps that remain after the screening investigation and should be submitted for MPCA review and approval when necessary. The primary goals of the remedial groundwater or soil investigation are to:

- Verify COPCs
- Identify contaminant source areas, release mechanisms, and migration pathways.
- Characterize the horizontal and vertical extent of contamination at Superfund and RCRA sites.
- Identify spatial patterns (e.g., hot spots from point sources vs. widespread and variable contamination associated with historical fill, etc.).
- Identify potential receptors and exposure pathways, based on current/future land use and extent and magnitude of groundwater contamination.

- Determine if groundwater contamination presents a potential risk to receptors.
- Groundwater: Assessing contaminant concentrations over time to determine the stability of a plume(s).
- Groundwater: Establish aquifer parameters that may affect fate and transport of COPCs (e.g. hydraulic conductivity, aquifer thickness, the potential presence of multiple aquifers, the presence of aquitards or confining units).
- Identify areas where groundwater or soil response actions are needed.
- Evaluate site and aquifer characteristics that may influence selection of a remedy.
- Refine the CSM (iterative process) based on sample results and other new information.
  - RIs may involve multiple investigations, stages of data analysis and interpretation, and evolving investigation boundaries, receptors, and COPCs. After scoping is complete, project plans for the scope of work are developed. The primary project plans for the scope of work are include in **Section 3.2.1**.

Groundwater

The approach to an RI can vary significantly for groundwater based on the types of COPCs (e.g., LNAPLs versus DNAPLs) or subsurface conditions (e.g., karst). Therefore, it is vital to understand site conditions to the extent available and to design/update the investigation approach accordingly based on known and future observed conditions throughout the RI lifecycle. Identifying and monitoring potential receptors is also often necessary.

Unlike the screening investigation, the RI often includes design and installation of a permanent monitoring well network which allows for periodic groundwater monitoring and evaluation of critical aquifer parameters.

The RI may include the following:

- Expanded receptor survey
- Hydrogeologic evaluation (or additional hydrologic evaluation)
- Source identification
- Additional COPC identification
- Identify and define the magnitude and extent of light non-aqueous phase liquid (LNAPL), dense non-aqueous phase liquid (DNAPL), and/or dissolved phase plumes
- Identify contaminant migration pathways and migration or flux rates
- Groundwater monitoring through installation of permanent wells or completion of additional delineation borings
- Receptor monitoring such as periodic sampling of nearby drinking water wells or surface water sampling
- Risk assessment –includes assessing and quantifying risk to human health and environmental receptors
- Assessing if an interim or emergency remedial/response action is warranted, like supplying bottled water to local residents with impacted private wells

3.3 Outcome and reporting

Data gathered during the site investigation are presented in various site investigation reports. The inset below identifies the type of reports commonly associated with each of the MERLA programs, for both the initial and subsequent groundwater investigations.

MERLA Remediation phase	Site assessment	Superfund	VIC
Site Investigation	N/A	•Phase II ESA •Remedial Investigation (RI)	•Phase II ESA

Note: Sites in the Site Assessment Program use document titles and terminology that differ from EPA Site Assessment terminology under CERCLA. Refer to EPA/CERCLA guidance/MERLA RBSE for additional information. Discuss reporting requirements with the MPCA project manager to clarify what is required for a particular site.

Urgent risks: After receiving the groundwater analytical results, it is crucial to identify any urgent risks associated with the COPCs promptly. Once the COPCs have been identified, the results of the groundwater sampling should assess the extent of any significant contamination and focus on the potential source areas or receptors where there is a high risk that the contamination poses to human health or the environment. Findings should inform further RI or determine the need to conduct immediate emergency actions (e.g., providing bottled water or point-of-use potable water treatment when drinking water supplies have been impacted) or interim response actions (e.g., NAPL recovery system to reduce the contaminant migration).

Community engagement: Groundwater and soil contamination problems investigated under the Superfund, RCRA Remediation Program, or Site Assessment may require a more aggressive approach to community participation than problems associated with other contaminated media such as sediment, especially if sensitive receptors or environmental justice concerns are identified. For additional information, the MPCA's Environmental Justice Framework (p-gen5-05) lays out strategies for equitable decision-making.

Groundwater contamination has a greater potential to migrate away from a source area, at times impacting areas much larger than the source of the contamination. Groundwater contamination that is migrating beyond the site boundaries may cause detrimental impacts to the local public water supply or neighboring domestic wells or result in vapor intrusion concerns for on-property and neighboring property buildings. Similarly, soil can result in vapor intrusion concerns for on-property and neighboring property buildings. Vapor intrusion guidance can be found on the MPCA's Vapor intrusion guidance webpage.

Community engagement often takes a prominent role in an RI; however, a limited amount of community engagement is not uncommon during the groundwater screening investigation phase. Typical community engagement activities during the early phases of a groundwater investigation may include the following:

- Private property or public right-of-way access requests for sampling activities.
- Limited requests to sample private water wells if they are identified as at-risk during the hydrogeologic information investigation.

Voluntary parties enrolled in VIC are not required to investigate or delineate off-site; therefore, community engagement may be very limited in this circumstance.

The CSM Update**:** The results from the site investigation should present an updated CSM based on information collected during the investigation. Having an updated CSM will aid in data interpretation and project planning. The report should describe the data findings in narrative and tabular format and evaluate the information to identify data gaps and determine if the investigation goals have been met.

3.3.1 Screening investigation (Phase II ESA)

Following completion of the groundwater or soil screening investigation, a report should be prepared describing in detail the sampling activities and results, with conclusions and recommendations. The screening investigation report should present an updated CSM based on information collected during the investigation. Having an updated CSM will aid in data interpretation and project planning. The report should describe the data findings in narrative and tabular format and evaluate the information to identify data gaps and determine if the investigation goals have been met. The format of this deliverable can vary based on the complexity of the investigation.

The groundwater and soil screening investigation is intended to serve as the first evaluation of groundwater and soil conditions at a site and is often focused on a contaminant presence or absence objective. The screening investigation may need to be completed in multiple phases before making a final RI determination.

The outcome of the soil screening investigation will be either a determination that no additional assessment is needed or a recommendation to conduct additional investigation. If a well-designed sampling effort provides sufficient evidence that no release has occurred, or that the identified soil contamination does not pose a risk to human health or the environment, no additional soil investigation is necessary. If the extent of soil contamination has not been defined or a risk to human health or the environment have been identified, additional soil investigation may be necessary before a risk-based decision can be made. In some cases, such as when significant soil excavation will occur for geotechnical and/or construction purposes, the need for additional soil investigation may be determined by soil reuse or disposal plans, rather than the need for a risk-based decision.

The need to advance to an RI is a decision-making process with several contributing factors as summarized below:

- Has the groundwater or soil screening investigation identified every potential source of groundwater or soil contamination associated with the site?
- Were all COPCs identified during the scoping and SAP development phase of the groundwater or soil screening investigation?
- Have all potential sources of groundwater or soil contamination and COPCs been identified and evaluated through groundwater sampling?
- Has the extent and magnitude of groundwater and soil contamination been delineated?
- Do all identified contaminants fall below applicable and appropriate rrisk-based values?
- Have all current and planned future human and environmental receptors at risk and all potentially complete exposure pathways been evaluated/identified?

The factors that typically drive additional groundwater investigation is a complete or potentially complete exposure pathway to receptors or undelineated extent and magnitude of impacts. If the answer to any of the questions above is “no” then a groundwater RI is likely warranted.

A groundwater or soil RI is always warranted if one or more of the following conditions is found to exist at the site:

- The groundwater or soil investigation confirms the presence of LNAPL or DNAPL.
- The receptor survey identifies receptors.
- COPCs have been identified exceeding applicable screening criteria (e.g., MDH HRLs, EPA MCLs, applicable surface water criteria, SRVs or SLVs).

3.3.2 Remedial investigation (RI)

The outcome of a remedial investigation is a site management decision: to determine whether all necessary objectives of the investigation have been completed, whether groundwater or soil contamination poses a risk to receptors, and whether response actions are necessary to address those risks. The RI report should present all data gathered during the RI are presented in a RI report or equivalent. The report should evaluate the information to determine if the investigation goals have been met and to identify data gaps.

The RI report may conclude that the identified groundwater contamination is fully defined and does not pose a risk to human health or the environment, and therefore no additional groundwater investigation or response actions are necessary.

If groundwater or soil contamination poses a risk to human health or the environment, then response actions are necessary, and a Response Action Plan (RAP) should be prepared and submitted to the MPCA for review and approval. The insert below identifies the type of reports commonly associated with each of the MERLA programs, including RAPs. For more information on site management decisions and when other reports may apply refer to MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33).

MERLA Remediation phase	Site assessment	Superfund	VIC
Site Management decision	N/A	•Feasibility Study (FS) •Remedial/Response Action Plan (RAP) •Minnesota Decision Document (MDD) •Remedial Design •Construction Contingency Plan (CCP)	•RAP •CCP

Note: Sites in the Site Assessment Program use document titles and terminology that differ from EPA Site Assessment terminology under CERCLA. Refer to EPA/CERCLA guidance/MERLA RBSE for additional information. Discuss reporting requirements with the MPCA project manager to clarify what is required for a particular site.

When response actions are required, the remedial groundwater or soil investigation typically serves as the basis for identifying, screening, and evaluating potential response actions. As such, investigating parties are encouraged to consider potential response actions during the remedial investigation to minimize the collection of unnecessary data and maximize the quality and usefulness of the data collected. Groundwater example, collecting monitored natural attenuation parameters during groundwater sampling activities may prove valuable when evaluating possible groundwater remedies. Soil example: if a soil excavation and off-site disposal is the intended remedy, collecting select soil samples during the investigation specifically for waste disposal characterization (e.g., toxicity characteristic leaching procedure (TCLP) extracts) may prove valuable when evaluating possible soil remedies or disposal options.

Groundwater

Unlike other impacted environmental media, groundwater RIs can be very complex and require extensive data collection, analysis, and an iterative approach to the investigation conducted over multiple rounds of mobilizations and sampling. Some of the typical groundwater RI data inputs for aquifer characterization are described in **Appendix C**.

4.0 Screening values

Once the COPCs are determined for the site, it is important to establish screening criteria for each COPC. This evaluation helps determine whether analytical detections pose a risk to human health or the environment and establishes a framework for remediation goals and objectives. The primary driving factor for establishing screening criteria lies in how the site will be classified and regulated by state and/or federal agencies. Regulatory oversight is integral to all groundwater investigation and remediation projects.

4.1 Groundwater screening values

Minn. R. 7060, Underground Waters, imposes regulations on pollution of all groundwater in the state. Minn. Stat. 103H.201 identifies HRLs as values that need to be established to protect people from unacceptable risk associated with groundwater contamination in compliance with Minn. R. 7060. The HRLs should be considered in conjunction with federal standards (MCLs, 40 CFR Parts 141-143) and state standards developed to protect human and environmental receptors (Minn. R. 7050.0220) when identifying cleanup levels to manage groundwater contamination. The MDH develops health-based rules and guidance to evaluate potential human health risks from exposures to chemicals in groundwater. The project screening criteria must be identified in the SAP and may include the following MDH and EPA water guidance standards both individually and as part of an additivity calculation:

- Health risk limits (HRLs)
- Health-based values (HBVs)
- Risk assessment advice (RAA)
- Maximum contaminant level (MCLs)
- MPCA water quality standards / applicable surface water standards if a surface water receptor has been identified (refer to Minn. R. 7050 and Minn. R. 7052)

MDH groundwater rules and guidance are updated periodically, and current values should be included in the SAP for analytes of interest. The current MDH health-based rules and guidance values and standards can be found in rule (Minn. R. 4717.7860) and viewed on MDH's Human Health-Based Water Guidance Table webpage.

4.1.1 MDH health risk limits (HRLs)

HRLs represent the concentration of a groundwater contaminant, or mixture of contaminants, that can be safely consumed daily for a lifetime. It is expressed as a concentration in micrograms per liter. HRLs are guidance used by the public, risk managers, and other stakeholders to make decisions about managing the health risks of contaminants in groundwater used as drinking water. The guidance values have been through the Minnesota rulemaking process, which includes at least one public comment period for stakeholders to provide feedback on the proposed guidance values.

4.1.2 MDH health-based values (HBVs)

Like HRLs, an HBV is the concentration of a groundwater contaminant, or mixture of contaminants, that poses little or no risk to health, even if consumed daily over a lifetime. HBVs differ however, in that they have not or will not go through the formal rulemaking process. MDH develops HBVs in response to requests from other Minnesota agencies that have found a contaminant in groundwater or during re-evaluations of chemicals with existing HRLs. Re-evaluations are conducted based on need (i.e., state agencies requesting a re-evaluation) and availability of new toxicity information. HBVs should be used for compounds for which HRLs or MCLs do not exist or for re-evaluation of existing HRLs. If such compounds do not have an established HBV, MPCA staff should consult with MDH to determine whether an appropriate HBV for the COPC can be derived.

4.1.3 MDH risk assessment advice (RAA)

RAAs are established by MDH and, like HRLs and HBVs, are based on potential health impacts, but are only developed when there is not enough information to develop an HBV or HRL. An RAA can be a level of chemical in drinking water that poses little or no health risk to a person drinking water, similar to HBVs or HRLs. RAAs can also be a written description of how harmful a chemical is, compared to a similar chemical. RAAs are generally based on more limited toxicity information than HBVs and HRLs or use an alternative risk assessment method. These values may also be developed on a case-by-case basis for a specific site or using specific conditions when other guidance values are not available. RAAs that are developed for a specific site should not be used for other sites without first consulting with MDH.

4.1.4 EPA maximum contaminant levels (MCLs)

MCLs represent the legal threshold limit on the amount of a hazardous substance that is allowed in drinking water under the Safe Drinking Water Act and apply to public water systems. The limit, set by the EPA, is usually expressed as a concentration in milligrams or micrograms per liter of water. States are allowed to enforce lower (stricter) standards than MCLs but are not allowed to enforce higher (less strict) standards. New MCLs or changes to existing MCLs are rarely made. MCLs not only consider health risk but also consider the existing technological limitations.

4.1.5 MPCA water quality standards (WQS)

In situations where surface waterbodies or ecologically sensitive areas are impacted or potentially impacted by groundwater contamination, WQS identified in Minn. R. 7050 and Minn. R. 7052 should be considered as appropriate cleanup levels. Minn. R. 7050.0220 defines specific standards of quality for the designated classes of water in the state. Screening values which are based on impacts to surface water will vary with the classification of the impacted surface waterbody. For further information regarding an evaluation of risk to surface waterbodies and associated environmental receptors, refer to MPCA's Surface Water and Sediment Evaluation at Remediation Sites guidance document (c-rem3-31).

4.1.6 Additivity risk

An investigation may identify multiple COPCs. The individual concentrations of identified COPCs may be below their respective Minnesota guidance values (HRLs, HBVs, RAAs, MCLs) but the in combination with other COPCs could pose a health risk (i.e., additive risk). The combination of groundwater contaminants can lead to adverse effects that would not be predicted by evaluating each contaminant separately. Per Minn. R. 4717.7870, when multiple groundwater contaminants exist at a site, a mixtures evaluation is required to determine whether the Health Risk Index, calculated through an additivity analysis, is exceeded. Refer to the MDH Health Risk Index and *Water Guidance and Additivity Calculator* Microsoft Excel tool, located on the MDH's Evaluating Concurrent Exposures to Multiple Chemicals website. While additivity is not common for most federal guidance values at this time, evaluation of an additive hazard index MCL is required for mixtures containing multiple PFAS to determine compliance with PFAS MCLs.

4.2 Soil screening values

4.2.1 Generic SRVs

If the need for a soil response action to address the soil-human health pathway is determined, soil data is first compared to the contaminant-specific generic SRVs on the SRV spreadsheet. Exceedance of a generic SRV does not necessarily indicate that a risk-based cleanup is required. It may indicate that additional soil investigation or information about site-specific exposure pathways is needed to

determine if an actual risk is present. However, many sites choose to use the generic SRVs as a cleanup goal, for convenience, predictability, and in consideration of a potential redevelopment schedule.

- **Generic SRVs:** The contaminant-specific generic SRVs for residential/recreational use and commercial/industrial use, included in the MPCA SRV spreadsheet (c-r1-06), are intended to be used as risk-based screening values.
- **Soil reference values:** The soil-human health pathway is defined by ways in which people may come into direct contact with contaminated soil. The MPCA's generic SRVs are a screening tool that may be used to evaluate potential human health risks from exposure to contaminated soil. They are derived based on the EPA's Superfund methodology using exposure assumptions based on specific land use categories depicting a specific land use scenario and set of receptors (people).

4.2.2 Site-specific SRVs

In some cases, it may be beneficial to derive site-specific SRVs to use as a site-specific cleanup value. Site-specific cleanup values are determined as part of a site-specific risk assessment, which is typically done after the remedial soil investigation has been completed and the extent and magnitude of soil impacts are known. A site-specific risk assessment may be less or more detailed depending on what factors influence the potential human health risks at a site and how much detail a party wishes to include. For example, although site-specific soil properties can be used to determine site-specific cleanup values, it is not necessary to include them. Site-specific cleanup values could be determined based on site-specific soil exposure parameters only.

Basic information about SRVs is included below. Refer to the MPCA's SRV Technical Support Document (c-r1-05) for additional information on these and other topics, such as:

- Land use categories.
- Derivation of the generic SRVs, including exposure assumptions
- Derivation of background threshold values used in place of certain generic SRVs.
- Exposure pathways addressed by SRVs.
- Performing a risk evaluation for the soil-human health pathway, including types of risk and evaluating exposure concentrations
- Derivation of site-specific background values
- Derivation of site-specific cleanup values
- Calculating 95% UCL of the mean

4.2.3 Soil leaching values

Soil leaching values (SLVs) are compound-specific, risk-based screening criteria developed by the MPCA to evaluate risks posed to groundwater by soil leaching. For historical releases, SLVs are used for certain leachable contaminants of concern at a site when groundwater data is not available. In many cases, determining whether the soil leaching pathway is a concern is best done through evaluation of groundwater data; this is always the case when a drinking water receptor is at potential risk. For a recent release, SLVs can be used to establish a target cleanup level that is protective of groundwater.

Screening SLVs are based on a set of default hydrogeologic parameters and provide a conservative estimate of the potential for groundwater contamination. *Site-adjusted SLVs* may be calculated for a more realistic estimation of risk associated with the soil leaching pathway. For additional information about SLVs and their proper application, see the MPCA's SLV spreadsheet (c-r1-03) and the MPCA's SLV guidance document (c-r1-04).

When SLVs to assess the soil-to-groundwater leaching pathway have been developed for various contaminants, SLVs are not being developed for PFAS. Given the low risk-based drinking water criteria established by the Minnesota Department of Health and the high mobility of PFAS in the environment, any detection of PFAS in soil is considered to pose a potential risk to groundwater. If a groundwater receptor is present at a site, the potential risk should be resolved by groundwater sampling for PFAS.

If soil impacted by VOCs is present, the soil leaching pathway for VOCs is often more pertinent than the soil-human health pathway, due to the magnitude of difference between the SRV and the SLV for any given VOC. For example, the MPCA's current residential SRV for PCE is 32 milligrams per kilogram (mg/kg), while the current SLV is 0.042 mg/kg. If a soil response action was designed solely to address an SRV exceedance, a significant source area may remain at the site, posing a risk to groundwater quality. Having a sound CSM will help determine the significance of the soil leaching pathway and the applicability of screening SLVs.

4.2.4 U.S. EPA screening value for lead

Similar to MPCA's SRVs described above, EPA's recommended screening level for lead is not a cleanup level. It is meant to be used when initially investigating a release to determine if the level of contamination is high enough to warrant further investigation. In January of 2024, the EPA lowered its recommended screening level for lead at residential properties from 400 parts per million (ppm) to 200 ppm, which is consistent with the MPCA's current residential SRV. At residential properties with multiple sources of lead exposure, such as through lead water service lines, lead-based paint, or air impacts, EPA's recommended screening level for lead in soil is 100 ppm. For further information, see EPA's Updated Soil Lead Guidance, which includes a Residential Lead Screening Level Checklist.

4.2.5 Exposure concentrations

An exposure concentration refers to the concentration of a contaminant in soil that a receptor is expected to be exposed to at a site. Data obtained from soil sampling is used to estimate an exposure concentration for evaluating potential risk. There are two types of exposure concentrations:

- Exposure point concentration
  - Used to evaluate **acute exposures.**
  - Exposure points are defined by **discrete samples** with one exposure concentration.
  - Samples used should be representative of the depth to which the potential receptor may be exposed.
  - Acute SRVs are only provided for residential/recreational land use. Not all contaminants have an acute SRV.
  - If an acute risk exists, contact the MPCA project team to determine if immediate action should be taken to mitigate any potential risks and how to proceed with the site investigation.
  - Do not use composite or incremental sampling to evaluate acute risks.

- Exposure area concentration
    - Used to evaluate **chronic exposure** (or sub-chronic/short-term exposure, with a site-specific risk assessment).
    - Consists of areas with similar contamination.
    - Does not contain uncontaminated soil or hot spots.
    - Samples from an exposure area are **averaged over the entire exposure area** (using the 95 UCL of the mean) to define an exposure area concentration.
    - Samples used should be representative of the area and depth to which the potential receptor may be exposed.
    - Must be determined in a way that reasonably reflects a receptor's potential exposure across the entire site.

Areas containing significantly higher concentrations of contamination than surrounding areas are referred to as hot spots. These areas may have been subject to larger releases or contaminated in different ways than other areas of the site. All hot spots should be defined as distinct exposure areas and evaluated separately.

5.0 Sampling

This section provides guidance on common groundwater and soil sampling strategies and best practices for evaluating groundwater and soil contamination. It does not provide a detailed description of the tools or procedures used to collect or analyze samples. Other sources are available that describe sampling and analytical procedures; selected references are included below. For special considerations related to sampling and analysis for PFAS, see MPCA's Guidance for PFAS Sampling and Guidance for PFAS Analytical.

5.1 Identify receptors and exposure pathways

Completion of the groundwater and soil screening investigation provides an excellent opportunity to conduct a preliminary field receptor survey. The field portion of the receptor survey should build upon the data collected during the pre-investigation phase and include the following:

- **Human receptors**: Identify populations that could be exposed to groundwater or soil contaminants. Soil examples may include residents, workers, and recreational users. Groundwater examples may include residents using private wells, industrial users, and municipal water supplies.
    - For groundwater, utilize evidence of water wells such as well houses, well casings, large industrial operations that may have their own well, water towers. A review of general information about water supplies for the area including a search using the Minnesota Well Index website and evaluating the use and availability of public water supplies in the area.
- **Ecological receptors**: Identify ecosystems, flora, and fauna that could be impacted by groundwater or soil contamination. For soil this could include plants, wildlife, and aquatic systems if the site is near water bodies. For groundwater this could include wetlands, rivers, streams, and lakes using maps and aerial photographs or other physical or hydrologic features.
- **Sensitive areas:** Locate schools, daycare centers, hospitals, parks, wildlife habitats, protected areas, and other sensitive areas or areas relying on groundwater.

Groundwater:

Once receptors are identified exposure pathways should be characterized, including:

- Assess the potential for humans to consume contaminated groundwater through drinking water wells (i.e., direct consumption)

- Evaluate potential indirect exposure pathways, such as irrigation of crops, recreational use of water bodies, and use of groundwater in industrial processes (i.e., indirect exposure)
- Determine if contaminants in groundwater could migrate to and impact surface water bodies, affecting both human and ecological receptors (i.e., migration to surface water).
- A visual assessment of the site and surrounding area for potential surface water receptors such as rivers, streams, lakes, and wetlands.
- A visual assessment of the site and surrounding area for neighboring property uses and evidence of water wells (well houses, well casings, large industrial operations that may have their own well, water towers, etc.).
- Other physical or hydrologic features that may influence future sampling designs such as access restrictions, topography, possible wetlands, etc.
- Reviewing maps and aerial photographs of the area.
- A review of general information about water supplies for the area including a search using the Minnesota Well Index website and evaluating the use and availability of public water supplies in the area.
- An assessment of buried utilities in area including, if available, depths, construction materials and backfill material.

Soil:

Once receptors are identified exposure pathways should be characterized, including:

- A visual assessment for the potential for humans or animals to come into direct contact with contaminated soil through activities like gardening, playing, or construction work (i.e., direct contact).
- Determine the likelihood of soil particles becoming airborne and inhaled, during dry conditions or construction activities (i.e., inhalation).
- Consider the potential for soil ingestion, particularly for children playing in contaminated areas or through consumption of home-grown produce (i.e., ingestion).
- Evaluate the possibility of contaminants leaching from soil into groundwater or being transported to nearby surface water bodies.
- Other physical or hydrologic features that may influence future sampling designs such as access restrictions, topography, uncovered soil, etc.
- Reviewing maps and aerial photographs of the area.
- An assessment of buried utilities in area including, if available, depths, construction materials and backfill material.

5.2. Sampling design

A sampling design should address the following topics:

- Investigation objectives
- Number and type of samples
- Sample locations
- Sample depths
- Rationale for choice of locations and depths

Careful selection of sampling locations and analytical methods is important to produce meaningful data that can be used for site decisions. For data to be useful, sample locations and depths must support the objectives of the investigation, and laboratory reporting limits must be less than the relevant risk-based screening values. A conclusion that no release or only an insignificant release has occurred will not carry weight if:

- COPC are omitted from the analyte list, including potential breakdown products;
- Samples are collected from areas that are not representative of potential source areas;
- Soil:
  - Soil samples are collected from depth intervals that are too deep (e.g., if evaluating a potential surface release) or too shallow (e.g., if evaluating a potential release from underground tanks, utility lines, or other subsurface features).
- Groundwater:
  - Groundwater samples are not collected to assess risk to identified receptors (e.g. drinking water wells or surface waters); or
  - Groundwater samples are not collected from representative depth intervals in the aquifer for the COPCs (e.g. COPC that may sink in the aquifer like chlorinated solvents).

Since site conditions and sampling objectives can vary widely, a good sample design should be tailored to meet site-specific objectives. For example, targeting samples to a specific location based on site information may be best for determining if a release has occurred, and collecting samples between suspected source areas and potential receptors to assess receptor risk.

Sample depths should consider the nature of the release (e.g., release from surface spill versus subsurface feature), the type of exposure that a current or future receptor will experience, and any planned disturbance of soil that might require characterization for reuse or landfill disposal.

Groundwater:

During the sampling design, additional factors that should be considered include the following:

- **Historical data:** The hydrogeologic information investigation should provide a reasonable understanding of the site history and land use. The hydrogeologic information investigation should provide the current and historical operations and practices at the site and recommended groundwater analytical parameters to be used for site characterization based on various types of operations. Additionally, previous analytical data should be incorporated into the CSM to guide initial and ongoing investigations.
- **Contaminant breakdown products:** When identifying COPCs, consideration must be given to the possible existence of contaminants created through the degradation of “parent” compounds. Some compounds break down to other compounds under common vadose zone and aquifer conditions; these breakdown products may be more toxic or mobile than their parent compounds. Parent compounds and their breakdown products may or may not be a part of the same analyte suite. Some common breakdown products, such as vinyl chloride (derived from many chlorinated solvents), may pose greater health risks than their parent compounds. Secondary chemicals are contaminants liberated in groundwater due to conditions at the site or in the aquifer. For example, closed landfill conditions may cause a release of other contaminants to the environment, or low pH environments may result in the liberation or increased mobility of some metals in groundwater.
- **Potential remedial actions:** During the RI phase, it is important to have potential remedial actions in mind when scoping groundwater sampling activities. Monitored natural attenuation (MNA) may be a potential remedy on sites where the contaminant plume is stable, there are no identified receptors, and the concentrations of contaminants and their metabolic intermediates or breakdown products are reduced before they pose unacceptable levels of risk to human health or the environment. Info on evaluating MNA is in **Appendix B**.

- **Aquifer characterization:** Aquifer characterization or assessment is the foundation (or key component) of a site's CSM for groundwater investigations and is completed by studying aquifer hydraulic properties, hydrogeology, contaminant distribution, and how they related to one another. Successful aquifer characterization will start with general information gathering during drilling, noting details such as moisture content, size, shape, and grading/sorting of particles, and will end with technical in situ or laboratory-derived data collection. More information on aquifer characterization is in **Appendix C** and aquifer characterization resources are in **Appendix D**.

5.2.1 Monitoring wells

Groundwater samples are collected using various drilling and sampling methods. A central aspect of scoping and developing planning documents is the careful consideration of the drilling and sampling methods that align best with the site conditions and analytical and data quality requirements. **Appendix E** of this document provides additional detail on groundwater sampling and drilling methods.

Monitoring well placement

The purpose of a monitoring well network is to identify, characterize, define, and monitor contaminants in the groundwater so that appropriate remedial actions can be taken to protect human health and the environment.

The monitoring well network also serves the purpose of providing hydrologic properties of contaminated aquifers and the rate and direction of groundwater and contaminant plumes.

The strategic placement of monitoring wells significantly influences the outcome of an RI. Properly located monitoring wells provide accurate data for evaluating the extent of contamination, groundwater flow patterns, and the effectiveness of remediation efforts.

The following considerations should be evaluated for the placement of monitoring wells during an RI:

Evaluation and considerations for monitoring well placement

Project data quality objectives (DQOs)	Site geology and hydrogeology	COPC characteristics	Accessibility	Safety
Local and state well code regulations	Aquifer type (bedrock, unconfined, confined)	Contaminant properties (e.g., LNAPL versus DNAPL)	Property ownership and access agreements	Utilities Traffic control and risks
Project regulatory compliance	Groundwater flow (direction, rate, gradient)	MNA properties	Land use restrictions	Well security
Pathway receptors	Depth to water table and aquifer target interval(s)	Fate and transport properties	Topographic features	Operation and maintenance
Short- and long-term objectives of wells	Site stratigraphy		Difficult or protected land terrain (wetlands, floodplains, wooded areas)	Environment hazards (wildlife, insects, vegetation, etc.)
Well spacing and target depth(s)	Porosity and permeability/hydraulic conductivity			
	Groundwater recharge and discharge conditions		Obstructions (roadways, buildings, etc.)	Exposure to COPCs during well installation
	Sensitive aquifer conditions.			

The configuration of the site monitoring well network is contingent upon the variables mentioned above. A comprehensive understanding of the dynamics of the site's groundwater flow (rate, direction, and gradient) within each hydrostratigraphic unit and aquifer conditions at the site will help identify potential contaminant migration pathways and select appropriate locations for the monitoring wells. If the site geology and hydrogeology are not properly investigated, contaminants may go undetected, impacted aquifers and receptors

The size and scope of a monitoring well network can vary significantly depending upon site conditions, but it has the following general well components:

- **Source(s) wells**: Monitoring wells installed within or near the source area(s) to 1) identify if non-aqueous phase liquid (NAPL) is present, 2) to monitor and potentially remove NAPL, 3) to monitor NAPL plume migrations and stability, 4) to determine what contaminants have been released, 5) to monitor concentration trends at the source, and 6) monitor remedy performance.
- **Dissolved phase plume wells**: Monitoring wells installed to 1) identify, define, and monitor the extent and magnitude of the dissolved contaminant plume, 2) monitor dissolved plume migration and/or stability, 3) to monitor hydraulic gradients, and 4) monitor remedy performance.
- **Compliance wells**: Monitoring wells installed to assess and ensure compliance with environmental regulations and standards. Compliance wells are often part of a regulatory framework, and data collected from these wells are used to demonstrate adherence to environmental regulations and permit conditions.
- **Sentinel wells**: Monitoring wells established between a plume front and a receptor to detect whether a plume has migrated beyond predicted boundaries and which is used to ensure there will be time for remedial actions to prevent contamination reaching the receptor. At remediation sites, sentinel wells may be used to document whether remedial goals are being met and potential impacts and risk to receptors.
- **Background wells**: Monitoring wells that are typically placed upgradient of the groundwater contamination source to provide and establish a baseline of water quality of the impacted aquifer.
- **Extraction Wells**: Wells that are installed as part of a site remedy and used for dissolved phase source removal, boundary containment, or aquifer hydraulic control.
- **Recovery wells**: Wells installed as part of a remedy and used in contaminant source areas to recover NAPL.
- **Paired or clustered wells**: Multiple wells installed in close horizontal proximity to each other (co-located) and screened or installed at different depth intervals. Used to sample at different discrete depth intervals and measure vertical hydraulic gradient to evaluate the vertical component of groundwater flow.

RIs are site-specific, leading to significant variations in monitoring well requirements from site to site. The project team must determine the optimal number of wells needed to assess and define NAPL and dissolved phase contaminant plumes efficiently and adequately. This involves specifying the targeted location, depth, and screen length of each well. The number of monitoring wells needed depends upon DQOs, contaminants, geology and hydrogeology, receptors and exposure pathways, site conditions, and size and depth of source areas and plume.

Monitoring wells should be installed in or immediately adjacent to all identified source area locations. Additionally, install monitoring wells to define mobile NAPL plume, if present. Place additional monitoring wells as needed to define the horizontal and vertical extent of the dissolved phase groundwater plume (any contamination exceeding established screening criteria). The location of the downgradient monitoring wells should be influenced by the location of the contamination source area(s); site geology, hydrogeology and aquifer characteristics; the locations of known or potential receptors (private water supply wells, municipal wells, surface water bodies, etc.); site conditions and features; regulatory requirements/guidance; and project DQOs. It is also important to consider that groundwater flow directions, rate, and gradient may vary between unconsolidated formations or aquifers at the site.

If DNAPL is present at the site, additional upgradient and/or side-gradient wells may be necessary for plume delineation and monitoring. The DNAPL has the potential to migrate vertically through the aquifer and may follow an alternate direction of groundwater flow, guided by the slope of a confining layer or bedrock formation and the presence of preferential pathways for groundwater flow such as bedrock fractures, bedrock bedding planes, karst dissolution features, buried utilities, or channels.

Development of a monitoring well network is an ongoing process that evolves based on progressive data collection and improved understanding of the existing site CSM through the course of the RI and remedial activities.

Monitoring well construction

Minn. Stat. 103I directs the MDH to protect public health and groundwater through the regulation of wells and borings. Minn. R. 4725 was adopted to regulate activities relating to water quality testing in constructed wells; the construction, sealing, and modification of wells and borings; permitting; and licensing. Minn. R. 4727 was adopted to regulate the construction and sealing of exploratory borings, and licensing. These regulations are legally enforceable requirements and standards. Details of monitoring well construction must be made on a site-specific basis in accordance with MDH and local regulations and should be a part of the site work plan.

A well installed as part of a groundwater investigation is considered an "Environmental Well" as defined in Minn. Stat. 103I.005, subdivision 8a. An exploratory boring is not considered an environmental well by Minnesota Rule. Environmental wells include monitoring wells (Minnesota Rules, chapter 4725), observation wells, remedial wells, piezometers, soil-vapor wells, slope stability monitoring borings (e.g., extensometers and inclinometers), and vibrating wire piezometers. An environmental well can only be constructed by either an MDH-licensed well contractor or an MDH-licensed environmental well contractor. The licensed contractor must submit an environmental well construction notification and fee to MDH prior to beginning construction of an environmental well. A site map identifying the location of all proposed environmental wells must be included with the construction notification. Within 60 days of the completion of the environmental wells, the licensed contractor must submit a construction record (MDH Unique Well Log) for each environmental well.

MDH also establishes Special Well and Boring Construction Areas. This designation alerts the public, including property owners, drilling contractors, and local officials, to the occurrence of groundwater contamination and the need to place special controls on the drilling of new wells and the modifications of existing wells. Contractors proposing to drill a well or boring in a Special Well and Boring Area must contact the MDH Well Management Section prior to construction. Contractors and property owners must submit a written request and well construction plan to MDH and must receive written approval before construction, repair, or sealing of a well in the special well and boring construction area.

The main construction components of an environmental well are the well casing, well screen, filter pack, grout seal, and surface completion. The construction requirements for monitoring wells and borings are described in Minn. R. 4725.

Properly constructed environmental wells produce the highest quality data. Wells may be screened at or below the water table, depending on aquifer characteristics, the physical characteristics of the contaminants being monitored, the desired depth or target interval for sampling, and on whether NAPLs are present.

Environmental wells designed to assess contaminant or aquifer conditions at the water table should be constructed with the well screen intersecting the water table (typically 10–15-foot length of screen with close to half the length below and half above the water table). A water table well screen should never be fully submerged, as it may lead to the underrepresentation of LNAPL contamination. If the site experiences significant seasonal variations in groundwater elevations, consider using a longer well screen range (15–20 feet) to compensate for water table fluctuations and minimize the potential for a well screen to become submerged. If the well is installed to monitor DNAPL or water quality at depth in an aquifer, place the screen entirely within that aquifer, typically using a shorter 5-foot screen or screen length corresponding to the target sampling interval.

Special care and very specific well construction specifications are needed when drilling borings and installing wells in areas with suspect or known contamination to prevent potential contaminant migration pathways between aquifers or water-bearing layers. Drilling deeper borings through shallower highly contaminated zones should be avoided if possible, and if not possible, special drilling methods such as setting and sealing multiple casings can be used to reduce the risk of contaminants migrating vertically between aquifer units or geologic layers. Consultation with MDH during the well design phase is required in these cases.

Environmental consultants should oversee environmental well installations to confirm that the wells are placed at the correct location and target depth and to ensure that the well construction process is conducted efficiently, properly, safely, and in compliance with Minn. R. 4725 and local regulations. Additionally, they should record construction information and develop well construction diagrams for each well.

Monitoring well development

All newly constructed monitoring wells should be developed per a specified time, volume, and/or water quality stabilization criteria, as outlined in the site work plan. Monitoring wells that have been installed need to undergo development before sampling to ensure sufficient hydraulic connection with the surrounding aquifer and to eliminate any residual sediment, drilling fluids, or debris generated during the construction process.

The specific development technique may vary based on site-specific conditions, the type of well construction, the drilling method used, and local regulatory requirements. The standard well development process for environmental monitoring wells involves a combination of well surging (raising and lowering a surge block inside the well to create turbulent flow) and purging (the extraction of groundwater from the well).

Effective well development enhances the connection between the monitoring well and the surrounding aquifer. This enables the collection of representative groundwater samples and accurate measurements of water levels and ensures that samples accurately reflect the hydrogeologic conditions of the site. Additionally, it reduces future stabilization purging time for groundwater sampling events and extends the period before well maintenance becomes necessary.

Well development procedures, including methods used, dates, start/stop times, gallons removed, turbidity, recharge, and any other observations made during the process, should be documented for future reference and evaluation.

Groundwater extracted during development must be managed appropriately. An appropriate discharge location for the expected volumes and rates needs to be determined and approved by property owners and involved parties. Contaminated groundwater may need to be contained and characterized prior to disposal. Refer to **Section 5.7** for further discussion on Investigation-derived waste (IDW).

Additional well locations

Following the initial RI activities, the need for additional wells should be evaluated. These additional wells should allow for the detection of significant plume changes and trends in concentrations over time. Placement of new wells should be based on site stratigraphy, plume behavior, and the potential for back diffusion conditions. Additionally, monitoring well screen lengths should focus on or target the plume or contaminated zones of the aquifer rather than screening the entirety of an aquifer to prevent skewed analytical results.

In the past, sites with clay and shale layers have been considered barriers to contaminant migration. However, recent studies have shown the ability of some COPCs to penetrate these confining layers and should not be considered a true confining layer until proven otherwise (Strategic Environmental Research and Development Program Project ER-1737, 2015). Drilling through potential confining layers should be done using an appropriate drilling technology to prevent the downward or upward migration of contaminants. Additionally, contaminants often bind to, adsorb to, and diffuse into fine-grained low permeability matrices and become reservoirs of ongoing back diffusion. Defining these layers and any associated contaminant concentrations within them can be an important component of the CSM, understanding the fate and transport of the COPCs, and provide crucial data for effective remedial options.

Diving and rising plumes

The depth of a contaminant plume below the ground surface and its elevation can change as it migrates from a source area. Having downgradient wells only at the same depth as those in the source area may lead to the belief that the plume has been fully delineated when site conditions downgradient have caused the plume to change its vertical position within the aquifer. Therefore, delineating the extent of a plume often requires sampling at multiple depth intervals and/or vertical profiling to determine if the depth or elevation of the plume is changing during migration from the source area.

Several factors including contaminant density, topography, vertical groundwater pressure or flow gradients, surface water infiltration rates, discharge areas, and changing hydraulic properties in soil or rock that the plume is moving can influence changing plume depths. Determining the full horizonal and vertical extent of a plume and the hydrogeologic factors affecting plume migration are an important part of a groundwater investigation.

5.2.2 Soil reuse

For any site that is being redeveloped, the scope of the soil investigation should consider what data will be needed for future soil management decisions. Depending on the specific site redevelopment plan and the concentrations of contaminants in soil, it may be possible to use some or all of the contaminated soil onsite in ways that eliminate an exposure pathway. Soil being excavated solely for construction purposes may be suitable for on-site or off-site reuse. Collecting soil data to address these soil management options can make a considerable difference in how soil is used on the site, whether it can be reused off-site, and how much soil must be sent for disposal in a permitted landfill. These questions should be considered early in the project so the appropriate data can be collected during the soil investigation.

For additional information on criteria for off-site reuse of soil, refer to the MPCA's Best Management Practices for the Off-Site Reuse of Unregulated Fill (c-rem1-01) and Off-Site Use of Regulated Fill (c-rem2-02) guidance documents.

5.3 Analytical method selection

It is important to choose the analyte list best suited for each contaminant of concern and individual site-specific circumstances. Analytical method selection involves consideration of additional variables such as field applicability and the type of monitoring point (e.g., monitoring well, private well, public well). Accessibility to analytical laboratories or shipping centers may impose constraints on acceptable hold times, preservatives, and sample containers. Choosing an analytical method with a short hold time for remote sites might be impractical. Additional analytes may be warranted based on field screening results and observations during the investigation. Positive field screening results such as staining, odor, elevated organic vapor measurements, and the presence of ash or debris, are indicators of potential contaminants to include for analysis. It is imperative to consistently reassess and refine the analytical method selection and screening criteria as a site evolves to ensure alignment with emerging data and evolving project requirements.

Analytical methods must be identified in the Work Plan or SAP and selected to ensure reporting limits at or below associated screening criteria and meet any other DQOs. The only exception would be for analytes that cannot be detected at these concentrations because of instrument capability (these should be identified). The MPCA requires that laboratories performing analyses for MPCA Remediation Division programs are accredited by MDH for the analytical methods to be performed. There are instances where a reporting limit is not specified. For these methods or analytes, the selected laboratory will need to be contacted directly so that the reporting limit can be compared to the screening criteria and included in the SAP. There may also be instances where the reporting limit identified for certified or standard methods is above project screening criteria. For these analytes, alternate analytical approaches, such as providing a larger sample volume or using alternative techniques, such as selective ion monitoring, should be evaluated. If the reporting limit is not specified or exceeds project screening criteria, it is the responsibility of the environmental consultant to discuss the issue in the SAP to include the potential impacts on the project DQOs.

Develop the list of screening criteria that is to be used for the site, noting that it should be used for scoping and sampling design but can be refined as site investigations progress. Alternatively for soil, site-specific values may be calculated by the MPCA, which are based on exposure assumptions that may be more representative of a specific site. For more on screening values see Section 4.0.

Groundwater:

Aquifers with very low recharge rates can impact the ability to select analytical methods that demand a large sample volume and/or are sensitive to high turbidity. Specialized well construction with larger diameter boreholes and wells may be necessary to collect large sample volumes or in low recharge aquifers.

The choice of analytical method may also be influenced by the type of monitoring point. For instance, EPA Safe Drinking Water Act methods may be required for compliance samples collected from public water systems. It is important to consider the practicality of the selected methods in the context of field applications and the specific types of monitoring points.

Groundwater investigations unfold as a stepwise process wherein COPCs and receptor risks may change based on information gathered during the hydrogeologic information assessment or SAP development.

Soil:

Most soil sampling procedures are straightforward regardless of the COPC and typically require a two- or four-ounce jar unpreserved and transported on ice. Refer to EPA's SW-846 Test Methods webpage to determine the best analytical test method to use for COPCs.

Volatile organic compounds (VOCs), however, are unique due to the potential for significant loss of contaminants through volatilization, resulting in a loss of VOCs into the air or headspace of the sampling container during collection and storage. Below is a list of best practices to consider when collecting a soil sample for VOC analysis.

- Samples to be analyzed for VOCs should be placed directly in the sample container immediately after being collected and should not be screened or disturbed in any way.
- Composite sampling should never be used for VOCs since the required mixing step may lead to loss of VOCs.
- Collect samples from split-spoon samplers or soil sample liners using a procedure that will minimize losses due to volatilization. Collect samples as soon as possible after the surface of the soil has been exposed to the atmosphere. Do not collect analytical samples from soil cores that have been exposed for more than a few minutes. Samples for VOC analysis should always be collected first from the target interval of the sample core and placed in the laboratory supplied container(s), before performing field screening tests and collecting samples for non-VOC laboratory analysis.
- The specific sample sent to the laboratory for VOC analysis is often chosen based on field screening results. In order to allow for sample selection based on field screening results, immediately transfer an undisturbed portion of the soil core to a resealable one-quart polyethylene freezer bag, sealed with no headspace, and placed on ice in a cooler. After the sampling interval has been determined, collect the analytical sample from the undisturbed bagged core sample.
- Coordination with the laboratory is necessary to ensure the use of proper containers, preservatives, storage, and analyses.
- EPA Method 5035 is required when sampling soil for volatile contaminants per EPA SW-846. Collect soil samples using coring devices, such as a cut syringe, En Core® sampler, US Analytical's EazyDraw Syringe® sampler, or other approved coring device. Either put the "cored" soil directly into containers provided by the analytical laboratory (verify that the laboratory has pre-weighed these containers) or place the sealed coring device (for an En Core® sampler) containing the soil in a cooler containing ice. The correct volume of soil to use in the coring device is established by weighing a similar soil sample before coring the analytical sample.

Many soil investigations include the eight RCRA metals because this list serves a dual purpose of soil characterization and meeting landfill disposal requirements. However, this analyte list may not include certain metals of potential concern associated with past use of a site, such as copper and zinc at a former brass foundry, or nickel at a site with a history of metal plating. Including the 13 Priority Pollutant metals or the 23 Target Analyte List metals in the sampling plan, when appropriate, would capture these additional metals of potential concern.

5.4 Field screening

In addition to relying on information from the desktop review, analytes may also be selected based on visual, olfactory, or field screening data obtained during soil investigations.

Groundwater:

Some types of contamination are readily visible in groundwater, surface water, and sediment. For example, groundwater and surface water may exhibit discoloration, surface sheens, foams, or chemical odors. If the site history indicates that wastes were likely disposed of at the surface, visual and olfactory evidence may indicate which areas are likely to have been impacted and what types of compounds are likely to be present.

Soil:

Indications of potential soil contamination include stained soils, stressed vegetation, lack of vegetation, presence of debris, and chemical odors. Visual and olfactory evidence of contamination is often corroborated by obtaining field screening data, such as headspace screening with a photoionization detector (PID), or by laboratory analysis of soil samples.

Field screening methods can be used during an initial soil investigation to identify locations that should be sampled and during a remedial soil investigation to help define the extent of a release. Field screening is a valuable qualitative tool but is not intended to replace soil sample collection for laboratory analysis. Field screening should not be the sole source of data to determine the need for mitigation or remediation.

Field screening methods have limitations concerning the types of contaminants and range of concentrations they can detect. The user should identify project specific data quality objectives and identify the method(s) that can obtain those objectives.

A few commonly used field screening procedures for soil are identified in Appendix **F**, along with cautionary notes about their limitations. Many other sources exist that describe these and other field screening technologies that may be applicable to a soil investigation. For additional information, refer to EPA's CLU-IN Characterization and Monitoring and the Interstate Technology Regulatory Council (ITRC) Implementing Advanced Site Characterization Tools.

5.5 Field sampling

5.5.1 Groundwater field sampling

Because of the complexity of groundwater sampling with numerous drilling and sampling methods available, this information is covered at a high level in this section and presented in more detail in **Appendix E**.

Drilling method selection

The selection of drilling methods is site specific and based on factors such as:

- Geologic conditions and depth to groundwater
- Well construction requirements
- Permanent or temporary sampling points required
- Required soil sample quality
- Site access
- Environmental impact of the drilling activities
- Investigation derived waste management
- Budget and time constraints
- Regulatory requirements

Groundwater sampling method selection

Evaluation factors when selecting a groundwater sampling method include:

- Site hydrogeology
- Static water level
- Target sampling depths
- Sample analytical parameters
- Aquifer formation hydrologic properties
- Borehole or well diameter
- Sample integrity requirements (e.g. avoiding loss of volatiles)
- Sampling point accessibility
- Equipment decontamination requirements
- Budget and time constraints

Stabilization parameters

Field stabilization parameters, if collected, should be included in the groundwater SAP. These parameters can be collected to ensure representativeness of groundwater samples following purging and some parameters can be used to evaluate MNA. Field parameters typically include turbidity, dissolved oxygen, specific conductance, temperature, pH, and reduction/oxidation potential (redox). The table below provides an example of typical field-measured stabilization parameters and acceptable ranges for each parameter. Refer to MPCA's [Groundwater sample collection and analysis procedures (c-prp4-05)]() for additional details.

Groundwater sampling evaluation factors

Field parameter	Typical stabilization range
Turbidity	±10% for values greater than 5 nephelometric units (NTU); if three turbidity values are less than 5 NTU, consider the values as stabilized.
Dissolved Oxygen	±10% for values greater than 0.5 mg/L; if three dissolved oxygen values are less than 0.5 mg/L, consider the values as stabilized.
Specific Conductance	±3%
Temperature	±3%
pH	± 0.1 unit
Redox	±10 millivolts

5.5.2 Soil field sampling

This section provides information on some of the most commonly used sampling approaches and general information on what types of situations or sampling objectives may be appropriate for each approach. Commonly used sampling designs are summarized below. The following EPA references provide additional guidance for sampling plan design.

- EPA Selecting a Sampling Design
- EPA Using Professional Judgment to Develop a Sampling Design
- EPA Guidance on Choosing a Sampling Design for Environmental Data Collection

Target sampling: Target sampling involves locating samples based on site history and available information. Target sampling is often used during an initial investigation when small potential areas of concern and site features are targeted for sampling to identify whether a contaminant release has occurred. Data obtained by this method is not appropriate to use in statistical calculations or to define contamination spatially. Target sampling is referred to as "judgmental sampling" in EPA's guidance. The following types of site-specific information are commonly considered when using this sampling design to determine appropriate sample locations:

- Potential contaminant sources.
- Known or potential patterns of chemical storage, use, management, and disposal.
- Characteristics of potential contaminants of concern, including mobility, persistence, and degradation products.
- Expected depth of fill and bedrock.
- Expected soil types.
- Underground structures (utility lines, buried stormwater control structures, underground storage tanks).
- Redevelopment plans, including planned locations and depths of excavations.
- Type and location of potential receptors.
- Property boundaries for redevelopment sites.

Probabilistic sampling: Probabilistic sampling designs apply sampling theory and random or systematic selection of sample locations instead of site history and available information. It is generally appropriate to use statistical methods to analyze this type of sample data, provided that a sufficient number of samples are collected. The most commonly used probabilistic sampling designs are discussed below.

Simple random sampling: A simple random sampling design involves randomly located samples within an investigation area. This type of design uses a random process for selecting sample locations that give all locations of the investigation area an equal chance of being sampled. This type of design is often used when estimating average concentrations within a defined exposure area. Some things to consider about this type of sampling design are:

- Easy to understand and determine sample locations.
- Most appropriate when no contaminant spatial patterns or hot spots are expected in the investigation area.
- May be used for calculating sample data set statistics for the investigation area. Provides unbiased estimates of mean concentrations, variance, and other statistical parameters within a defined area.
- Can be used when calculating the minimum sampling size needed to achieve a level of statistical confidence for an investigation area.
- Accessing all randomly selected locations may be difficult at some sites.
- Likely will not provide even spatial coverage of an area when sample sizes are small.
- Does not consider site information regarding potential sources of contamination.
- May not provide adequate information for revealing spatial patterns or applying spatial statistics.

Systematic/grid sampling: Systematic/grid sampling involves sampling at regularly spaced intervals across an investigation area, with sample locations arrayed in one, two or three dimensions. Although the density of sample locations can vary, it is generally intended to provide even spatial coverage across a sampling area. It is often used because it can provide better spatial coverage of an area with a smaller number of samples than if samples were randomly located. This type of sampling design is most appropriate to use in the circumstance listed below:

- During an initial soil investigation
- Little information available regarding location of contaminant targets in a larger area
- Identify multiple separate areas of contamination over a larger area.
- Identify hot spots.
- Define extent of known impacted areas

- Identify spatial patterns of contamination.

Stratified sampling: Using some form of a stratified sampling design is common for investigations of larger sites with multiple areas of concern. Stratified sampling separates a site into separate investigation areas (strata) that are thought to have different soil characteristics. Each stratum is sampled and evaluated independently using an appropriate design and methods for the area.

Stratification may be especially useful when different sampling procedures and/or designs are needed for different portions of a project area, possibly based on conditions such changing soil types, land use, surface cover or sampling depths. More reliable estimates of contaminant types and concentrations within each separate stratum may be achieved with this method.

Composite sampling: Composite sampling involves combining and mixing soil from multiple locations to form a single homogeneous sample for laboratory analysis. This can be a cost-effective way to incorporate information from multiple locations. Compositing is often used along with other types of sampling designs when the objective is to estimate contaminant concentrations of an area or volume of soil and information on spatial variability is not needed. Sampling can be designed to retain individual subsamples (aliquots) that can be analyzed separately at a later time if necessary.

Several concepts to consider for composite sampling are:

- Not appropriate to use to analyze for VOCs.
- Not appropriate to use when evaluating acute human health risks.
- Not appropriate to use to delineate hot spots.
- Individual subsamples should be representative of the same exposure scenario.
- Individual subsamples should be the same size and composed of the same type of material.
- Results should represent an average concentration of the subsamples if mixing is thorough.
- Variability among groups of composite samples should be less than the variability of all individual subsamples used to form the group of composites.
- Retesting aliquots from individual subsamples is possible.

Composite sampling is most appropriate for the following situations:

- Estimate overall mean concentration while information about individual samples or spatial variability within the sampling unit are not important.
- Identify if the average concentration of a contaminant within an area exists above or below a specific threshold.
- Project threshold concentration objectives are high compared to detection levels.

Homogenizing the individual subsamples and then the composite sample itself is important. This ensures the composite sample represents a true average of the subsamples it is formed from and/or the split portions of the subsamples are consistent and can be resampled. Composite sampling should only be performed when individual subsamples can be homogenized without affecting sample integrity or resulting in safety issues.

Incremental sampling: Incremental sampling is intended to provide a reasonably unbiased estimate of the average contaminant concentration over a specific area (decision unit). This method involves collection of multiple discrete soil aliquots (typically 30 to 100) within each decision unit. The aliquots are combined into a single sample, which is submitted to the lab. The lab processes the sample and then takes subsamples for analysis according to a specific procedure. Refer to ITRC's Incremental Sampling Guidance for additional information.

Other sampling designs: In some cases, a modified version of one of the sampling designs described above or a combination of designs may be appropriate to use. Other types of innovative sampling designs, such as ranked set sampling and adaptive cluster sampling might also be considered when designing a sampling plan. See the references linked in **Section 5.4** for additional information.

Sampling design considerations: Sampling plans for large areas usually involve using a systematic grid or random sampling to ensure adequate spatial coverage. The number of lateral soil sampling locations will be determined by the surface area of the site and the level of desired confidence in detecting areas of contamination, if present. General guidelines regarding the number of sampling locations *for an area with no apparent discrete areas of soil contamination* are listed in the table below. These general guidelines are intended to provide a starting point and can be modified if sufficient rationale is provided.

Individual features or operational areas suspected to be associated with higher concentrations of contaminants such as discrete source areas or previously identified hot spots should not be included in area-wide sampling. These areas should be investigated as separate areas.

Recommended minimum preliminary soil sampling density

Surface area of site	Number of lateral sample locations
less than 2 acres	6 sample locations per 0.5 acre (12/acre)
2-5 acres	sample locations placed on 75’ centers (~ 8 /acre)
5-40 acres	sample locations placed on 100’ centers (~ 4 /acre)
40+ acres	sample locations placed on 130’ centers (~ 3 /acre)

Sampling methods: Factors that influence the choice of sampling method include the *target depth* for the soil samples (surface/shallow versus deep), *site conditions* for access of equipment (e.g., space limitations, hardscape), and special sampling considerations related to the specific *contaminants of potential concern.* General guidelines for soil sample collection are provided below. Detailed guidance about soil sampling procedures, methods and considerations can be found in EPAs Soil-Sampling document.

Surface soil sampling: The most common sampling interval to characterize surface soil is 0 to 6 inches below ground surface (bgs) to help characterize risk to direct exposure; however, the data quality objectives of the investigation may dictate another interval, such as 0 to 3 inches bgs, for risk assessment purposes. Samples are collected using hand tools such as a trowel or shovel. Below is a list of additional best practices to consider when collecting a surface soil sample.

- Prior to collecting a surface soil sample, carefully remove the top layer of vegetation or debris to expose the top layer of bare soil or target sample layer using a dedicated or pre-cleaned tool.
- Stainless steel tools are generally the most appropriate to use for extracting surface or near surface samples. Tools should be made from materials that will not cause cross contamination that may interfere with the analysis of target contaminants. For example, tools plated with chrome, brass, or nickel should not be used if sampling for those metals, and certain types of plastics should be avoided when sampling for organic compounds.

Subsurface soil sampling: Subsurface soil samples can be obtained using a hand auger or mechanical drilling, coring, or excavating equipment. Soil cores are often obtained from the subsurface by driving split spoon sampling tools or thin-wall sampling sleeves into the target sampling layer, with soil samples then collected from depth intervals of interest. Below is a list of additional best practices to consider when collecting a subsurface soil sample.

- Target subsurface samples to depths or subsurface layers with field evidence of contamination, a specific soil type, and the likelihood of potential exposure and/or disturbance.
- In some soil conditions, it may be difficult to obtain an adequate volume of soil for all required tests when using drilling and coring methods. The work plan may be written to include multiple cores from borings near the same location or prioritizing tests to be performed when a limited volume is recovered.

Using an excavator or backhoe to obtain subsurface samples allows for the recovery of large volumes of material for observation and sampling. Entering a trench or excavation to observe sub-surface soil layers or to collect samples is often unsafe and may not be allowed by Occupational Safety and Health Administration (OSHA) safety regulations unless protective systems are in place (e.g., benching, sloping, or shoring). Because of safety concerns, soil samples collected from an excavation are often obtained from the bucket of the equipment. The excavator should dig to the desired sample depth, then scrape the target area to remove slough and smeared material. Paint, grease, and rust must be removed and the bucket decontaminated prior to obtaining soil for sampling. When collecting the sample from the bucket, care should be taken to collect soil that has not touched the bucket itself.

5.4.3 Soil general best practices

The following general best practices should be used:

- Recommended sample containers and sample preservation for soil samples being submitted to the laboratory for different analytes or analyte groups are outlined in the appropriate EPA reference method. Refer to EPA's Hazardous Waste Test Methods (SW-846) for additional information. The type of sample container and amount of sample material to be collected for each type of analysis should be determined by the laboratory prior to sampling.
- Always provide a description of soil appearance and physical properties, to aid in the interpretation of data.
- Sampling equipment should be made from materials that will not cause cross contamination that may interfere with the analysis of target contaminants. Minimize the possibility of cross-contamination by using disposable sampling equipment for each sample collected. If disposable sampling tools are not available, the equipment must be thoroughly cleaned and decontaminated with an appropriate detergent and rinsed with distilled water between each sample.
- Clean nitrile gloves should be used by all personnel handling samples, sampling tools, and sample containers.
- Separate samples should be collected for headspace screening, soil description, laboratory testing of physical properties, and laboratory testing for chemical parameters. Do not retain soil previously used for field screening or soil classification for analytical samples.
- In most cases, samples for *non-VOC* analytes can be screened to remove debris and large fragments. A #10 sieve may be used to remove fragments larger than two millimeters.
- Samples for *non-VOC* analytes should be homogenized by thoroughly mixing in a decontaminated or dedicated bowl to ensure a representative sample is obtained before splitting into sample containers.
- Chemical preservation of soil samples to be analyzed for *non-VOC* contaminants is not generally recommended; however, most samples should be cooled on ice or refrigerated and protected from sunlight to minimize the potential for reactions. Most types of soil samples must be preserved by storing samples at a cool stable temperature of less than or equal to six degrees Celsius until they are analyzed. Include a temperature blank sample in the cooler for sample temperature verification.
- Label all sample containers. The labels should indicate:
  - Type of analysis
  - Site name
  - Sample identification.
  - Name of person collecting sample
  - Time and date the sample was collected.
- Collect, transport, and deliver samples under a chain of custody record.

5.6 Spatial data collection and surveying

The collection of accurate and detailed spatial data through Global Positioning System technology or online mapping-based systems enhances the precision and effectiveness of the RI process. Spatial data should be collected for all relevant site features (e.g., utilities, source areas), but is required for all relevant site features (e.g., boring and permanent monitoring well locations, utilities, source areas).

Note that precise elevation data are essential for uniformly assessing the gradient and direction of groundwater flow in a monitoring well network, for determining the depth to a targeted interval of an aquifer(s) at various ground surface elevations present across the investigation area, and for assessing the ground surface elevations and depths. Groundwater and ground surface elevation data with a vertical accuracy of 0.01 feet is typical. Refer to MPCA's Spatial data collection at Remediation Division sites (c-rem1-28) for spatial data collection and reporting requirements.

5.7 Investigation derived waste management

All investigation derived waste (IDW) is required to be managed in accordance with state and federal regulations. IDW includes all materials generated during performance of an investigation or corrective action that cannot be effectively re-used, recycled, or decontaminated in the field. IDW consists of materials that could potentially pose a risk to human health and the environment, as well as materials that have little potential to pose risk to human health and the environment.

Common IDW associated with groundwater and soil investigations includes the following:

- Soil cuttings from borings or temporary or permanent monitoring well installations
- Drilling fluids or water used during well installation
- Purge water generated during well development
- Purge water generated during well stabilization and sample collection
- Drilling equipment used during boring installation
- Disposable sampling equipment/tools
- Personal protective equipment
- System condensate and filters

IDW should be considered contaminated until it is identified or characterized as non-contaminated through proper analytical testing or by MPCA staff. A waste containing a listed hazardous waste is hazardous at any concentration unless a de minimis concentration has been set. Environmental media is not a waste but if it is hazardous by characteristic or contains a listed waste that poses an unacceptable risk to human health or the environment it must be handled as if it were a hazardous waste. In many cases, the risk-based number becomes the de minimis concentration for the listed waste in environmental media but the concentration is set by the MPCA and includes the use of analytical testing but cannot be based on analytical testing alone. Contact your MPCA project manager for additional information regarding establishing de minimis concentrations in a waste stream. Once the material has been characterized, it can be properly marked and then profiled to an approved disposal end-facility. The material will be profiled to the approved disposal end-facility based on the analytical characterization, which will determine the proper disposal method required to properly manage the material.

All hazardous waste containers must adhere to United Nations specifications and be packaged according to the requirements outlined in Title 49 of the CFR, Subtitle B, Chapter 1 – Pipeline and Hazardous Materials Safety Administration, Department of Transportation, Subchapters A, B, C.

To transport IDW material from the site to an approved staging area or disposal end-facility, proper shipping documents are required to accompany the waste containers. If the material is characterized as a non-hazardous waste, it will be transported using either a Non-Hazardous Waste Manifest or a Bill of Lading, depending on the acceptance criteria of the disposal end-facility. If the waste is characterized as a hazardous waste, the material will be required to be transported using a Uniform Hazardous Waste Manifest to an approved disposal end-facility.

Some IDW such as spent personal protective equipment, miscellaneous papers, etc. are considered trash and can be disposed of in the trash.

IDW management procedures should be detailed in the SAP and project work plans to facilitate proper waste characterization and disposal coordination before initiating RI activities. All wastes generated during environmental investigations need to be managed in accordance with all federal, state, and local generator requirements.

6.0 Data analysis

This section provides a framework for analyzing data collected during site investigations. The objective is to support informed decision-making through data evaluation and risk assessment.

6.1 Verify COPCs

Suspected COPCs are identified in the SAP development for the groundwater or soil screening investigation. Following completion of the groundwater or soil screening investigation, it is important to complete a comprehensive review of the field observations and analytical results to verify if the COPCs should be expanded or narrowed. This critical step ensures the planning stages of the next phase are well-informed and additional investigations are optimized for efficiency and accuracy.

Verifying contaminants during the RI planning stages allows for the inclusion of any newly identified contaminants that may not have been considered in the initial groundwater screening investigation. Continuous assessment of COPCs ensures the investigation assesses all existing and emerging contaminants. A comprehensive and continuous evaluation of COPCs will strengthen site conclusions and limit misguided remediation efforts.

6.2 Analytical results QA/QC

Confirm screening values established during project scoping and design are still appropriate for the site and adjust if needed. A thorough understanding of the project DQOs established in the investigation planning process is critical to evaluate the final data.

Data should be evaluated against appropriate QA/QC requirements as defined by the project's DQOs, to establish their validity before use. This evaluation should be performed by staff trained to review and evaluate laboratory data and ensure hold times were met, sample temperatures were maintained in transit to the laboratory, laboratory QA/QC criteria are within acceptable limits, project required RLs were met, etc. The data review should include completion of MPCA’s Laboratory data review checklist (p-eao2-11b) in accordance with MPCA’s Laboratory data checklist guidance (p-eao2-11a) and Laboratory quality control and data policy (p-eao2-09a). Additional information about data quality can be found at the MPCA’s Science and data website.

The data should be presented in a clear and concise manner in tables and include the following information:

- Sample date, sample point numerical identification, sample location identifier, lab sample identifier, and sample depth.
- Units.
- Analytical results of each individual sample.
- Detection limits.
- Qualifiers associated with each result, such as “J flag” to reflect estimated concentrations.
- Sample results below the RLs be included in the table with <RL as a value (not ND for non-detect).
- Duplicate results paired with parent samples.

- To characterize potential human health risks, tables must include applicable and appropriate regulatory standards with exceedances of those standards highlighted for easy identification. See **Section 4.0** screening values.
  - Groundwater: Groundwater results in Minnesota are typically compared against MDH water guidance values or EPA values if MDH has not established a value. A table of MDH and EPA drinking water guidance can be found on MDH's Comparison of State Water Guidance and Federal Drinking Water Standards webpage.

6.3 Risk evaluation

The risk evaluation is an iterative process that occurs as additional data is collected. It is documented in each groundwater or soil investigation report and used to update the CSM.

To determine if groundwater or soil response actions are necessary, a risk evaluation must be completed to estimate any risks to human health and the environment posed by the groundwater or soil contamination. The risk evaluation is included in the screening investigation report(s) through an evaluation of groundwater data collected at the site with respect to the *groundwater-human health pathway* or soil data collected at the site with respect to the *soil-human health pathway* and the *soil leaching pathway*. The risk evaluation must consider all potential exposure pathways and receptors, both current and future, which may be exposed to groundwater contamination. On certain sites, ecological risk may be of concern, such as toxicity to aquatic receptors in surface waters from groundwater or toxicity to plants or soil invertebrates from soil. Groundwater and soil investigations and risk evaluation specifically for these and other ecological pathways of potential concern are beyond the scope of this guidance document. Site-specific risk assessments are also beyond the scope of this guidance document. Refer to the MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33) for more info.

There are always uncertainties involved when conducting a groundwater or soil investigation and risk evaluation. Some examples are exposure assumptions, sampling, laboratory analysis, toxicity information, contaminant daughter products, natural variability, and professional judgment. By evaluating uncertainties, data gaps may be identified that can be resolved by the collection of additional groundwater data or information, leading to a more accurate estimation of risk.

6.4 CSM update

6.4.1 Groundwater characterization CSM update

The goal of the groundwater investigation is to facilitate the compilation and evaluation of information to identify remedial actions and remediation requirements necessary to manage the risk groundwater contamination poses to human health and the environment.

The goal of a CSM is to provide an understanding of relevant site features and conditions to understand the extent of COPC and the critical exposure pathways for evaluation in risk assessments. The RI groundwater investigation data inputs first presented in **Section 3.2.3** help define the groundwater pathway component of the overall CSM including fate and transport of COPCs, and the complete and potentially complete exposure pathways to identified receptors. This process is detailed in MPCA's MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33) **Section 4.2.2**.

6.4.2 Soil characterization CSM update

Following the reviewing of soil characterization, update the CSM and integrate new data to refine contaminant distribution and migration pathways, and evaluating geological factors influencing contaminant transport. The updated CSM should also considers exposure pathways, risk assessments, and the effectiveness of proposed response actions. Findings are documented should support informed decision-making process.

7.0 References and resources

MPCA program guidance

Other MPCA program guidance or relevant external guidance that may assist or help guide the investigation and characterization of groundwater contamination include the following:

- MPCA, Remediation Division Programs General Policy (c-rem2-02): Provides an overview of the processes used in common by Remediation Division programs to address human and environmental impacts from contaminated sites, and the principles that guide the work of the Remediation Division.

MPCA Cleanup Guidance and Assistance webpage: https://www.pca.state.mn.us/business-with-us/cleanup-guidance-and-assistance

- MPCA, MERLA Remediation Process and Risk-Based Site Evaluation (c-rem3-33)
- MPCA, Typical contaminants based on site use and processes (c-rem3-35)
- MPCA, Phase I ESA Report for Brownfield Program enrollment (c-brwnfld4-03)
- Environmental Justice Framework (p-gen5-05)

Groundwater:

- MPCA, Natural Attenuation of Chlorinated Solvents in Ground Water, June 2006 (c-s4-05)
- MPCA, Dense Non-Aqueous Phase Liquids (DNAPL) Technical Guidance Series – Dense non-aqueous phase liquids: Site remediation and redevelopment, September 2022 (c-rem3-23)
- MPCA, Groundwater Investigation in Karst Area, Guidance Document, April 2005 (c-prp4-09)

Soil:

- MPCA, Best Management Practices for the Off-Site Reuse of Unregulated Fill (c-rem1-01)
- MPCA, Off-Site Use of Regulated Fill (c-rem2-02)
- MPCA, SRV spreadsheet (c-r1-06)
- MPCA, SRV Technical Support Document (c-r1-05)
- MPCA, SLV spreadsheet (c-r1-03)
- MPCA, SLV guidance document (c-r1-04)

Per- and Polyfluoroalkyl substances-specific guidance:

- MPCA, Guidance for perfluorochemicals analysis (p-eao2-06)
- MPCA, Guidance for per- and polyfluoroalkyl substances (PFAS): Analytical (p-eao2-28)
- MPCA, Guidance for per- and polyfluoroalkyl substances (PFAS): Sampling (p-eao2-27)
- MPCA, Developing PFAS remediation guidance webpage
- MPCA, PFAS monitoring plan webpage

Laboratory, data, and quality control:

- MDH, MDH Accredited Laboratories website
- MPCA, Laboratory data review checklist (p-eao2-11b)
- MPCA, Laboratory data checklist guidance (p-eao2-11a)
- MPCA, Laboratory quality control and data policy (p-eao2-09a)
- MPCA Science and data webpage: Science and data | Minnesota Pollution Control Agency

MPCA Electronic Data Submittal

Beginning November 15, 2023, the MPCA's Remediation Division required electronic submittals of all field and analytical data. Field data must be submitted using EarthSoft's Environmental Quality Information System (EQuIS®) Data Gathering Engine (EDGE) using the MPCA's EDGE_MN electronic data deliverable (EDD) format, and laboratory data must be submitted using the MPCA's Lab_MN EDD format. Guidance on these formats includes:

- EDGE Webpage: MPCA, wq-s5-80, Environmental Data Gathering Engine (EDGE), Standard Operating Procedures, July 2023. https://www.pca.state.mn.us/about-mpca/remediation-data-submittals
- EDGE_MN EDD format: https://earthsoft.com/products/edp/edge-format-for-mnpca/ webpage
- Lab_MN EDD format: https://earthsoft.com/products/edp/edp-format-for-mnpca/ webpage

Minnesota Department of Health program guidance

MDH is the state authority for drinking water. Several programs at MDH work together to ensure safe and adequate drinking water. The Drinking Water Protection Program focuses on public water systems. Public water systems serve 25 people or more in places where they live, work, gather, and play. Information regarding the Drinking Water Protection Program is located at MDH's Drinking Water Protection webpage.

MDH Guidance Values and Standards for Contaminants in Drinking Water include the Additivity Calculator for groundwater impacted with multiple contaminants, can be found at MDH's Guidance Values and Standards for Contaminants in Drinking Water webpage.

Interstate Technology and Regulatory Council (ITRC)

- ITRC. Integrated DNAPL Site Characterization and Tools Selection. ISC-1. https://projects.itrcweb.org/DNAPL-ISC_tools-selection/.
- ITRC. LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies. March 2018.
- ITRC. The Use of Direct Push Well Technology for Long-term Environmental Monitoring in Groundwater Investigations, March 2006.
- ITRC. Natural Attenuation of Chlorinated Solvents in Groundwater: Principles and Practices. September 1999.
- ITRC. PFAS Technical and Regulatory Guidance Document. September 2023. https://pfas-1.itrcweb.org/#1_7.
- ITRC. Hydraulic and Groundwater Profiling Tools. 3.6 Hydraulic and Groundwater Profiling Tools – Implementing Advanced Site Characterization Tools.
- ITRC. Implementing Advanced Site Characterization Tools. ASCT-1. Implementing Advanced Site Characterization Tools.
- ITRC. Incremental Sampling Methodology (ISM) Guidance (ISM-2)

American Society for Testing and Materials (ASTM ®)

- ASTM® 2021. ASTM® E1527-21, Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process.
- ASTM® 2023. ASTM® E2247-16, Standard Practice for Environmental Site Assessments: Phase I Environmental Site Assessment Process for Forestland or Rural Property.
- ASTM® 2020. ASTM® E1903-19, Standard Practice for Environmental Site Assessments: Phase II Environmental Site Assessment Process.
- ASTM® 2023. ASTM® D5903-96(2023), Standard Guide for Planning and Preparing for a Groundwater Sampling Event.

- ASTM® 2020. ASTM® D7929-20, Standard Guide for Selection of Passive Techniques for Sampling Groundwater Monitoring Wells.
- ASTM® 2024. ASTM® D5092/D5092M-16, Standard Practice for Design and Installation of Groundwater Monitoring Wells.
- ASTM® 2020. ASTM® D6001M-20, Standard Guide for Direct-Push Groundwater Sampling for Environmental Site Characterization.

U.S. EPA guidance

- U.S. EPA. CLU-IN. Technologies and Characterization and Monitoring. CLU-IN | Technologies > Characterization and Monitoring.
- U.S. EPA. Guidance for Performing Preliminary Assessments Under CERCLA. 157081.pdf.
- U.S. EPA. Guidance for Performing Site Inspections (SI) under CERCLA. Document Display | NEPIS | US EPA.
- U.S. EPA. Guidance for Conducting Remedial Investigations and Feasibility Studies (RI/FS) under CERCLA. GUIDANCE.PDF.
- U.S. EPA. Guidance on Choosing a Sampling Design for Environmental Data Collection. g5s-final.pdf.
- U.S. EPA. Hazardous Waste Test Methods. SW-846. https://www.epa.gov/hw-sw846.
- U.S. EPA. RCRA Facility Assessment Guidance. October 1986. rfaguid.pdf.
- RCRA Facility Investigation (RFI) Guidance
- Residential Lead Screening Level Checklist
- Selecting a Sampling Design
- Soil Sampling
- SW-846 Test Methods
- Typical Wastes Generated by Industry Sectors
- Updated Soil Lead Guidance
- Using Professional Judgment to Develop a Sampling Design webpage

Acronyms

ASTM®	American Society for Testing and Materials
bgs	Below ground surface
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CLP	Closed Landfill Program
CFR	Code of Federal Regulations
COPC	Contaminant of potential concern
CSM	Conceptual site model
DCE	Dichloroethylene
DNAPL	Dense non-aqueous phase liquid
DQO	Data quality objective
EDGE	EQuIS® Data Gathering Engine
EDD	Electronic data deliverable
EQuIS®	Environmental Quality Information System
ESA	Environmental site assessment
eV	Electron volts
FID	Flame ionization detector
GIS	Geographic information system
GPS	Global Positioning System
HASP	Health and Safety Plan
HBV	Health-based value
HRL	Health risk limit
HRSC	High resolution site characterization
ID	Identification
IDW	Investigation-derived waste
ITRC	Interstate Technology & Regulatory Council
K	Hydraulic conductivity value
LCL	Lower confidence limit
LNAPL	Light non-aqueous phase liquid
MCL	Maximum contaminant level
MDH	Minnesota Department of Health
MERLA	Minnesota Environmental Response and Liability Act
mg/kg	Milligrams per kilogram
mg/L	Milligrams per liter
MNA	Monitored natural attenuation
MPCA	Minnesota Pollution Control Agency
NAPL	Mon-aqueous phase liquid
NIOSH	National Institute for Occupational Safety and Health
NTU	Nephelometric turbidity unit
OSHA	Occupational Safety and Health Administration
PA	Preliminary assessment
PAH	Polycyclic aromatic hydrocarbon
PCB	Polychlorinated biphenyl
PCE	Tetrachloroethylene
PFAS	Per- and polyfluoroalkyl substances
PID	Photoionization Detector
ppm	Parts per million
PVC	Polyvinyl chloride
QA	Quality assurance
QA/QC	Quality assurance/quality control
QAPP	Quality assurance project plan
QAPrP	Quality assurance program plan

QC	Quality control
RAA	Risk assessment advice
RCRA	Resource Conservation and Recovery Act
REC	Recognized environmental condition
redox	Reduction/oxidation potential
RFA	RCRA facility assessment
RFI	RCRA facility investigation
RI	Remedial investigation
RL	Reporting limit
RPs	Responsible parties
RSD	Relative standard deviation
SAP	Sampling and analysis plan
SI	Site investigation
SLV	Soil Leaching Values
SRV	Soil Risk-Based Screening Values
TCE	Trichloroethylene
TCLP	Toxicity characteristic leaching procedure
UCL	Upper Confidence Level
U.S. EPA	United States Environmental Protection Agency
VIC	Voluntary investigation and cleanup
VOC	Volatile organic compound
VP	Voluntary party
WQS	Water quality standards
XRF	X-ray fluorescence

Appendix A. Regulations and policies

This section provides a summary of some of the various regulations and guidance documents that are available for groundwater investigation scoping and remediation decision making under the state of Minnesota MERLA and Site Assessment programs and the federal CERCLA and RCRA programs. Below is a summary of relevant existing guidance and regulations that stakeholders can use to help drive their decision-making processes.

A-1. State regulations and guidance

A-1-1. Minnesota statute 115B. Environmental response and liability act (MERLA)

The MERLA statute does not provide technical guidance on the groundwater investigation process; it does, however, detail the statutory authority for the program, definitions of various stakeholders in the MERLA process, cost recovery authority, liability overview and available protections/assurances, and possible penalties.

A-1-2. Minnesota statute 103H. Groundwater protection

It is the goal of the State that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged.

A-1-3. Minnesota statute 326.12 license or certificate as evidence; seal

Each plan, drawing, specification, plat, report, or other document which under sections 326.02 to 326.15 is prepared by a licensed architect, licensed engineer, licensed land surveyor, licensed landscape architect, licensed geoscientist, or certified interior designer must bear the signature of the licensed or certified person preparing it, or the signature of the licensed or certified person under whose direct supervision it was prepared.

A-1-3. Minnesota administrative rule 7050

This chapter applies to all waters of the state, both surface and underground. This chapter includes a classification system of beneficial uses applicable to waters of the state, narrative and numeric water quality standards that protect specific beneficial uses, antidegradation provisions, and other provisions to protect the physical, chemical, and biological integrity of waters of the state. MDH drinking water guidance values are often used for groundwater resource protection and as the basis for groundwater cleanup goals at remediation sites. This corresponds to Minnesota water quality protection statutes and rules (Minn. Stat. 115.063 and Minn. R. ch. 7060) which protect groundwater for its highest priority use as potable drinking water.

A-1-4. Minnesota administrative rule 7060

It is the purpose of this chapter to preserve and protect the underground waters of the state by preventing any new pollution and abating existing pollution.

A-2. Federal regulations

Specific federal guidance or regulations that provide valuable resources for the investigation and characterization of groundwater contamination at CERCLA/MERLA, RCRA, or Site Assessment sites include the following. The hazardous waste regulations apply to owners and operators of all facilities which treat, store, or dispose of hazardous waste, except as specifically excluded in the regulation.

- 40 CFR Part 312 All Appropriate Inquiry.

- 40 CFR Part 300, Appendix A, "Hazard Ranking System; Final Rule."
- U.S. Environmental Protection Agency (EPA) 1991. 9345.0-01A, EPA Guidance for Performing Preliminary Assessments Under CERCLA.
- EPA 1992. 9345.1-05, EPA Guidance for Performing Site Inspections Under CERCLA.
- EPA 2022. OLEM9200.3-157, Superfund Program Implementation Manual Fiscal Year 2022, April 2022, 337 pp.
- EPA 1986. PB87-107769, RCRA Facility Assessment Guidance.
- EPA 1989. 9502.00-6D, Interim Final RCRA Facility Investigation (RFI) Guidance.
- EPA 1988. 9355.3-01, EPA Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA, Interim Final.
- EPA 2014. 530-F-11-003 Resource Conservation and Recovery Act Orientation Manual
- 40 CFR Part 264 Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.
- 40 CFR Part 265 Interim Status Standards for Owners and Operators of Hazardous Waste Treatment, Storage, and Disposal Facilities.
- Drinking Water Regulations (EPA).

Appendix B. Monitored natural attenuation (MNA) evaluation

During the RI phase, it is important to have potential remedial actions in mind when scoping groundwater sampling activities. Monitored natural attenuation (MNA) may be a potential remedy on sites where the contaminant plume is stable, there are no identified receptors, and the concentrations of contaminants and their metabolic intermediates or breakdown products are reduced before they pose unacceptable levels of risk to human health or the environment.

To assess a site for implementation of MNA as a remedy, specific field and laboratory parameters can be collected during the RI to assist in establishing aquifer conditions and determine if they may be amenable to MNA. This sampling is not intended to satisfy the requirements of remedy selection but meant as a cost-effective method of providing data for eventual evaluation of groundwater remediation alternatives.

The table below provides a list of common data needed to demonstrate that MNA is a viable remedy for chlorinated solvents in groundwater. This information was taken from the MPCA's Natural Attenuation of Chlorinated Solvents in Groundwater (c-s4-05) and should be used when evaluating natural attenuation rates for chlorinated VOCs

Items are grouped by those that can be collected in the field using commonly available field meters or test kits and those that are typically analyzed in the laboratory.

Common examples of monitored natural attenuation parameters and their interpretation

Field measured geochemical data or analyte	Concentrations in most contaminated zone	Interpretation
Dissolved Oxygen	<0.5 milligrams per liter (mg/L)	Tolerated; suppresses reductive dechlorination at higher concentrations.
Dissolved Oxygen	>1 mg/L	Vinyl chloride may be oxidized aerobically, but reductive dechlorination will not occur.
Temperature	>20 degrees Celsius	At temps >20 degrees Celsius, chemical process can be accelerated.
Eh (reduction/oxidation potential)	<50 millivolts against Ag/AgCl	Reductive pathway possible.
pH	5 – 9	Tolerated range for reductive pathway.
Nitrate (NO_3^-)	<1 mg/L	May compete with reductive pathway at higher concentrations.
Sulfate (SO_4^{2-})	<20 mg/L	May compete with reductive pathway at higher concentrations.
Sulfide (H_2S)	>1 mg/L	Reductive pathway possible.
Methane (CH_4)	>0.01 mg/L	Ultimate reductive breakdown product.
Chloride (Cl^-)	<2X background	Product of organic chlorine; compare chloride in plume to background conditions.
Total organic carbon	>20 mg/L	Carbon and energy source; drives dechlorination.
Reduced iron (Fe^{2+})	>1 mg/L	Reductive pathway possible; anaerobic oxidation of vinyl chloride to CO_2 possible.
Reduced manganese (Mn^{2+})	>1 mg/L	Anaerobic oxidation of cis-DCE possible.
Trichloroethylene, dichloroethylene (DCE), vinyl chloride	Presence or absence	Breakdown products – may suggest aquifer conditions conducive to dechlorination.
Ethene/ethane	<0.1 mg/L	Greater concentrations associated with increased dehalogenation rates

Appendix C. Aquifer characterization

Aquifer characterization or assessment is the foundation (or key component) of a site's CSM for groundwater investigations and is completed by studying aquifer hydraulic properties, hydrogeology, contaminant distribution, and how they related to one another. Successful aquifer characterization will start with general information gathering during drilling, noting details such as moisture content, size, shape, and grading/sorting of particles, and will end with technical in situ or laboratory-derived data collection. During drilling, detailed boring logs should be completed and include primary components, secondary descriptions, minor percent of other particle sizes, shape of the particles, grading/sorting, geologic and soil structures, moisture content, and color using the standard Munsell color notation. Any potential confining layers, like silt/clay layers or high-conductivity zones (gravel stringers and lenses), and evidence of fluctuating water levels should be called out. These data gathered will be the basis for the CSM, numerical and analytical modeling, forecasting migration rates and pathways, as well as form the foundation for considering and developing remedial strategies. Combining methodologies like EPA's Environmental Sequence Stratigraphy, ASTM® D-5434, and ASTM® D-2488 may provide additional benefits in the long-term management of the site and may support the development of an adequate/high-quality/comprehensive CSM.

In summation, aquifer characterization should include:

- Lithology and stratigraphy
- Hydrology/hydrogeology
- Contaminant distribution

C-1. Aquifer types and key characteristics

These physical geologic properties of the aquifer will help determine if the studied aquifer is one of the four basic aquifer types.

Unconfined Aquifer:

- Water table aquifer.
- Aquifer water levels have continuity with land surface and are greatly influenced by natural surface processes.
- Occurs in both bedrock and unconsolidated material.

Perched Aquifer:

- Localized zone of groundwater situated on top of a confining layer, typically discontinuous.
- Confining layers may be unconsolidated or impervious bedrock material.

Confined Aquifer:

- Separated from other aquifers by low permeability confining layers or aquitard.
- Water levels are potentiometric measurements, NOT water table elevations.
- Commonly characterized by groundwater under hydrostatic pressure with groundwater elevations above the top of the aquifer.
- May have artesian effects.
- Occur in both bedrock and unconsolidated material.
- Confined aquifers can be leaky or nonleaky.

Bedrock Aquifer:

- Aquifer within consolidated material such as sandstone, dolomite, or fractured crystalline rock.
- Characterized by the importance of both primary and secondary porosity.
- Major transport could be via fracture-dominated flow or matrix-dominated.
- Requires special drilling techniques.

C-2. Aquifer parameters

Some important aquifer properties that influence groundwater movement, contaminant migration, and fate and transport are discussed in this section. The properties discussed can be highly variable even within short distances, and understanding these aquifer properties and their numerical ranges at a site are critical to understanding the current state of contamination, its fate and transport, and developing remedial designs for management. Common aquifer parameters are listed below and discussed in greater detail, along with common aquifer tests for measuring them, in **Appendix C**:

- Saturated thickness
- Grain size
- Hydraulic conductivity
- Hydraulic gradient
- Flow directions
- Porosity (primary, secondary, total, effective)
- Velocity
- Transmissivity
- Storativity

C-3. Plume delineation

Plumes in groundwater are dynamic 3D systems that will shift laterally and vertically depending on multiple factors such as hydraulic conductivity, zones of low permeability, and forces driving or pulling a plume (e.g., supply wells or groundwater recharge zones), and COPC physical and chemical characteristics. Evaluation of an aquifer with contamination requires data collected in the vertical and horizontal profiles for each COPC at a site to determine the extent and magnitude of the contaminants.

Plume delineation is not only about defining the extent and magnitude of groundwater contaminants, but also about the importance of establishing a thorough understanding of the hydrogeologic environment and how it changes spatially (laterally and vertically) across the study area. The careful placement of investigation borings and monitoring wells and collection of aquifer parameters across the investigation area adds to the understanding of the aquifer physical characteristics and serves to refine the CSM.

C-4. Groundwater contamination extent and magnitude

Vertical and horizontal sample spacing for determining the extent and magnitude of a groundwater plume is site-specific and should be guided by the behaviors of the aquifer. Successful plume characterization will be completed in the following two parts:

- Identify and evaluate ongoing contamination sources, including contaminant mass present zones of back diffusion.

- Conduct sampling transects downgradient and cross-gradient of the plume vertically and horizontally. Spacing and depth is dependent on site-specific conditions, including COPCs. Extent of transects must be adequate to define the source area(s) and plume.

A plume is considered delineated when the following two conditions are met:

- Contaminant concentrations in wells located at the plume boundaries for all site COPCs are equal to or below applicable regulatory levels, or site screening levels.
- The contaminant plume is stable in accordance with MPCA Guidance on Plume Stability, MPCA Guidance Document c-w3-02, Plume Characterization and Stability.

Natural background groundwater data for comparison should be collected from a hydraulically upgradient location from the site but within the same groundwater depth or zone. Sufficient samples should be collected based on the size and complexity of the site. Any statistical methodology used to eliminate naturally occurring compounds must be documented and included in any report discussing results.

C-5. Plume geometry

An effective compliance monitoring well network should establish monitoring locations placed within all groundwater exposure pathways identified within the horizontal and vertical extent of the plume geometry. This would include definition of the downgradient extent of the plume, well clusters with different screened interval depths to determine the vertical distribution of contaminants and provide an estimation of the NAPL extent (if present), side-gradient wells to delineate the lateral extent of the plume, and upgradient wells to delineate where groundwater contamination begins. Plume geometry can be illustrated by the following:

- Using analytical data collected from both temporary and permanent groundwater sampling points to generate isoconcentration maps to illustrate the extent of contamination in the plan (aerial) view.
- If multiple depth interval data are available from temporary points or from well clusters with wells screened at different depth intervals, plot the vertical distribution of groundwater contaminants in cross-sectional view.
- Using 3D rendering computer software, plot the plan view and cross-sectional contaminant concentrations together to generate a 3D representation of the groundwater contaminant plume.

C-6. Source area(s) – NAPL presence

LNAPLs are less dense than water and form a separate phase in the subsurface. LNAPLs are frequently associated with petroleum releases such as crude oil, gasoline, diesel fuel, and heating oil; however, any contaminant with a density less than water has the potential to be encountered as an LNAPL if released in sufficient quantity. Because they are typically associated with petroleum contamination, they are not covered in more detail here but are included as some sites exist with both petroleum and non-petroleum contamination. A LNAPL source zones can naturally degrade over time by processes including sorption, volatilization, and dissolution (ITRC: LNAPL Site Management: LCSM Evolution, Decision Process, and Remedial Technologies). Large LNAPL releases, however, may migrate to the water table over a large area, leaving residual contamination in the vadose zone that presents significant remediation challenges.

DNAPLs are denser than water and exist as a separate phase in the subsurface if released in significant quantities. Common examples of DNAPLs include chlorinated solvents such as trichloroethylene (TCE) and tetrachloroethylene (PCE), creosote, coal tar, chlorobenzenes, and polychlorinated biphenyls (PCBs). Unlike LNAPLs, DNAPLs sink in the subsurface below the water table and can become sorbed into low-permeability zones or bedrock. DNAPLs can be difficult to remediate and may result in persistent groundwater contaminant plumes as they may back-diffuse contaminants into more permeable zones.

As described in the ITRC Integrated DNAPL Site Strategy Guidance (ITRC, 2011), remediation of DNAPL can cause technical challenges, especially in sites with complex geology and a heterogeneous distribution of contaminant mass, leading to substantial back diffusion from bedrock/soils even after the application of in situ groundwater remedies.

Determining the presence of suspected NAPL is a critical part of any groundwater RI. Locating, mapping, and characterizing the presence of NAPL bodies in the subsurface may require multiple investigation phases and advanced aquifer characterization techniques such as the following:

- Installation of clustered wells screened across multiple depth intervals.
- Implementation of high-resolution site characterization (HRSC) technologies such as laser-induced fluorescence for delineation of LNAPL (typically petroleum hydrocarbons and polycyclic aromatic hydrocarbons [PAHs]) in the subsurface.
- Membrane interface probe, another HRSC technology, which applies heat at intervals as the tool (typically direct push) is being advanced and can detect and profile VOCs in the subsurface using gas chromatography.
- Hydraulic profile tooling, which is used to estimate soil permeability as the tooling is advanced.

Additional information on site characterization of DNAPLs can be found on MPCA's Dense non-aqueous phase liquids: Site remediation and redevelopment (c-rem3-27).

C-7. Fate and transport assumptions

The groundwater RI builds an understanding of the geology, hydrogeology, and water quality data to evaluate the physical and microbial processes affecting contaminant concentrations (fate) and how and where the contaminants are moving through the groundwater system (transport) at a site. The evaluation of fate and transport must consider the contaminant source(s), their mass distribution, concentration trends, natural attenuation factors, and migration understanding. Then, based on the results of this evaluation, potential risks to groundwater receptors are assessed and applied to the CSM.

C-8. Plume velocity/travel times

Unlike groundwater velocity, plume velocity is also subject to several physical and chemical factors. Due to these, the plume will typically migrate at slower speeds than groundwater. Monitoring of contaminants over a network of wells is required to determine current velocities and forecast plume travel times. Sentinel well locations should be established upgradient of a potential receptor at a distance which provides a minimum advance warning of at least two years with respect to arrival of the plume at the receptor point to provide an adequate period for a contingency remedial action to be developed and implemented. Plume velocity can be affected by several contaminant and aquifer parameters, summarized below:

Sorption: Some constituents have an affinity for organic carbon and will bind to organic matter residing on the surfaces of lithologic materials. Sorption acts as a significant mass reservoir and causes the contaminant to migrate at a rate *slower than the groundwater velocity*. Sorption occurs in both the saturated and unsaturated zones.

Dispersion: Dispersion is the process whereby the plume mixes and spreads due to variations in groundwater velocity and flow direction on both a microscopic and macroscopic scale. Dispersion occurs in three directions:

- Longitudinally (in the direction of the plume migration)
- Transversely (along the plume's width)
- Vertically

Longitudinal dispersion is the spreading of a plume in the direction of flow and affects how sharp or diffuse the plume front is observed to be as it passes a location. In heterogeneous aquifers, dispersion of a groundwater plume is likely to increase due to the variations in groundwater gradients and velocities.

Diffusion: Diffusion is the process by which contaminant molecules migrate along a concentration gradient from areas of higher concentrations to areas of lower concentrations. Diffusion acts independent of groundwater flow. Diffusion over time results in contaminant migration into less connected porosity pathways and lower permeability strata. Diffusion also can transfer mass from fracture porosity into the rock matrix. This process occurs slowly over time and also works in reverse once groundwater concentrations decrease to less than what is in the solid phase media. The reverse process is commonly called “back diffusion” and can result in the long-term slow release of contaminants back into groundwater.

Biodegradation: Biodegradation is the process in which microbial organisms transform or alter a chemical by metabolic or enzyme action. Microbes obtain energy from the degradation of an organic constituent through paired redox reactions in which an electron donor compound is oxidized and an electron acceptor compound is reduced. Biodegradation can occur through a number of redox pathways, for example, TCE biodegradation has been documented through two pathways: reductive dechlorination and aerobic co-metabolism.

Advection: Advection is the flow of fluid in the aquifer. The velocity at which groundwater is moving in the aquifer, or seepage velocity, is calculated using the hydraulic conductivity, the hydraulic gradient, and the effective porosity of the aquifer. Hydraulic conductivity can be estimated using pumping tests, slug tests, or results from laboratory grain size analysis. If grain size analysis is used, select a hydraulic conductivity that represents the contamination’s primary flow path, which will typically be representative of zones or layers with the highest conductivity. Hydraulic gradient is measured in monitoring wells installed during the RI; it is acceptable to use an average gradient when multiple measurements are available and the results are similar. Effective porosity can be estimated using a referenced value based on the aquifer material.

Advective transport: The hydrophobicity of chlorinated ethenes decrease as they reduce from PCE -> TCE -> DCE -> VC and become less susceptible to partition out of water and sorb onto soil or sediment.

Multiple groundwater velocity calculations may be necessary if:

- Wells are installed at multiple depths (e.g., shallow, intermediate, and deep).
- Sites that contain multiple or changing hydrogeologic conditions (bedrock versus unconsolidated, different depositional environments, etc.).
- Aquifer is or may be influenced by continuous or seasonal pumping wells (like irrigation wells).
- Hydraulic gradients are variable across the site.

C-9. Plume stability

Plume stability must be evaluated using data collected from multiple rounds of groundwater monitoring. Since one of the goals of site remediation is to prevent the further migration of contaminated groundwater at concentrations which exceed cleanup levels, it is important to make the distinction between stable and unstable plumes to identify the most appropriate remedial action to manage the plume and associated risk to human and environmental receptors.

A plume is considered stable when the concentration of COPCs within the contaminated aquifer do not increase over time. Stability can be achieved either by natural attenuation or remedy implementation, like barrier well systems, pump and treat systems, soil-vapor extraction systems, etc. During an RI, data should be collected to distinguish between stable and unstable plumes. This distinction is intended to separate those plumes which continue to migrate and pose an unacceptable risk to receptors from those which have reached their maximum extent and do not present a risk to future receptors.

Multiple lines of evidence should be used to evaluate plume stability. Creating time series plots to show contaminant concentrations over time is one line of evidence that is useful for visualizing data and qualitatively evaluating trends. Plot water levels on the secondary y-axis to look for correlations between water level and concentration. At least six quarters of groundwater monitoring data should be collected to complete a qualitative trend analysis.

Another way to evaluate plume stability is by monitoring for natural attenuation. Additional parameters can be collected during groundwater sampling events to assess for natural attenuation. **Appendix B** provides a brief discussion of common MNA parameters that can be measured during the RI and groundwater monitoring program. In the case of chlorinated solvents, additional guidance on evaluating in situ biodegradation as a component of a natural attenuation remedy can be found on MPCA's Natural Attenuation of Chlorinated Solvents in Groundwater (c-s4-05).

Appendix D. Aquifer characterization resources

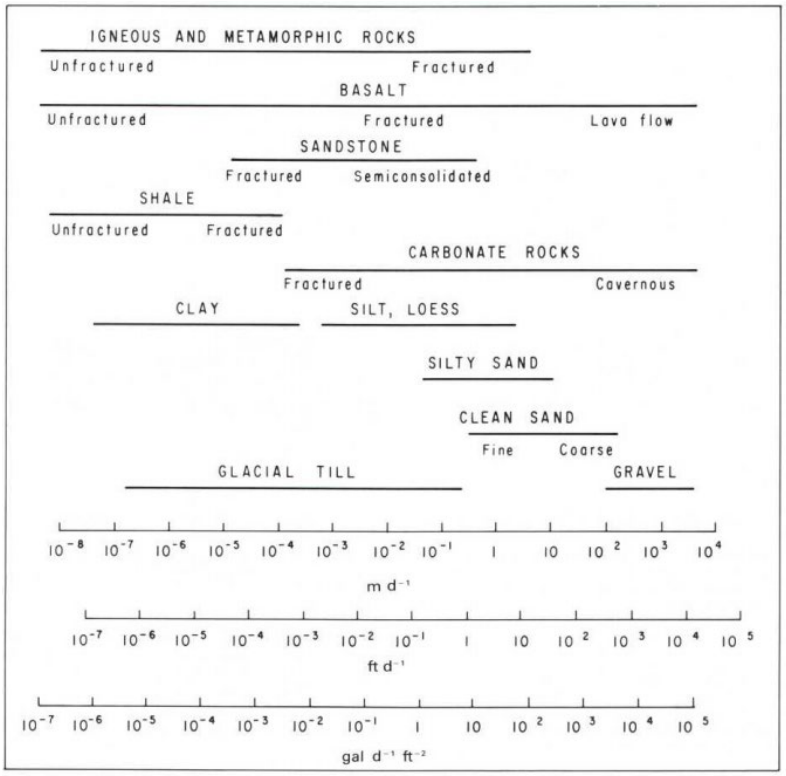
Saturated thickness: The saturated thickness of an aquifer is defined as the vertical distance between the upper and lower physical boundaries with a saturated zone or confining layer. Aquifers in the unconsolidated material could be bounded at the top by unsaturated conditions (water table) and at depth by a confining layer usually consisting of a clay and/or silt layer of sufficient thickness or bedrock that prevents either the downward or upward migration of water. Bedrock aquifers are bounded by soil layers above or less permeable bedrock above. These layers of significantly lower permeability limit water movement between layers.

Including geologic details collected from boring logs when working with hydrology data sets will be crucial when calculating the transmissivity of an aquifer. One common mistake made during aquifer thickness interpretation is conflating potentiometric surface with the water table surface, especially when dealing with confined conditions. For example, a dry clay layer from 5 to 20 feet bgs, underlain by a saturated sand zone 20 to 25 feet bgs, followed by an additional 10 feet of dry clay from 25 to 35 feet bgs. After installing a well with a 5-foot screen only in the saturated coarse sand layer (20-25 feet bgs), the water level in the well is now at 15 feet bgs. While there is 10 feet of water in the well, the saturated thickness is still only 5 feet.

Grain size: Grain size distribution or particle gradation is a fundamental physical property of soil and sedimentary bedrock and is important for understanding hydraulic properties of a formation and contaminant absorption factors. Multiple laboratory methods exist for analyzing grain size of a sample, but two of the most common are sieve analysis method and hydrometer analysis method. Sieve analysis method uses a set of known size screens to sift the sample through to determine relative fraction or percentage of particles sizes present in the sample and compare each particle fraction to each other. As there are a set amount of sieve sizes that only go to a minimal diameter, this method is best for coarser-grained materials. Fine-grained materials are best evaluated using the hydrometer analysis method, which generally includes an initial sieve analysis to partition coarse-grained material from fine-grained. The fine-grained material is then analyzed using the hydrometer analysis method which requires the suspension of the sample in an aqueous solution and the density of the suspended solids is measured at set time intervals.

Hydraulic conductivity: Hydraulic conductivity is a coefficient of proportionality describing the rate at which water can move through a permeable medium (Applied Hydrogeology, C.W. Fetter). Using laboratory tests like grain size analysis is a common practice for indirectly estimating a site’s hydraulic conductivity (K). More direct methods of determining hydraulic conductivity include slug testing, pumping tests, or hydraulic conductivity profiling tools which provide a more accurate aquifer representation of K values for a specific well or boring location. These tests can be scaled up to include the area of interest. Each method has benefits and uses depending on the site conditions and budget constraints needed for project objectives. If direct or even indirect methods for estimating hydraulic conductivity are not available, using published, peer-reviewed, and accepted data like the exhibit below can be acceptable; however, the values for K can range over multiple orders of magnitude. Therefore, these values should only be used if direct or indirect methods are not available.

Hydraulic conductivity (K) of selected rocks



Heath, R.C., 1983. Basic ground-water hydrology, U.S. Geological Survey Water-Supply Paper 2220, 86 pages

Hydraulic gradient: Hydraulic gradient is the driving force of groundwater flow. Determination requires the installation of multiple wells or a well cluster network across the site or hydrologic investigation area. Gradients are usually measured in one dimension both vertically and horizontally. Horizontal hydraulic gradient is determined using three or more wells screened in the same horizon of an aquifer and calculated by measuring the change in groundwater elevation over a known distance. The vertical hydraulic gradient component uses well clusters (closely grouped wells screened at different depths of a same aquifer) and will assist in characterizing the vertical gradient component at a single point in the aquifer. These data can be used as model inputs to estimate flow direction and velocity. More well measurements allow for better and more accurate gradient estimations.

Seasonal variabilities: Measuring hydraulic gradients year-round is recommended to capture enough data to determine seasonal fluctuations in the aquifers, especially near surface water features that may be prone to flooding or drying. For example, the flood waters of a large river during the spring melt may create site conditions where the potentiometric high is the river (a losing stream) and introduce excess water to the site in the spring, whereas the river may be the potentiometric low during the winter months (a gaining stream). Another consideration should be given to areas with large production supply wells used seasonally, like irrigation wells installed in agricultural settings.

Flow direction: While flow direction will always flow in the direction of decreasing head, the rate is dependent on the change in hydraulic head over a certain distance. A comparison of a minimum of the hydraulic gradients in three wells screened in similar hydrologic units is needed to determine flow direction horizontally.

Porosity: Part of any aquifer investigation should be to identify and quantify pore spaces of the aquifer, to the degree possible, based on the medium being studied. This value will help when estimating hydraulic conductivity.

The following items should be physically identified during the investigation and characterized:

- **Primary porosity:** Affected by the shape, grain size, packing, and cementation of the grains. Important for intergranular flow.

- **Secondary porosity:** Acquired after medium formation via physical and chemical weathering. Can either increase porosity by fractures or cavities or decrease by mineral precipitation.

Additional related, but separate, porosity types should be evaluated in the laboratory or in the field:

- **Total porosity:** Calculated by the laboratory by measuring the bulk density of a sample.
- **Effective porosity:** Calculated by the laboratory and is the value of the pores that connect to each other. This interconnection is what allows groundwater to move through the aquifer. The table below provides a list of various types of aquifer materials and typical observed ranges of porosities and hydraulic conductivities (Freeze, 1979).

While site conditions may allow multiple laboratory measurements to be averaged across the site to represent the aquifer conditions, these may not be adequate for complex sites and may require field-scale testing to be completed. This is especially true for calculating effective porosity. During bedrock investigations, secondary porosity may become the main primary mechanism of groundwater transport and can be challenging to map, especially in karst formations. Further guidance for these conditions can be found in the MPCA Karst investigation guidance (https://www.pca.state.mn.us/sites/default/files/c-prp4-09.pdf).

Total, effective porosity, versus hydraulic conductivity

Aquifer material	Total porosity (dimensionless)	Effective porosity (dimensionless)	Hydraulic conductivity (meters/second)
Unconsolidated Material			
Gravel	0.25 – 0.44	0.13 – 0.44	3×10^{-4} – 3×10^{-2}
Coarse Sand	0.31 – 0.46	0.18 – 0.43	9×10^{-7} – 6×10^{-3}
Medium Sand	—	0.16 – 0.46	9×10^{-7} – 5×10^{-4}
Fine Sand	0.25 – 0.53	0.01 – 0.46	2×10^{-7} – 2×10^{-4}
Silt, Loess	0.35 – 0.50	0.01 – 0.39	1×10^{-9} – 2×10^{-5}
Clay	0.40 – 0.70	0.01 – 0.18	1×10^{-11} – 4.7×10^{-9}
Sedimentary and Crystalline Rocks			
Karst and Reef Limestone	0.05 – 0.50	—	1×10^{-6} – 2×10^{-2}
Limestone, Dolomite	0.00 – 0.20	0.01 – 0.24	1×10^{-9} – 6×10^{-6}
Sandstone	0.05 – 0.30	0.10 – 0.30	3×10^{-10} – 6×10^{-6}
Siltstone	—	0.21 – 0.41	1×10^{-11} – 1.4×10^{-8}
Basalt	0.05 – 0.50	—	2×10^{-11} – 2×10^{-2}
Fractured Crystalline Rock	0.00 – 0.10	—	8×10^{-9} – 3×10^{-4}
Weathered Granite	0.34 – 0.57	—	3.3×10^{-6} – 5.2×10^{-5}
Unfractured Crystalline Rock	0.00 – 0.05	—	3×10^{-14} – 2×10^{-10}

Data from Enviro Wiki Contributors, 2019

Velocity: Groundwater velocity is a critical aquifer parameter when evaluating risk to receptors and potential groundwater remedies.

Velocity is an important component of evaluating plume migration and travel time to down gradient receptors or when evaluating MNA as a possible remedy. Velocity is also an important component of evaluating contaminant mass flux, which is the measurement of the concentration and movement of contaminants from a source. Contaminant flux measurements show how much, how fast, and where a contaminant is moving, which again, are important remedy evaluation criteria, especially for active remedies such as plume capture/containment and pump and treat.

Velocity can be directly and indirectly estimated using a variety of methods depending on budget and scale of the site. Darcy-based methods (or Darcy's Law for groundwater flow calculation) using site water levels and hydraulic conductivity estimations are adequate for generalized flow characterization or plume migration trends. More technical and expensive methods can help determine localized flow patterns at smaller scales and may identify preferential flow zones in vertical profiles.

Darcy velocity is a measure of the average velocity over an entire transect area and does not account for effective porosity. Interstitial or seepage velocity is typically used to calculate solute travel times and does account for effective porosity of the aquifer (Freeze, 1979).

Transmissivity: Transmissivity is an aquifer's ability to transmit water and is directly proportional to the hydraulic conductivity and saturated thickness. It is estimated for a specific aquifer layer and can be used for confined and unconfined condition (Freeze, 1979). This value is a requirement for many flow and transport computer models and can be calculated by using field-collected water levels, aquifer saturation thickness and hydraulic conductivity values.

Storativity, specific storage, and specific yield: Aquifer storativity is involved in predicting a pumping rate that would be sustainable in an aquifer. These values can most commonly be derived from laboratory tests of intact cores and field tests. Storativity calculations will change based on whether conditions are confined or unconfined. Measurement/evaluation of these parameters may be useful for pumping or capture system design or along with aquifer testing, used when estimating other aquifer properties or developing groundwater flow models. Definitions of these terms are as follows:

- **Storativity:** The volume of water that an aquifer releases from storage per unit surface area of aquifer per unit decline in the component of hydraulic head.
- **Specific storage:** The volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head.
- **Specific yield:** The term is mostly used when describing the storativity of unconfined aquifers and is defined as the volume of water an aquifer will release from storage per unit surface area of aquifer per unit decline in the water table (Freeze, 1979).

The table below provides general information on some of the different aquifer tests that can be conducted at a site. Alongside each test, included are values the test can provide, some of the test's advantages, and some of the limitations that should be considered. It is by no means all inclusive; each test should be evaluated based upon site and project constraints.

Aquifer test

Test	Results	Advantages	Limitations
Grain size test	Values to calculate hydraulic conductivity	Inexpensive, easy, common laboratory techniques, minimal solid IDW	Grain size is not a substitute for in-field downhole aquifer tests (slug, pump, etc. tests) to determine hydraulic conductivity Choosing the wrong test (sieve test on high silt/clay soils) could generate data reports with necessary values unreported
Packer Testing	Transmissivity Storativity	Discrete transmissivity and storativity values down-hole High precision values are obtained with lower flow rates	Time-consuming Short-circuiting can interfere with test results Long screen lengths and large filter pack will provide a preferential flow path and can lead to erroneous data Generates IDW
FLUTe™ Profiling	Transmissivity	Obtains down-hole Transmissivity profile Quick No IDW	Vertical gradients can interfere with test results. Designed for discrete interval groundwater sampling but limited for determining aquifer characteristics.
Borehole Dilution Tests	Values for Darcy flux	Inexpensive	Strong vertical gradients can affect data
Flow Metering	Darcy Flux	Identifies flow within borehole/well	Low-flow zones cannot be identified
Slug Tests	Transmissivity Hydraulic Conductivity	Relatively quick Inexpensive No IDW depending on the slug method	Must collect accurate water levels Multiple rising and falling head tests needed for accuracy checks
Cross Borehole Slug Tests	Transmissivity Storativity	Inexpensive Identify anisotropic conditions	Must collect accurate water levels in the slugged well and observation wells Displacement must be large enough to see response at observation well(s) Must conduct multiple rising and falling head tests to validate data integrity
Pumping and Recovery Tests	Transmissivity Storativity Hydraulic conductivity	Identify dual permeability Identify aquifer boundaries	Must collect accurate flow rates and water levels in pumping and observation wells Long testing times Considerable generation of IDW
Constant Head Step Tests	Transmissivity	Ensures results are free from errors due to non-Darcian flow	Must collect accurate flow rates and water levels Considerable generation of IDW
Tracer Testing	Darcy flux Groundwater velocity Groundwater flow direction	Relatively easy	Long screens may be susceptible to vertical flow in well causing erroneous values 100% mass recovery difficult Needs large well network in place

Referenced from ITRC Site Characterization and Tools Selection

Appendix E. Groundwater drilling and sampling methods and equipment

Groundwater sampling strategies depend on many factors; this appendix provides a quick reference for various common sampling strategies based on factors including access restrictions, depth to groundwater, aquifer characteristics, site-specific geology, COPCs, sample depth requirements, and sample quality/quantity requirements.

E-1. Sampling from borings

E-1-1. Direct-push

Direct-push sampling uses hydraulically- and hammer-operated rams to push a screened sampling tube into the subsurface to a water bearing zone. A groundwater sample is then withdrawn either manually or using a small sampling pump. Direct-push sampling is generally limited to aquifers occurring in unconsolidated deposits and has a maximum practical depth of about 50 feet. It is typically used to characterize the extent of groundwater contamination and choose locations and screen intervals for permanent wells, rather than for long-term monitoring. Direct-push sampling is useful in determining the vertical extent of contamination as numerous discrete samples can be collected at different depths. The discrete nature of the samples is due to the short length (1 or 2 feet), which is screened in the sampling probe. These discrete samples are useful for determining preferential contaminant migration pathways. Care must be taken that clean materials at depth are not contaminated by shallower contamination through smearing when samples are taken at more than one depth or from beneath contaminated soils or portions of an aquifer. This condition is usually avoided using dual tube sampling tools. These technologies may be appropriate, particularly for plume delineation, if applied correctly with prudent QA/QC. When the highest level of data quality is necessary, permanent wells may be a better choice than direct-push sampling points. Push-points must be abandoned per MDH well code and points left in place for more than 48 hours must be permitted as monitoring wells.

Generally speaking, there are three tools available for sampling groundwater using direct-push tools:

Riser and screen: Riser and screen are placed inside probe hole, then the probe is pulled back and sample is collected through the screen. The riser and screen (generally polyvinyl chloride [PVC]) may be left in place for up to 72 hours and used as a temporary well. It must be decontaminated before reuse or disposed of after one use. Samples may be taken using:

- Peristaltic pump (discussed in further detail below).
- A length of tubing may be used in combination with a vacuum pump to withdraw the sample. The vacuum pump may be inappropriate for VOC sampling as it may cause volatilization of the sample.

Expendable point sampler: Samples are taken through an expendable point with a screen or slots - the point is lost after one use. The tools are generally too small in diameter to allow the use of a bailer for sampling this method. Sampling methods which may be acceptable include a peristaltic pump or tubing methods.

Screenpoint sampler: Some push-probe rigs utilize an inner and an outer rod; the inner rod is screened, then the outer rod is pulled back to expose the screen on the inner rod, through which the sample is withdrawn. Sampling methods which may be acceptable for these types of tools include the following:

- Small-diameter bailer inserted inside inner rod
- Peristaltic pump
- Tubing methods

E-1-2. Hollow stem auger

Hollow stem augers are larger in diameter than direct-push and are most commonly used for collecting groundwater samples or well installation in unconsolidated materials. The hollow stem auger rotates as it drills into the ground and is designed to push soil up and outside of the borehole. A plug is typically placed through the auger to prevent soil from entering the hollow portion of the stem, and samples can be retrieved by retracting the plug and advancing split spoon or soil core samplers ahead of the augers. Casings and screens can then be placed into the hollow stem to prevent collapsing and to collect discrete samples or setting a monitoring well into place. Hollow stem augers can also be sampled using PVC temporary well installation, peristaltic pump, tubing methods, or other grab/discrete sampling methods discussed in further detail below.

E-1-3. Rotosonic

Rotosonic drilling is a method for continuous sampling and provides a large volume of core in a wide variety of drilling conditions and geologic formations in a manner that minimizes the risk of compromising the integrity of capillary barriers. Rotosonic drilling, also known as vibratory or simply sonic drilling, uses an oscillating drill head or core barrel to quickly advance through the subsurface. Drill cuttings are limited to essentially the diameter of core barrel. A benefit of rotosonic drilling method is the ability to advance borings using dual core barrels. Dual core barrels can serve to maintain the integrity of the borehole; the outer barrel will keep the hole open as the inner barrel is advanced ahead for sample collection. Dual barrels can also be used to isolate water-bearing units and allow for collection of groundwater samples from discrete intervals and minimize the potential for cross-contamination. Rotosonic drilling allows for drilling through bedrock, if necessary, and the collection of large-diameter continuous cores. Sonic borings can also be sampled using the methods described below.

Disadvantages of rotosonic drilling include the need for the addition of drilling fluids in some environments, large heavy support vehicles, and relative cost compared to other drilling methods. Contractor selection can also be a limitation of rotosonic drilling as many drilling contractors do not own or operate rotosonic rigs due to the initial purchase and ongoing maintenance costs of the equipment.

E-1-4. Air and mud rotary

Air and mud rotary drilling methods have limited value during the investigation phase (extent and magnitude assessment) of a groundwater investigation due to their poor sample quality. Air and mud rotary drilling methods are typically used where geology is already well known and understood, and the goal is installation of wells only. Both methods work well in very consolidated or bedrock drilling environments; air rotary works well for deep boreholes in a wide range of geologic formations, and mud rotary works well in poorly consolidated or fractured bedrock environments where the mud helps maintain the integrity of the borehole.

Disadvantages of air and mud rotary methods, aside from the poor environmental sample quality, is the difficulty and cost of managing drilling fluids and cuttings that are often contained within a slurry. Air and mud rotary drilling methods also have the disadvantage of requiring several large heavy support vehicles including the drill rig itself, water truck, roll-off containers to contain IDW, and drill pipe support vehicle.

The following table summarizes the advantages and disadvantages of the various drilling methods.

Drilling methods

Drilling methods	Advantages	Disadvantages
Direct Push	Continuous soil recovery Ideal for temporary wells Best mobility and accessibility, especially small spaces and inside buildings Minimal soil IDW generated Minimal ground surface disturbance No drilling fluids or additives required – low environmental impact Availability – most environmental drilling contractors have direct push rigs Low cost Rapid deployment and drilling for shallow investigations Can facilitate several soil coring and borehole development methods Can be used in combination with a host of downhole geo-chemical and physical sensing technologies applied in real time while direct push drilling Compatible with various high resolution site characterization techniques	Total depth limitations Limited to unconsolidated formations May not penetrate hard clay along with coarse sand and gravel layers Boring diameter range Limited effectiveness in hard or rocky formations Limited permanent monitoring well installation capability Sand heaving can be problematic in deep holes. Consult direct push manufacturers technical manual for methods to minimize sand heaving problems.
Hollow Stem Auger	Continuous soil recovery (when used in conjunction with split spoons) Minimizes cross-contamination between intervals Effective for monitoring well installation Drilling fluids or additives may not be required for shallower boreholes – low environmental impact Moderate cost Fast drilling Can facilitate split spoon core sampling standard penetration testing	Limited to unconsolidated Can have challenges in hard or rocky formations Equipment size and accessibility Generates significant soil IDW Impact to surrounding ground surface
Sonic Drilling	Undisturbed and continuous soil cores recovered Can drill through consolidated/bedrock materials Recovery of large diameter cores for higher volume sampling Fast drilling Minimal drilling fluids Casing advancement minimizes slough and increases sample integrity “Mini-Sonic” track mounted rig option for increased mobility and accessibility at remote sites Compatible with various high resolution site characterization techniques	Site access and mobility of standard sized sonic rig Cost Limited casing installation capacity

Drilling methods

Drilling methods	Advantages	Disadvantages
Mud Rotary*	Total depth capacity (capable of deeper drilling than hollow stem auger and direct push) Borehole diameter range Effective method in loose unconsolidated or bedrock formations May be more effective for drilling through deep loose and wet soil Suitable for most soil and rock types and geological conditions Sample Recovery Controls borehole walls and formation pressures Can facilitate core sampling and penetration testing	Environmental impact – requires drilling fluids and additives Cost IDW generation – disposal of drilling mud and cuttings Equipment size and accessibility Ground surface disturbance May be more risk of cross contaminating sampling zones
Air Rotary*	No drilling fluids required – low environmental impact Minimal soil/rock IDW produced Rapid drilling rates Works in variety of soil and rock types, works well in hard rock conditions Can facilitate core sampling and penetration testing	Increase potential for dust issues Equipment size and accessibility May not be suitable for landfill drilling
Reverse Circulation Drilling*	Soil and rock formation versatility Fast drilling Allows casing installation while drilling Total depth capacity	Environmental impact – typically uses drilling fluids Equipment size and accessibility

**Some drilling methods do not generate intact cores. If one of these methods is selected, additional details from the driller will need to be included in the boring logs, noting zones of chattering, smooth and easy drilling, and the amount of fluid loss as these are indicative of fracture zones and water content.*

In selecting a drilling method for an SI, it is essential to assess the following key factors:

Key factors in selection of drilling method

Key evaluation factors	Considerations
Geologic Conditions	Evaluate the geological characteristics of the site, such as soil types, rock formations, and stratigraphy. Different drilling methods are more effective in specific geological conditions.
Well construction	Drilling method must accommodate specific well construction requirements like well depth and well diameter.
Permanent vs. temporary wells	Permanent wells may be needed when multiple sample rounds are required, or accurate water levels or aquifer testing is needed to assess aquifer characteristics.
Depth of Investigations	Consider the depth to which subsurface investigation is required. Some drilling methods are more suitable for shallow depths, while others are designed for deeper penetration.
Soil Sample Quality	Assess the need for undisturbed samples or continuous core samples. Certain drilling methods are better at preserving sample integrity than others.
Site Accessibility	Evaluate the accessibility of the site. Restricted or challenging terrains may influence the choice of drilling method, with considerations for equipment size, mobility, and setup.
Environmental Impact	Consider the environmental impact of drilling activities. Some methods may be more environmentally friendly than others, minimizing disturbance to the surrounding environment and reducing the risk of contamination.
IDW Management	Some methods produce large amounts of soil/mud/water IDW which can be difficult to manage depending on site access, weather, and nearby disposal options.

Key factors in selection of drilling method

Key evaluation factors	Considerations
Budget and Time Constraints	Assess project budget constraints and time requirements. Different drilling methods have varying costs and rates of progress, and these factors may influence the selection of the most appropriate method.
Site Objectives	Clearly define the goals of the subsurface investigation. Whether the focus is on geological characterization or groundwater sampling, the drilling method should align with the project's informational objectives.
Regulatory Requirements	Consider local regulations and permitting requirements that may affect the choice of drilling method. Some methods may be subject to specific restrictions or approvals.
Previous Site History	Review any historical data or information about the site, as it can provide insights into the subsurface conditions and influence the choice of drilling method.

E-2. Sampling from monitoring wells

Various methods and devices can be utilized when sampling from monitoring wells and will vary based on site-specific factors including geologic conditions, quality objectives, site objectives, and regulatory requirements.

When sampling from monitoring wells, it is recommended that water quality indicator parameters be used to determine purging needs. Stabilization parameters that should be considered are pH, dissolved oxygen, specific conductance, redox, temperature, and turbidity. It is important to establish specific well stabilization criteria and then consistently follow the same methods thereafter, particularly with respect to drawdown, flow rate, and sampling device.

The following are recommendations to be considered before, during, and after sampling:

- Use low-flow rates (<0.5 liters per minute) during both purging and sampling to maintain minimal drawdown in the well.
- Maximize tubing wall thickness, minimize tubing length.
- Place the sampling device intake at the desired sampling point.
- Minimize disturbances of the stagnant water column above the screened interval during water level measurement and sampling device insertion.
- Make proper adjustments to stabilize the flow rate as soon as possible.
- Monitor water quality indicators during purging.
- Collect unfiltered samples when the intent is to estimate contaminant loading and transport potential in the subsurface system.

E-2-1. Low-flow

Low-flow refers to the velocity water enters a pump intake and is imparted to the pore water in the vicinity of the well screen. Low-flow does not necessarily refer to the flow rate at the surface, as flow rate can be affected by flow regulators or restrictions. The objective of low-flow is to minimize drawdown of the water level. This is typically accomplished by using flow rates on the order of 0.1 to 0.5 liters per minute; however, these numbers may vary based on site-specific hydrology. The low purge rate will reduce the possibility of stripping VOCs from the water and will reduce the chances of increasing the turbidity in the sample. A variety of sampling devices are available for low-flow (minimal drawdown) purging and sampling, including peristaltic and bladder pumps.

E-2-2. Peristaltic pump

A peristaltic pump can be used for low-flow sampling if the depth to water is < 29 feet deep. Peristaltic pumps are portable and relatively inexpensive for sample collection. The primary issue with the peristaltic pump is the vacuum generated may cause problems for VOC samples as it may cause volatilization of the sample. The volatilization can be minimized by using the pump to draw the sample up into the tubing, without running the water through the pump. Then the pump can be reversed to dispense the sample into the vials after carefully removing the tubing (full of water) from the well.

E-2-3. Bladder pumps

Bladder pumps use a source of compressed gas to compress and release a bladder by check valves within the pump body. Bladder pumps are a low-flow sampling method and are not capable of high flow rates. Bladder pumps can be used when water exceeds 25 feet below ground surface (bgs). Bladder pumps have the least danger of VOC loss, as the sample train is under positive pressure throughout the duration of sample collection.

E-2-4. Submersible pump (high-flow)

Submersible pumps use a rotating motor impeller to obtain a groundwater sample. As the voltage is increased at the pump's controller at surface, the pump's motor turns faster and increases the flow rate. A submersible pump is able to reach greater depths than a peristaltic pump and allows for high purging and sampling rates. High-flow sampling is not recommended when VOCs are the COPC, as volatilization can occur from the impeller action of the pump and agitation associated with high flow rates. Benefits to submersible pumps include portability and higher rate of well sampling.

E-2-5. Passive samplers

Passive samplers acquire a sample from a discrete position within a well and collect formation-quality water samples in ambient equilibrium with formation water with little or no well-water agitation. The samplers can be deployed at any location within the screened interval to evaluate the highest or lowest contaminant concentration in a stratified flow screened interval. It is possible to deploy multiple passive samplers in a well at varying depths to provide a contaminant concentration vertical profile of the screened interval of a well.

Grab samplers are typically installed within the well screen at a prescribed depth. The sampler is opened mechanically, allowing groundwater to enter the sampler from that specific depth interval. The sampler is then retrieved from the well and the sampler contents are transferred to a sample container for submission for analysis. Grab samplers can be deployed in a well days or weeks prior to sampling. Common grab samplers include the Snap Sampler™ and the Hydrasleeve™ sampler.

Equilibrium or diffusion samplers consist of a porous membrane that allows groundwater to passively flow into and through the sampler; contaminants diffuse into the sampler and reach equilibrium with the aquifer or formation water. The samplers are deployed in a well for up to several weeks depending on the contaminant being measured and the sampler type. Passive diffusion bag samplers are the most common type of equilibrium sampler.

Sorptive samplers are hung within a well screen interval and made of a porous media to which aquifer contaminants sorb over time. After deployment in the well, the samplers are retrieved and submitted intact to the laboratory for analysis of COPCs. Sorptive samplers require careful recording of the deployment and retrieval date and time to calculate the contaminant concentration based on the accumulated mass on the sampler. The resulting contaminant concentration is a time-weighted average concentration over the period of exposure.

Careful consideration should be used when assessing if passive sampling technology is appropriate for a site. An ITRC has comprehensive guidance for the use of passive sampling techniques at the link below: https://psu-1.itrcweb.org/

E-2-6. Bailers

Bailers are portable grab samplers that are typically an inexpensive way to collect groundwater samples. Bailers do not require a power source so therefore are highly portable. Using bailers as a groundwater sampling method is discouraged due to the potential for aeration of the sample, and using bailers for purging permanent wells is usually only acceptable when all other sampling techniques and equipment have failed. However, bailers may be used during special circumstances with MPCA approval. Special circumstances include, but are not limited to, the following:

- Equipment/pump breakdown during sampling
- A petroleum sheen is observed on water (LNAPL)
- Slow recovery well

Refer to the *Groundwater Sample Collection and Analysis Procedures* (c-prp4-05) document for further discussion on the use of bailers.

E-3. Packer isolation sampling method

In complex hydrogeologic environments that are suspected of having multiple vertical zones of differing aquifer flow regimes, permeabilities, and contaminant zones, pneumatic packers can be used to isolate discrete zones in a well or borehole to prevent vertical mixing of groundwater. This technique allows for collection of groundwater samples from discrete zones at specific depths. Future subsurface investigations or remediation efforts can then be focused on the isolated zone(s) only.

Often, sampling designs utilizing packers are developed following collection of high-resolution site characterization data or downhole geophysical data that identifies the target zones based on aquifer characteristics such as:

- Hydraulic conductivity
- Permeability
- Caliper measurements
- Suspected presence of NAPL
- Electrical resistivity and conductivity

At the desired depths, packers are inflated to seal off the discrete zone. This can be done using a single packer, to monitor the zone above or below it, or using straddle packers to create an isolated section between two packers. Using packers can be helpful for isolating discrete zones for the following:

- Groundwater sampling and monitoring
- Hydraulic conductivity testing
- Slug and pump tests
- Reducing well development time
- Minimizing purge volumes

E-4. Push-ahead sampling method

The "push-ahead" sampling method, typically used with either direct push or rotosonic drilling techniques, involves advancing (pushing) a screen point discrete sampler ahead of the drill stem, either core sampler for direct push, or the core barrel for rotosonic. The sampler is advanced ahead of the drill tooling, so the groundwater sample is collected from undisturbed formation. The screen point sampler is typically a small-diameter stainless-steel barrel, 18 to 24 inches in length, that contains a stainless-steel screen. When the desired sampling depth interval is reached, the stainless sampler core barrel is pulled back, exposing the screen to the formation. A groundwater sample is subsequently collected using a small-diameter bailer or flexible tubing fitted with a check ball valve. This type of sampling can save time because continuous soil core sampling is not required to sample groundwater at a specific depth interval. This sampling technique minimizes the potential for cross-contamination when collecting discrete samples. Turbidity in groundwater samples can be a problem for this sampling technique as it can be difficult to purge an adequate water volume from the screen point sampler to remove sediment and suspended solids.

E-5. Sampling from residential wells

Residential wells require special consideration during an investigation, since different procedures must often be used to access, purge, stabilize, and sample the well. Information about the well depth and construction may be unknown or severely limited. Ideally, a residential well sample should be collected at the tap nearest the actual wellhead and should be taken before the water has passed through any pressurized holding tank, water softener, or filtration system. If these systems are in place, see if they can be bypassed or turned off for 72 hours prior to sampling. If they cannot, do not collect the sample from this residence.

It is advisable to take the time to select the location that will permit the collection of the least-disturbed water sample. If possible, before sampling, the residential well should be purged until the pH, temperature, specific conductivity, and other parameters have stabilized, before a sample is collected. However, this is rarely possible, given the plumbing and other limitations that exist in most residences. The table below details sampling methods.

Residential well sampling methods

Condition	Purge	Stabilize	Sample	Notes
Well depth and diameter known; no pressure tank or softener ahead of tap; drain available for purge water	Until pH, temperature, and conductance are stable	Utilize flow-through cell and probes with multi-parameter meter	"Trickle" flow with minimum aeration of water; remove aerator if present in tap	If well cannot be stabilized, purge three volumes before sampling
Well depth unknown; may be pressure tank ahead of tap; drain available for purge water	Until pH, temperature, and conductance are stable	Utilize flow-through cell and probes with multi-parameter meter	"Trickle" flow with minimum aeration of water; remove aerator if present in tap	If pressure tank in-line, note on sampling forms; if well cannot be stabilized, purge at least one volume of pressure (holding) tank

Residential well sampling methods

Condition	Purge	Stabilize	Sample	Notes
Well depth unknown; pressure tank or softener ahead of tap; no drain available for purge water; no significant volume recently purged (e.g., laundry done)	Ten minutes at full discharge rate, or until temperature stable; use bucket to collect purge water	Use thermometer to assess water temperature	"Trickle" flow with minimum aeration of water; remove aerator if present in tap	If pressure tank or softener in-line, note on sampling forms; if temperature cannot be stabilized, purge at least one volume of pressure (holding) tank
Well depth unknown; pressure tank or softener ahead of tap; no drain available for purge water; significant volume recently purged (e.g., laundry done)	One minute at full discharge rate, or until temperature stable; use bucket to collect purge water	Use thermometer to assess water temperature	"Trickle" flow with minimum aeration of water; remove aerator if present in tap	If pressure tank or softener in-line, note on sampling forms

E-5-1. Sampling from public supply wells

The goal of water supply well sampling is to collect a representative sample of the groundwater supplying a well. To ensure a representative sample, carefully evaluate the water supply system, including the well, water line, water treatment units, such as water softeners or filters, and other appurtenances, such as water heaters or pressure tanks. Identify a sampling location and determine how much water to purge prior to sampling. Sample collection procedures must minimize sample disturbance and potential cross-contamination. Follow the protocols listed below when sampling a water supply well and document site-specific procedures on the sampling form. Detailed sampling instructions are found in *Groundwater Sample Collection and Analysis Procedures* (c-prp4-05).

In Minnesota, samples from noncommunity public water supply systems are most often collected either by MDH or the local health department. Occasionally, a facility will be required to collect its own bacteria or nitrates samples. In these cases, MDH will supply the facility with the necessary sample bottles and precise guidelines for taking the samples to ensure that they provide an accurate picture of drinking water quality.

Facilities such as schools, offices, factories, and childcare are typically tested for one or more of the following contaminants:

- Arsenic
- Bacteria (total coliform)
- Copper
- Lead
- Nitrate
- Nitrite
- VOCs
- Soluble organic chemicals
- Inorganic chemicals

When analyzing water samples for lead as a means of assessing the impact from lead pipes, worst-case scenario water or "first draw" samples are advisable. "First draw" samples are collected early in the morning to capture water that has been in the pipes overnight. Do not purge the water from the system prior to collecting first draw samples for lead analysis.

E-6. Summary of groundwater sampling methods

Groundwater sampling is a crucial aspect of environmental investigations, providing valuable insights into the quality and characteristics of impacted aquifers. Selecting the appropriate groundwater sampling method is important to ensure project DQOs are met. The tables below provide a summary of the various groundwater sampling methods used in environmental investigations:

Groundwater sampling methods

Groundwater sampling methods	Important features	Types of equipment
Grab sampling	Collected during a specific point in time and location and depth with minimal to no groundwater purging.	Tubing and check valve, bailers, peristaltic pumps
Purge and stabilize	The process involves removing a determined volume of water (minimum of three well volumes) from the well before sampling to ensure the water is representative of the in situ groundwater conditions.	Peristaltic pump, various submersible pumps
Purge and recovery	The process involves removing water from wells in aquifer conditions with very low hydraulic conductivity where it’s not possible to purge the well at a reasonable rate without drawdown or complete dewatering. Typically, in this scenario, the well is purged until dry and then allowed to recover to a point where sample collection is possible.	Peristaltic pump, various submersible pumps
Low-flow sampling	Low-flow groundwater sampling is the preferred method used to collect representative groundwater samples from monitoring wells at flow rates that are minimized (ideally less than 0.2 to 0.3 liters/minute) to reduce disturbance to the natural conditions of the aquifer. This technique is employed to obtain water samples that closely reflect the in situ conditions of the groundwater. The wells should be purged at or below their recovery rate so that migration of water in the formation above the well screen does not occur. The low purge rate will reduce the possibility of stripping VOC from the water and will reduce the chances of increasing the turbidity in the sample.	Bladder pump, peristaltic (if static water <25 feet bgs), electric centrifugal pumps
Passive sampling	A method of collecting groundwater samples from an aquifer without pumping or groundwater extraction. Utilizes passive devices to collect samples over a period through diffusion or sorption, capturing an average concentration of contaminants over the investigation period.	Various types of passive sampling devices designed for specific COPCs and site conditions

In selecting a groundwater sampling method and equipment type, it is essential to assess the following key evaluation factors:

Groundwater sampling evaluation factors

Key evaluation factors	Considerations
Site hydrogeology	Understanding the hydrogeological conditions, including the types of aquifer, permeability, and groundwater flow, is crucial for selecting a sampling method that aligns with the site’s characteristics.

Groundwater sampling evaluation factors

Key evaluation factors	Considerations
Static water level	Identifying depth to groundwater and static water levels at a site helps determine whether a groundwater sampling device or method is suitable for the targeted sampling intervals. Groundwater sampling devices are designed for specific depths and aquifer elevation head pressures (e.g., peristaltic pump only works if the static water level is <25 feet bgs).
Target depths	Several pumps have depth capacity thresholds. It is important to select a groundwater sampling method and device that has capacity to sustain continuous flow rates at targeted depths.
Sample parameters	The project COPCs will influence the sampling protocol. For example, collection of samples for dissolved metals analysis may require the inclusion of field filtering.
Formation properties	Expected water level recovery rates will affect the choice of equipment and sampling methods. For instance, bailers may be acceptable in wells with extremely slow recovery rates.
Borehole diameter	The diameter of the borehole affects the selection of sampling tools and equipment.
Sample Integrity	Consider the need for undisturbed samples. Preservation of sample integrity is key to obtaining accurate data. Choose equipment that minimizes contamination risks for select analytical parameters and allows for proper sample handling. For instance, low-flow or passive sampling methods are ideal for volatile or sensitive analytes.
Temporal variability	Assess the temporal variability with the sampling methods and equipment. Evaluate how the sampling methods and equipment fare in unfavorable cold, heat, or precipitation weather events.
Accessibility	Consider the accessibility of the site and wells. Choose equipment that is suitable for the site’s physical constraints and allows for easy setup, deployment, and retrieval.
Decontamination	Evaluate whether decontamination procedures or using dedicated or disposable equipment is best suited for the project DQOs and budget.
Regulatory requirements	Federal or state regulatory agencies might have preferred sampling methods for site COPCs and conditions.
Costs	Evaluating the budget constraints and cost-effectiveness of each sampling method and equipment type.

E-7. Example quality assurance/quality control requirements

Example quality assurance/quality control requirements

	QC sample type	Frequency of sample/analyses	Details
Field samples	Duplicate Sample	1 duplicate per 10 samples per matrix, or 1 duplicate per sample matrix if fewer than 10 samples	Duplicate sample to be collected by the same methods at the same time as the original sample. Used to verify sample and analytical reproducibility.
	Equipment Blanks**	1 equipment blank per 20 samples, minimum, or 1 equipment blank per day as applicable	Used to assess quality of data from field sampling and decontamination procedures. The number and type of samples are method- and matrix-specific. ** If all disposable equipment/single-use sampling equipment is being used, then field blanks may be collected at a rate of 1 bottle lot or per site, whichever is more frequent.
	Field Blanks**	1 field blank per bottle lot used, or 1 per site, whichever is more frequent	
	Trip Blanks	1 trip blank per cooler containing samples for VOC analysis for water samples	Laboratory-prepared organic-free blank to assess potential contamination during sample container shipment and storage, for VOCs in waters only.
		1 trip blank per field sampling event, or per lot of bottles, whichever is more frequent	One set of laboratory-prepared preserved vials will be included to assess potential contamination during sample container shipment and storage.

Appendix F. Common field screening methods for soil

F-1. Photoionization detector

A PID is commonly used to detect organic vapors in soil samples collected from borings, test pits, remedial excavations, and stockpiles.

How it works: A PID uses ultraviolet light to ionize VOC molecules, which releases electrons. This creates a small electrical current that is measured by the PID. The more organic vapors in the air entering the PID, the more ionized molecules and electrons will be generated and the higher the PID reading. The two most common lamps used in a PID are 10.6 electron volts (eV) and 11.7 eV. The 11.7 eV lamp measures the broadest range of compounds, since it generates higher energy photons, while the 10.6 eV lamp is more limited in range. The 11.7 eV lamp is typically more expensive, tends to require more frequent calibration, and has a much shorter lifespan than the 10.6 eV lamp. In general, if the VOCs of interest have ionization energy below 10.6 eV and therefore are detectable with a 10.6 eV lamp, a 10.6 eV lamp is typically used.

Limitations:

- The response of the PID depends on the ionization energy of the lamp and the ionization potentials of the molecule and calibration gas. The ionization potential of a molecule is a measure of the energy needed to ionize the molecule. To understand whether a PID with a 10.6 eV lamp will be effective for a particular VOC, compare the ionization potential of the VOC to the ionization energy of the lamp. The ionization potential of a VOC can be found in many standard references, such as the National Institute for Occupational Safety and Health (NIOSH) Pocket Guide to Chemical Hazards. For example, the ionization potential for 1,2,4- trimethylbenzene, a common petroleum-related VOC, is 8.27 eV, and the ionization potential for carbon tetrachloride is 11.47 eV. A PID with a 10.6 eV lamp would detect organic vapors from the former but not from the latter. Note that the closer the ionization potential for a compound is to the lamp (without exceeding the lamp value), the better response the PID will have to that compound.
- A PID does not measure methane. If field screening for methane is necessary, a flame ionization detector (FID) should be used, as described below.
- Chlorinated ethenes such as PCE and TCE tend to absorb much of the ultraviolet light produced during the excitation process. This quenching affect results in poor detection of chlorinated ethenes. Because of the quenching affect and other common interference issues, a PID is not a reliable field screening tool for chlorinated ethenes. If chlorinated VOCs are a contaminant of concern at a site, soil samples for laboratory analysis of VOCs must be collected from potential source areas. Screening the soil samples with a PID, even when no significant organic vapors are detected, does not negate the need for analytical samples.
- A PID reading can be affected by several factors, such as instrument calibration, the ambient air temperature, humidity, and sample handling procedures.
- Cold temperatures will reduce contaminant volatility and lead to a lower PID response.
- The effect of humidity can vary based on instrument design and circumstances. Water vapor in the bag headspace can absorb UV light and lead to a lower PID response (i.e., false negative). On the other hand, fogging of the lamp in humid conditions can cause a higher PID response (i.e., false positives).

Field procedure:

Use the polyethylene bag headspace method described below when screening for elevated organic vapors using a PID.

- For a PID, use a 10.6 eV (+/-) or greater lamp source, depending on the VOC contaminants of concern. Perform PID instrument calibration on site and at least daily to yield "total organic vapors" in parts per

- Million by volume of isobutylene equivalent. Refer to the manufacturer's recommendations for calibration frequency during use.
- Immediately after opening the split spoon sampler or soil sample liner, transfer soil to a resealable one-quart polyethylene bag. If collecting a sample from an excavation or stockpile, collect the soil sample from a freshly exposed surface. Half-fill the bag so the volume ratio of soil to air is equal, then immediately seal it. Manually break up the soil clumps within the bag.
- Allow headspace development for at least 10 minutes at approximate room temperature. Vigorously shake bags for 15 seconds at the beginning and end of the headspace development period. Headspace development is faster in warmer temperatures; more time is needed for headspace development in colder temperatures. When temperatures are below the operating range of the instrument, perform headspace development and screening in a heated vehicle or building. Record the ambient temperature during headspace screening. Complete headspace screening within approximately 20 minutes of sample collection.
- After headspace development, introduce the instrument sampling probe through a small opening in the bag to a point about one-half of the headspace depth. Keep the probe free of water droplets and soil particles.
- Record the highest meter response on a sampling form. Maximum response usually occurs within about two seconds. Erratic meter response may occur if high organic vapor concentrations or moisture is present. Note any erratic headspace data on the sampling form.
- Sample handling time prior to bagging the sample should be minimized to avoid volatilization.
- Do not collect analytical soil samples from the polyethylene bag.

F-2. Flame ionization detector

Flame Ionization Detectors (FID) are also used to detect organic vapors, most commonly for certain VOCs and methane.

How it works: A FID operates on the same principle as a PID, by generating electrons that are detected as a current; however, the electrons are generated in a different way. A soil sample is placed in a sealed container, and the FID uses a hydrogen flame to burn the organic vapors emitted from the soil. This combustion produces positively charged ions and electrons, the latter of which are measured by the detector.

Limitations:

- As with a PID, a FID measures the total organic vapors present but does not distinguish between individual substances. A FID detects only organic vapors from compounds containing carbon, with the magnitude of the response dependent on the chemical structure of the organic compound. Hydrocarbons, including saturated hydrocarbons (e.g., methane, hexane, propane, etc.) and aromatic hydrocarbons (e.g., benzene, toluene, xylene, etc.) produce the highest response. A FID is less sensitive to organic compounds that contain nitrogen, oxygen, sulfur, or halogen atoms (e.g., fluorine, chlorine, and bromine), such as trichloroethene (TCE) (C_2HCl_3). Materials containing no hydrogen, such as PCE (C_2Cl_4) and carbon tetrachloride (CCl_4), give the lowest response. Thus, a FID is not a useful field screening tool for chlorinated VOCs.
- Because a FID involves combustion, a FID used for screening methane or other potentially explosive gases should be certified as intrinsically safe.

Field Procedure: The field procedure for using a FID is similar to a PID, as described above.

F-3. X-Ray fluorescence

Field screening with an X-ray fluorescence (XRF) meter can be used to determine the metals composition of both in situ and ex situ soils. It is commonly used during soil investigations conducted at gun ranges to screen for elevated lead concentrations but can also be used to detect other heavy metals such as arsenic, mercury, chromium, cadmium, copper, and nickel.

How it works: The soil sample is bombarded with x-rays, causing the emission of secondary fluorescent x-rays from the sample, based on the contaminants present. Each of the elements present in a sample produces a set of characteristic fluorescent X-rays ("a fingerprint") that is unique for that specific element. Use of an XRF does not eliminate the need for traditional laboratory analyses.

Limitations:

- Preparation of quality control sample(s) is required.
- Low battery, foreign material on the XRF reading window, and slight movements while the XRF operator is analyzing the sample may cause variability in results. Regular quality control checks with the XRF are needed.
- There may be difficulty obtaining sufficiently low detection limits because of matrix interference.
- A moisture level greater than 10% may create a low bias in the XRF results.
- It may be necessary to collect enough duplicate samples for laboratory analysis to allow a statistical comparison of XRF verses lab results.

Field procedure: The information below is largely from an XRF Field Operations Guide prepared by EPA Region 4 Superfund Division. Refer to the link provided for additional important information.

- Before starting, establish a decision point value for the target metal.
- Mix and disaggregate the soil sample in a bowl. Sieving the soil samples to remove large particles increases the reproducibility of the XRF analysis.
- Place the sample in resealable clear one-quart polyethylene bag to achieve a sample thickness of at least ¾ of an inch. Prior to taking a reading, examine the bag to ensure the fines and coarse particles are well mixed. If segregation has occurred, remix the bag by rotating the bag vertically so that the particles tumble together.
- Statistically valid data can be collected by increasing the number of XRF readings on a bagged soil sample and calculating an upper confidence limit (UCL) and/or lower confidence limit (LCL) on the sample. Take a minimum of four XRF readings of each bagged soil sample through the plastic bag by taking an XRF reading from the left and then one from the right side of the bag, then flip the bag over and repeat, one reading from the left and then one from the right side of the bag.
- If after four XRF readings, the relative standard deviation (RSD) is less than 35%, no additional XRF readings are needed. The 95% UCL value should be compared to the decision point.
- If after four XRF readings, the RSD is greater than 35%, continue flipping the bag and collecting readings until the % RSD is below 35% or 10 readings are taken.
- If individual results are both above and below the decision point and the RSD is >35% after 10 readings, sieve the sample to remove particles greater than coarse sand size (~#10 sieve). Having fewer large particles will reduce analytical interference and scattering sometimes caused by larger particles. It may
- Be necessary to collect additional samples and/or perform laboratory analysis of subsamples from that bag.
- A duplicate XRF reading should be collected at least every 20 soil samples. Duplicate XRF readings are performed by collecting multiple readings in the same location on the soil sample bag without moving the placement of the bag or XRF analyzer.

- One duplicate soil sample for laboratory analysis should be collected for at least every ten XRF sampling points, to confirm that the XRF results are within an acceptable range. The soil samples collected for laboratory analysis must be selected from the lower, middle, and upper range of concentrations encountered at the site. To ensure the duplicate soil sample will be representative, soil within the bag should be thoroughly mixed prior to collecting the sample.

Radiation emitted from a portable or handheld XRF analyzer is similar to the exposure received in a normal medical or dental X-ray. Field sampling personnel must follow the XRF analyzer's manufacturer's operating and safety instructions. Never aim the device at yourself or others when the primary beam (x-ray on) lights are illuminated. Never hold samples during the analysis.