DEPARTMENT OF ECOLOGY
State of Washington

Guidance for Monitoring at Landfills and Other Facilities Regulated Under Chapters 173-304, 173-306, 173-350, and 173-351 WAC

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Guidance for Monitoring at Landfills and Other Facilities Regulated Under Chapters 173-304, 173-306, 173-350, and 173-351 WAC

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1 Introduction

This document provides guidance for monitoring landfills and other facilities regulated under Chapters 173-304, 173-306, 173-350, and 173-351 of the Washington Administrative Code (WAC). Topics covered include operation of groundwater-monitoring systems, methods of data analyses and reporting, and other subjects. "Landfill" refers to any facility covered under these regulations that is required to have a monitoring program. This guidance does not address solid wastes regulated under Washington State's Dangerous Waste Regulations, Chapter 173-303 WAC.

The science of groundwater monitoring has advanced since the Washington State Department of Ecology (Ecology) released the 1990 guidance titled, *Ground Water Monitoring Guidance for Solid Waste Facilities*. Professional licensing, laboratory procedures, statistical analyses, and the understanding of contaminant fate and transport have improved with continuing research and technology. This document does not cover all phases of groundwater monitoring at regulated landfills. Rather, it discusses requirements associated with the four regulations and Ecology's recommendations on specific topics of concern. This 2018 update to the 2012 version of this guidance primarily includes the changes in the 2018 update of Chapter 173-350 WAC.

The state adopted Chapter 18.220 Revised Code of Washington (RCW), which regulates the practice of geology and the specialty of hydrogeology, in 2002. This statute requires individuals to hold a professional license to practice geology or hydrogeology and affects individuals who prepare hydrogeologic or monitoring reports for landfills. The Geologist Licensing Board at the Washington State Department of Licensing governs this law. The Washington Department of Licensing can answer questions about meeting professional requirements under Chapter 18.220 RCW. Contact them by phone at 360-664-1497, email at https://www.dol.wa.gov/business/geologist/, or by mail at Geologist Licensing Board, Department of Licensing, PO Box 9045, Olympia, WA 98507-9045.

2 History of Solid Waste Regulation in Washington

Before 1969, no state or federal statutes or rules were in place to directly deal with the handling of Washington's solid waste. In 1969, the state legislature passed the first statute specific to solid waste, Chapter 70.95 RCW, *The Solid Waste Management Act*.

State regulations for municipal and non-municipal solid waste landfill construction, operation, and closure began in 1972 with the adoption of Chapter 173-301 WAC, *Regulations Relating to Minimum Functional Standards for Solid Waste Handling*. This rule was performance-based, and it was up to the operator's discretion as to how to meet the requirements. In 1985, Chapter 173-304 WAC, *Minimum Functional Standards for Solid Waste Handling*, was enacted. This rule was more prescriptive, limiting the options for meeting facility requirements. Rule amendments in 1988 included additional closure, post-closure, and financial assurance requirements. Chapter 173-304 WAC also required groundwater monitoring for certain piles and surface impoundments.

In 1990 Chapter 173-306 WAC, *Special Incinerator Ash Management Standards*, set up performance standards, emissions standards, and design requirements for municipal solid waste incinerator and energy recovery facilities. It defines special incinerator ash, bans disposal of this ash in municipal solid waste (MSW) landfills, and includes strict handling requirements.

Both Chapters 173-304 and 173-306 WAC state that the Chapter 248-54 interim maximum contaminant levels (MCLs) for groundwater are to be used until Ecology establishes groundwater quality standards. Ecology adopted Chapter 173-200 WAC, *Water Quality Standards for Groundwaters of the State of Washington* in December 1990. Ecology revised the *Implementation Guidance for the Ground Water Quality Standards* in October 2005 as Publication #96-02.

In 1991, the Environmental Protection Agency (EPA) established federal requirements for the construction, operation, monitoring, closure and post-closure of MSW landfills under the Resource Conservation and Recovery Act (RCRA), subpart D. States had two years to adopt these rules or modify them to be more stringent than the federal requirements in order to receive federal delegation authority. In response to the federal requirements, Ecology adopted Chapter 173-351 WAC, *Criteria for Municipal Solid Waste Landfills* in 1993, and received partial delegation authority from EPA.

Ecology updated Chapter 173-351 WAC in November of 2012. The revisions were made to adopt new federal regulations which allow for issuance of Research, Development, and Demonstration (RD&D) permits; address landfill design and post-closure issues; to address "general housekeeping" issues such as clarifying definitions, making formatting changes, and ensuring the rule is consistent with Chapter 173-350 WAC. Some important changes that affect groundwater-monitoring activities include:

1. Most metals analyses for groundwater sampling must now be for total metals rather than for dissolved metals. This change is consistent with federal regulations and state groundwater standards.

2. The requirement for use of forms for annual and quarterly groundwater reports (WAC 173-351-415) now refers to the checklist available online at:

   https://fortress.wa.gov/ecy/publications/summarypages/ecy070316.html.

3. Submission of groundwater-monitoring data must be consistent with procedures required by the department as described in Section 8 of this document.

4. A licensed professional must prepare the groundwater monitoring and hydrogeological reports according to the requirements of Chapter 18.220 RCW.

Two additional contaminants were added to Appendix III in 2017, and the EPA gave Washington State full delegation on February 27, 2017.

Chapter 173-350 WAC, *Solid Waste Handling Standards*, was enacted in 2003 to address non-municipal solid waste landfills. It requires groundwater monitoring at limited purpose landfills and surface impoundments constructed without leak detection layers including those at biosolids facilities. The regulation provides beneficial use options and applies modern standards to other solid waste facilities. There is no federal equivalent to this regulation.

Chapter 173-350 WAC was updated in August 2018. The two principal changes to groundwater monitoring are as follows:

1. All groundwater-monitoring data must be submitted in an electronic format by April 1 of each year.

2. For metals analyses, since groundwater standards refer to “total metals,” but ion analyses require “dissolved metals,” both types of analyses will be required for some constituents.

3 Groundwater-Monitoring Requirements

The life of a landfill has several stages. Active landfills currently accept waste. Once a landfill ceases to accept waste, the owner or operator must close the landfill as agreed under the approved closure plan. When the owner or operator completes and certifies closure activities, the landfill is considered closed. Following closure, a landfill enters post-closure care.

Owner/operators conduct monitoring and maintenance to evaluate and assure a landfill's proper performance while waste materials continue to degrade. Landfill post-closure care can end after the site has stabilized and the permitting agency authorizes the owner or operator to discontinue post-closure care.

The time period when a landfill operated or closed, the type of waste contained, and landfill construction determines which groundwater-monitoring regulations apply. All four landfill regulations require the owner/operator:

- Design and install a groundwater-monitoring network at appropriate locations and depths that characterizes background groundwater concentrations and capable of detecting groundwater contaminants and is consistent with the applicable regulations.
- Measure groundwater elevations in each monitoring well prior to purging.
- Determine the rate and direction of groundwater flow.
- Follow the current approved sampling and analysis plan (a.k.a. Quality Assurance Project Plan or QAPP).
- Determine groundwater quality at each well at the approved sampling interval while the landfill is active and through the post-closure care period.
- Compare groundwater quality results to Chapter 173-200 WAC, *Water Quality Standards for Ground Waters of the State of Washington*, or the 2005 *Implementation Guidance for the Ground Water Quality Standards* criteria.
- Use approved statistical procedures following each sampling event to determine if there has been a significant change in groundwater quality.
- Notify the jurisdictional health department (JHD) and Ecology if there has been a statistically significant increase (SSI) for any monitoring parameter, and resample the groundwater for that parameter. (The time frame notification is 7 days in Chapters 173- 304 and 173-306 WAC, and 30 days in Chapter 173-350 WAC. Chapter 173-351 WAC provides 30 days after receipt of data to determine an SSI, then 14 days to send notice.)
- Complete remedial actions in consultation with the JHD and Ecology when contamination thresholds have been exceeded.
- Submit annual reports (by March 1 for Chapters 173-304 and 173-306 WAC, and April 1 for Chapters 173-350 and 173-351 WAC).

The four regulations also contain significant differences in monitoring requirements. Chapter 173-306 WAC establishes Ecology as the agency with regulatory authority for landfills for special incinerator ash. The other three regulations provide the local JHDs with regulatory authority. Under Chapter 173-304 WAC, Chapter 173-350 WAC, and Chapter 173-351, Ecology serves as a technical consultant and subject matter expert to the JHD.

Chapter 173-350 WAC requires groundwater monitoring for limited purpose landfills and surface impoundments constructed without leak detection layers, as well as compliance with approved local solid waste regulations that require monitoring at certain solid waste handling facilities. Additionally, Chapter 173-350 WAC surface impoundment standards apply to biosolids facilities with surface impoundments that lack leak detection systems.

3.1 Points of Compliance

The regulations vary in how the point of compliance is addressed. The requirements are as follows:

- Chapters 173-304 and 173-306 WAC establish the point of compliance as that part of groundwater that lies beneath the perimeter of a landfill's active area as it would be at closure.

- Chapter 173-350 WAC indicates the point of compliance be established by the JHD as near to the possible source of release as technically, hydrogeologically, and geographically feasible.

- Chapter 173-351 WAC specifies the point of compliance be located on land owned by the landfill owner and that it be no more than one hundred fifty meters (four hundred ninety-two feet) from the waste management unit boundary. Beyond this, WAC 173-351- 300(6) describes a number of factors that must be considered when determining a point of compliance.

3.2 Required Parameters

The four regulations have different monitoring parameter requirements. The parameters required during groundwater monitoring in Chapters 173-304, 173-306 and 173-350 WAC are as follows:

- Chapter 173-304 WAC requires monitoring of static water level, three field-monitored parameters, and eleven analytical constituents.

- Chapter 173-306 WAC requires monitoring of static water level, three field-monitored parameters, and sixteen analytical constituents including gamma radiation. This regulation also includes ash and soil sampling and analyses requirements, as well as ambient air quality sampling for lead.

- Chapter 173-350 WAC requires monitoring of static water level, and a minimum of three field-monitored parameters, ten groundwater, and three leachate indicator analytical constituents.

Chapter 173-351 WAC is more prescriptive and takes a different approach for groundwater monitoring. This regulation makes a distinction between a Detection Monitoring Program and an Assessment Monitoring Program as follows:

Detection Monitoring is similar to the quarterly monitoring requirements of the other solid waste regulations, except it requires the monitoring of more constituents. Chapter 173-351 WAC lists these constituents in Appendices I and II. Appendix I includes 62 organic and inorganic constituents. Appendix II includes static water levels, three field monitored parameters, ten geochemical analytical constituents, and three leachate indicator analytical constituents.

Assessment Monitoring is triggered whenever there is a statistically significant increase (SSI) above background for any constituent listed in Appendix I or an approved alternative groundwater-monitoring list (see WAC 173-350-440(2)). An Assessment Monitoring Program involves much more comprehensive groundwater monitoring, as described in Section 9 of this guidance document.

3.3 Procedures for Gaining Approval to Alter Groundwater-Monitoring Requirements

Approval to vary from the standard groundwater-monitoring requirements depends on the regulation. WAC 173-304-700, WAC 173-306-900, and WAC 173-350-710 allow owners/operators to apply for variances from those respective regulations. Variances may be granted as long as the proposed practices do not endanger public health, safety or the environment, and compliance with the regulation from which variance is sought would not produce hardship without equal or greater benefits to the public.

The jurisdiction for approval of a variance request or a demonstration depends on the regulation. The JHD and Ecology must approve a variance request under Chapter 173-304 WAC. Under Chapter 173-306 WAC, a variance request must be approved by Ecology. Under Chapter 173-350 WAC, a variance request must be approved by both agencies, while a demonstration need only be made to the JHD.

Chapter 173-350 WAC contains terms allowing owner/operators to request a variance to decrease monitoring parameters or make a demonstration to change monitoring frequency (WAC 173-350-500 (4) (g)). A related form titled *Application for Modification of Solid Waste Handling Permit Chapter 173-350 WA* is available at:

https://fortress.wa.gov/ecy/publications/publications/ecy070401.pdf.

WAC 173-351-450 describes requirements about altering standard groundwater-monitoring elements based on site-specific demonstrations through a permit modification. These demonstrations must show that the changes will protect human health and the environment. Chapter 173-351 WAC discusses the form that an application to modify groundwater-monitoring elements must take in two places. WAC 173-351-720 states,

(6) Permit modifications.

(a) Any owner or operator intending to modify a valid MSWLF permit must file a modification application at least forty-five days before the intended modification. A modification application must be made on forms authorized by the jurisdictional health department and the department, and the forms must include information identified in WAC 173-351-730 (3)(a).

And WAC 173-351-730 states,

(3) Modification and renewal applications.

(a) Modification applications. An application specified by the jurisdictional health department and the department to modify a valid MSWLF permit issued pursuant to WAC 173-351-700 must include, and address, the following:

(i) A description of the proposed modification,

(ii) The reasons for the proposed modification,

(iii) A description of the impacts from the proposed modification upon the MSWLF unit or the facility as presently permitted,

(iv) A showing that, as modified, the MSWLF unit will be capable of compliance with the applicable requirements of this regulation, and

(v) Any other information as required by the jurisdictional health department.

Ecology is specifying through this guidance document that any document that contains the information in items (i) through (v) in WAC 173-351-730(3) will be deemed to meet the “forms” requirement described in WAC 173-351-720.

4 Site Characterization and Groundwater Monitoring

Site characterization is conducted to ensure an adequate groundwater-monitoring system is installed at a landfill. Groundwater monitoring determines landfill impacts on groundwater quality. Many elements go into setting up a groundwater-monitoring program, including an adequate characterization of the site hydrogeologic setting and the installation of a viable monitoring well network. Monitoring programs usually utilize interwell sampling that compares samples from upgradient wells to samples from downgradient wells. Depending on the situation, landfills may opt for an intrawell sampling program that compares samples collected before facility begins operation to samples collected from the same well during facility operation.

Some landfills have both older, closed landfill units permitted under an earlier regulation, and more recent landfill units permitted under a newer regulation. If a landfill has a distinct monitoring network for the old units(s) and a distinct network for the new units(s), then different regulations apply to those units. The landfill is regulated under the newer regulation if it has a single monitoring network that covers both old and new units.

4.1 Similarities and Differences in Requirements in the Four Regulations

Chapters 173-304 and 173-306 WAC provide minimal, but similar, requirements on site characterization and development of a groundwater-monitoring network. These regulations require that the groundwater-monitoring system consist of at least one background or upgradient well and three downgradient wells. The wells are at suitable locations and depths to yield groundwater samples from the uppermost aquifer and all hydraulically connected aquifers below the active portion of the facility. In addition, the groundwater-monitoring system must:

- Represent the quality of background water that has not been affected by a release from the active area; and

- Represent the quality of groundwater passing the point of compliance. The JHD or Ecology may require additional wells in complicated hydrogeological settings or to define the extent of contamination detected.

Chapters 173-350 and 173-351 WAC are more prescriptive about site characterization, development of a groundwater-monitoring network, development of a sampling and analysis plan, groundwater-monitoring data analysis, and notification and reporting. In Chapter 173-350 WAC, the groundwater-monitoring requirements are described in the WAC 173-350-500 section.

The groundwater-monitoring requirements in Chapter 173-351 WAC are described in several sections, including:

- WAC 173-351-405 - Performance standards for groundwater-monitoring system designs.
- WAC 173-351-410 - Groundwater sampling and analysis requirements.
- WAC 173-351-415 - Groundwater reporting.
- WAC 173-351-490 - The hydrogeologic report contents. This section includes a description of the site characterization requirements.

WAC 173-350-330 indicates that monitoring guidance provided in Chapter 173-350 WAC applies not only to landfills, but also groundwater monitoring required for leachate lagoons that lack leak detection systems.

Rather than specifying the monitoring of aquifers, the newer regulations refer to hydrostratigraphic units. The term is defined in both Chapters 173-350 and 173-351 WAC as:

> "Hydrostratigraphic unit" means any water-bearing geologic unit or units hydraulically connected or grouped together on the basis of similar hydraulic conductivity which can be reasonably monitored; several geologic formations or part of a geologic formation may be grouped into a single hydrostratigraphic unit; perched sand lenses may be considered a hydrostratigraphic unit or part of a hydrostratigraphic unit, for example.

Although the language in Chapters 173-350 and 173-351 WAC is not identical, both rules require that a sufficient number of wells be installed at appropriate locations and depths to yield representative groundwater samples from those hydrostratigraphic units which have been identified as the earliest potential contaminant flowpaths. Consider the following questions when designating appropriate hydrostratigraphic units for groundwater-monitoring purposes:

- Is the uppermost water-bearing unit hydraulically connected to underlying aquifers?
- Where are all the potential contaminant pathways?
- Where are the earliest hydraulic pathways to detect a release from the landfill?
- What are the groundwater travel times and direction?
- Will the monitoring well screen intercept the water table or appropriate depth interval where a potential release would be expected to be present?

Later expansion of landfills regulated under either Chapter 173-350 or 173-351 WAC requires additional site characterization and may require added monitoring wells.

4.2 Monitoring Well Network Considerations

Many considerations need to go into monitoring well placement. Wells should be located both upgradient and downgradient of a facility to detect any changes in groundwater quality. Placement must also consider well depth and potential perched groundwater conditions for detection of impacts on all hydrostratigraphic units. Monitoring multiple units is appropriate in some cases, since more than

one unit may be affected by the landfill activities. However, evaluation of groundwater flow direction and comparison of water quality data should occur in upgradient and downgradient wells screened in the same hydrostratigraphic unit.

4.2.1 Number of Monitoring Wells

Monitoring networks should consist of enough wells installed at suitable sites and depths to yield representative groundwater samples from those hydrostratigraphic units identified during site characterization as the earliest potential contaminant flowpath. An understanding of a site's hydrogeology is necessary to meet these requirements.

The different regulations have different requirements for the minimum number of monitoring wells. Those regulations indicate:

> WAC 173-304-490 and WAC 173-306-500 - The groundwater-monitoring system must consist of at least one background or upgradient well and three downgradient wells, installed at appropriate locations and depths to yield groundwater samples from the upper most aquifer and all hydraulically connected aquifers below the active portion of the facility.
>
> WAC 173-350-500 (3)(a)(i) - A sufficient number of monitoring wells shall be installed at appropriate locations and depths to yield representative groundwater samples from those hydrostratigraphic units which have been identified in the site characterization as the earliest potential contaminant flowpaths.
>
> WAC 173-351-405(1) - A sufficient number of wells must be installed at appropriate locations and depths to yield representative groundwater samples from those hydrostratigraphic units which have been identified as the earliest target hydraulic pathways and conduits of flow for groundwater and contaminant movement, and storage.

4.2.2 Upgradient Well Locations

Based on the groundwater flow analyses, upgradient wells must be located beyond any potential impacts from the landfill. Groundwater samples from wells should represent the quality of the water passing beneath the landfill. Because gas transport of volatile organic compounds can impact upgradient wells, these wells should be far enough away from the waste to ensure background conditions. Installation of multiple upgradient wells is recommended (see Section 6.0).

4.2.3 Downgradient Well Locations

Downgradient wells must monitor or intercept all potential contaminant pathways from a facility. Potential contaminant pathways should be evaluated based on the site characterization information, and may include zones of higher hydraulic conductivity, both laterally and vertically in the aquifer, and fracture or fault zones present in the aquifer.

Downgradient well locations must monitor the groundwater quality passing the relevant point(s) of compliance (see Section 3.1 above), for differences in point of compliance requirements). Additional wells may be required based on the extent of the landfill unit, complexity of the hydrogeologic

settings, or to define the extent of contamination at a site. Washington State's Model Toxics Cleanup Act (MTCA) regulations provide different point of compliance requirements than those in the solid waste regulations.

4.2.4 Well Spacing Distance

Appropriate spacing between monitoring wells depends on the hydrogeology of the site. Spacing determinations are based on the judgment of a licensed professional considering all relevant factors. Unlined landfills may release contaminants over a large area, while lined landfills may produce point discharges. Closer well spacing may be required to detect point discharge contaminant plumes.

4.2.5 Monitoring Well Design and Construction

Monitoring well design and construction accounts for specific hydrogeologic conditions faced during drilling. The main objectives are to provide representative groundwater quality samples and water-level measurements. A secondary purpose may be to conduct aquifer pumping tests. Monitoring well construction must not create a conduit for contaminant migration. Some information to consider when constructing monitoring wells includes:

- All wells must be constructed in accordance with Chapter 173-160 WAC, *Minimum Standards for Construction and Maintenance of Water Wells*, and Chapter 173-162 WAC, *Regulation and Licensing of Well Contractors and Operators*.

- Monitoring or screened intervals must be placed vertically within an aquifer such that representative water quality samples and water-level measurements can be obtained.

- Monitoring wells may monitor the water-table aquifer, the base of the aquifer, a confined or semi-confined aquifer, or a specific zone within an aquifer. According to WAC 173-160-450, all wells must be constructed to prevent interconnection of separate aquifers. Therefore, more than one well will be required when screening more than one hydrogeologic unit.

- In horizontally layered sediments or where contamination may occur in a single zone, screen lengths should be designed to monitor across specific hydrostratigraphic units. Shorter screens may be necessary to obtain meaningful chemical results, since longer screens may allow for dilution across several saturated zones. A rule of thumb is that screened intervals not exceed 10 feet.

4.3 Other Groundwater-Monitoring Considerations

Factors to consider when establishing groundwater-monitoring strategies at landfills within Washington .

4.3.1 Interwell versus Intrawell Strategies

As discussed in the statistics section of this document (Section 6.0), either interwell or intrawell strategies may be used during the analyses of groundwater-monitoring data. The choice of one or both of these strategies will depend on spatial variation in aquifer properties or water quality, groundwater

gradient, presence or absence of seasonal fluctuations, and possibly the type of background data available for a site.

4.3.2 Low Flow Sampling

In general, the use of low flow sampling methods will produce more representative groundwater samples than those obtained using bailers or the evacuation of 3 to 5 well volumes of water. Ecology recommends the use of low flow groundwater sampling and the use of dedicated pumps.

Low flow sampling relies on the slow withdrawal (< 1.0 liter/minute) of groundwater from monitoring wells. The typical low flow sampling system consists of a pump (e.g. bladder or electric submersible) with a variable speed controller, an air compressor (for bladder pumps), polyethylene or Teflon tubing and instruments that measure pH, dissolved oxygen, conductivity and static water levels. The low flow sampling technique is designed to minimize the impacts of turbidity volatilization, and mixing while pumping, and allows for the continuous monitoring of field parameters (i.e. pH, dissolved oxygen, conductance and temperature) to determine when sample collection is suitable. The EPA specifies the pump intake should be located within the screen interval and at a depth that will remain under water at all times. The EPA's *Low Stress (low flow) Purging and Sampling Procedure for collecting Groundwater Samples from Monitoring Wells* is at the following website:

https://www.epa.gov/sites/production/files/2017-10/documents/eqasop-gw4.pdf

Purge water generated from wells with historically high levels of contaminants (above the groundwater standards) or any sheen should be deposited into the landfill's leachate lagoon, wastewater treatment plant, or appropriate off-site disposal facility. Purge water from wells that has historically have been clean (below the groundwater standards for the past three (3) sampling events) may be discharged to the surface of the site. Water should not be discharged within five (5) feet of any monitoring wells.

4.3.3 Water Sampling by Qualified Field Personnel

All water samples should be collected by well-qualified and well-trained individuals in accordance with the facility's approved Quality Assurance Project Plan (QAPP) and RCW 18.220.

4.3.4 Water-Level Measurements

The depth to water is measured from a surveyed marked reference point on the casing and should be accurate to 0.01 feet. All water-level measurements should be made within a reasonably narrow timeframe, such as over a single day period.

4.3.5 Groundwater Flow Rate Calculations and Flow Direction

The different solid waste regulations have varying requirements associated with groundwater flow, as indicated in the table below.

Table 4.1. Frequency of groundwater flow rate and flow direction calculations.

Regulation	Frequency
Chapter 173-304 WAC	At least annually.
Chapter 173-306 WAC	At least annually.
Chapter 173-350 WAC	Annual report will summarize for each sampling event.
Chapter 173-351 WAC	Quarterly.

The following modification of Darcy's Law (Freeze and Cherry, 1979) can be used to calculate the horizontal groundwater velocity:

$$V = \frac{Ki}{n}$$

Where:
V = Average linear velocity in cm/sec
K = Hydraulic conductivity in cm/sec
i = Hydraulic gradient in ft/ft
N = Effective porosity (unitless)

Groundwater gradients can be calculated from water-level elevations in the monitoring wells. Hydraulic conductivity values can be determined from aquifer tests, laboratory effective porosity results for borehole samples, or tables in hydrogeology textbooks. Effective porosity results are specific to the boreholes where an aquifer was sampled. Site conditions can vary significantly from those described in a textbook. For these reasons, values determined from aquifer tests are generally the most likely to represent overall site conditions.

Calculated flow rates allow estimations of solute transport times, but actual transport times may be considerably faster or slower. Groundwater flow velocity calculations are for advective flow, but preferred pathways and other transport mechanisms such as dispersion and diffusion also affect the flow rates of contaminants in groundwater.

5 Quality Assurance Project Plan (QAPP)

Washington's solid waste regulations require a sampling and analysis plan (SAP) for groundwater-monitoring programs. Since implementing the solid waste regulations, overall methods for SAPs have become more prescriptive and are now often referred to as Quality Assurance Project Plans (QAPPs). When referring to sampling and analysis plans in this document the term QAPP will be used.

The facility permit application must include the QAPP approved by the permitting agency, the JHD or Ecology, depending on the regulation. The QAPP becomes part of the facility permit.

Requirements for sampling and analysis at landfills are discussed in the following regulations:

WAC 173-304-490(2)(c),
WAC 173-306-500(2)(c),
WAC 173-350-500(4), and
WAC 173-351-410.

Ecology recommends using *Guidelines for Preparing Quality Assurance Project Plans for Environmental Studies*, Ecology, June 2004, to ensure that data collection and use is adequate to determine if there is a release from the landfill. A QAPP ensures the project collects the data necessary to meet the requirements of the activity, provides direction on how to perform activities during the project, and describes data assessment to determine how and if the data can be used. The QAPP process aims to produce continued improvement in data collection and assessment. The development of the QAPP requires an understanding of the concepts related to sampling, field and laboratory measurements and the assessment of data quality.

Each facility's QAPP must describe procedures for generating reliable data for statistical evaluations and prepare quarterly and annual reports. Data quality must be documented to be scientifically and legally defensible.

A QAPP should:

- Identify the goals and objectives of monitoring at the facility.
- Identify the type and quality of data needed (e.g., detection limits at or very near the groundwater quality criteria).
- Identify the sampling and measurement procedures needed to acquire the data.
- Describe the quality control and assessment procedures needed to ensure the QAPP objectives are met.

5.1 Elements of the QAPP

The QAPP should include a site history section, a monitoring network map for all environmental monitored media, a footprint of the landfill, and the property boundary at a readable scale. For groundwater, the procedures and techniques in the following table should be described:

Table 5.1. Procedures and techniques to be included in a QAPP.

Elements	Details

Data handling	• Data Quality Objectives
	• Measurement quality objectives
	• Data Validation
	  • Review of analytical data
	  • Identification of questionable data
	  • Identification of unusable data
	  • Consultation with JHD if resampling is necessary

Sample collection and handling	• Groundwater elevation with each sampling event to the nearest 0.01 feet at each well. Provide a table with the survey data, locations, depths, and construction details of all the monitoring wells. • Frequency of sampling • Sampling devices (Ecology encourages dedicated devices and low-flow purge/sampling techniques) • Field parameters indicating stabilization prior to sample collection • Sequence of sample collection (taking into consideration volatilization) • Filtering (depending on the regulation) • Disposal of purge water • Equipment list • Examples of field logs
Sample preservation and shipping	• Sample containers and preservatives • Sample preservative and holding times • Sample numbering scheme • Storage and shipment including custody seals and documentation of samples
Analytical procedures	• List of constituents and test methods • Detection limits that allow comparison of results to groundwater criteria (Chapter 173-200 WAC)
Chain-of-custody control	• Sample labels • Field logbook • Sample analysis request sheet • Custody tape on sample bottles or cooler • Lab receipt records • Example of chain-of-custody form

Elements	Details

Quality assurance and quality control (field and analytical)	• Field
	  • Documentation of field activities
	  • Calibration and maintenance of field equipment
	  • Sample identification scheme and record keeping
	  • Blanks (e.g. field, trip, temperature, or equipment)
	  • Duplicates
	  • Collection of the lab quality assurance samples for matrix spike, matrix spike duplicates
	• Analytical
	  • Calibration to standards
	  • Method blanks, laboratory control samples, duplicates and matrix spikes
	  • Reporting of percent recovery of surrogates and internal standards
	  • Data flags

Decontamination of sampling equipment	• Decontamination of water level probe, pumps, meters, etc.
Procedures to ensure employee health and safety conducting groundwater monitoring	• Follow site health and safety plan
Well operation and maintenance procedures	• Frequency of sounding the total well depth • Inspection of monitoring wells for security or vandalism
Statistical procedures/data evaluation	• See Section 6
Reporting	• See Section 8

Many of these elements can be used for other environmental monitoring such as surface water, leachate, gas probes, hydraulic gradient control system, gas extraction wells, leak detection system, vadose zone, and soil.

Samples must be analyzed by an accredited laboratory in accordance with Chapter 173-50 WAC, *Accreditation of Environmental Laboratories*. The laboratory must be accredited for each analytical method performed.

Analytical testing must be performed using the latest version of *Test Methods for Evaluating Solid Waste, Physical/Chemical Methods*, US EPA Publication SW-846 or other test methods approved by the permitting agency. Other test methods that will be considered are listed in the latest version of *Guidelines Establishing Test Procedures for the Analysis of Pollutants* contained in 40 CFR Part 136 or the latest version of *Standard Methods for the Examination of Water and Wastewater* (APHA). Test methods for drinking water are not considered equivalent.

All laboratory results for groundwater sampling are to be compared to the Chapter 173-200 WAC *Groundwater Quality Criteria*. Appendix A of Ecology's *Implementation Guidance for the Groundwater Quality Standards* (revised 2005) provides most current groundwater criteria and is included as Appendix C of this document. However, other factors may need to be considered when determining applicable criteria, as discussed in Section 7.5.1.

Facilities and their consultants need to work with their laboratories to achieve reporting limits low enough to detect chemical concentrations at the regulatory limits. For example, to detect vinyl chloride down to the groundwater criteria of 0.02 µg/L, EPA Method 8260, Selected Ion Monitoring (SIM) for vinyl chloride may be required.

Appendix D of this document provides lists of constituents grouped by chemical type. These lists were developed from Chapter 173-351 WAC Appendices I, II and III. Not all analyses are required at all landfills. Applicable regulations need to be consulted to determine which analyses apply.

5.2 Filtering

Field filtering removes particulate matter from water samples. Field filtering is needed when samples are analyzed for dissolved ion concentrations, since the presence of suspended particles interferes with ion results. This includes metals such as Ca, Mg, Fe, and Mn, as well as sulfate. Mineral particulates in the sample can skew the results.

For metals analyses, there are instances when field filtering and dissolved metals analyses are appropriate, and other times when they are not. Field filtering and dissolved metals analyses are needed when metals analyses are conducted to facilitate cation-anion balancing or produce ion diagrams (such as a trilinear diagram). However, when metals analyses are conducted to produce results for comparison to the groundwater quality standards (Chapter 173-200 WAC) or cleanup criteria (Chapter 173-340 WAC), samples should not be filtered and those results must be reported as total metals.

The following table indicates the filtering requirements for the inorganic constituents in the four regulations.

Table 5.2. Regulations related to inorganics filtering requirements.

Regulation	What Regulations Specify
Chapter 173-304 WAC	Requires dissolved iron, manganese, zinc, WAC 173-304-490(2(d)(i)
Chapter 173-306 WAC	Requires dissolved iron, cadmium, lead, mercury, zinc, manganese, WAC 173-306-500(2)(d)
Chapter 173-350 WAC	Requires dissolved calcium, iron, magnesium, manganese, potassium, and sodium. WAC 173-350-500(4)(h)(ii).
Chapter 173-351 WAC	For existing landfills requires both total and dissolved metals for eight sampling events to establish relationship, then total metals thereafter, WAC 173-351-430 and 440 (see Section 7.4 for more details.)

5.3 Changes to QAPPs

Review plans periodically during the landfill life cycle to determine whether updates are warranted prior to renewal or issuance of permits. Do not implement modifications until approved by the permitting agency. Changes to the required sampling frequency or parameter list are allowed, based on successful demonstrations or variances.

All of the solid waste regulations require quarterly monitoring. To perform less than quarterly monitoring requires the actions described in the following table.

Table 5.3. Actions required for less than quarterly monitoring.

Regulation	Action to Change Frequency
Chapter 173-304 WAC	Variance, WAC 173-304-700
Chapter 173-306 WAC	Variance, WAC 173-306-900
Chapter 173-350 WAC	Demonstration, WAC 173-350-500(4)(g)
Chapter 173-351 WAC	Demonstration, WAC 173-351-450(2)

Table 5.4. Actions required for changes to the parameter list.

Regulation	Action to Change Parameters
Chapter 173-304 WAC	JHD in consultation with Ecology can add or subtract parameters depending on waste, WAC 173-304-490(d)(ii)
Chapter 173-306 WAC	Ecology can add or subtract parameters based on leachate analysis, the composition of ash, and other information, WAC 173-306-500(d)(ii)
Chapter 173-350 WAC	JHD with written concurrence from Ecology can issue variances to decrease required list, WAC 173-350-710(7). Parameters can be added based on waste and leachate profile, WAC 173-350-500(4)(i)
Chapter 173-351 WAC	Demonstration to the JHD to delete parameters, WAC 173-351-450(3)

6 Statistics

Groundwater sampling determines if landfill activities affect groundwater quality and whether corrective action should be initiated. Changes in groundwater quality at landfills are sometimes subtle. The significance of the numbers on a laboratory's analytical report often cannot be determined without comparisons to background values and past sampling results. Statistical procedures provide a mechanism for determining when groundwater changes are significant and when they are within a normal, acceptable range. For a statistical analysis to be meaningful, factors like hydrogeology, sampling procedures, and laboratory quality control must be considered.

For guidance on statistical analysis of landfill groundwater data, Ecology recommends the U. S. EPA's *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities – Unified Guidance*, March 2009 (Unified Guidance). This guidance is available online at:

http://nepis.epa.gov/Exe/ZyNET.exe/P10055GQ.TXT?ZyActionD=ZyDocument&Client=EPA&Index=2006+Thru+2010&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C06thru10%5CTxt%5C00000011%5CP10055GQ.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=p%7Cf&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPURL#.

This comprehensive document contains important updates and improvements over previous versions, as well as background and usage information for many statistical tests. Many of the statistical procedures used in evaluating contamination at landfills are specialized and complex. Computer programs can perform statistical calculations, but results can be misleading unless the data meets specific criteria and the statistical test is appropriate for the data and the problem. Ecology recommends consultation with a qualified statistician with expertise in groundwater monitoring when designing and implementing a statistical program for landfill monitoring.

6.1 Regulatory Requirements

All four landfill regulations in Washington require owner/operators to use statistical procedures with each sampling event to determine if groundwater constituents show a significant increase over background. The landfill owner/operator should become familiar with the specific regulation(s) for their landfill due to wording differences. The statistical procedures used at a landfill are included in the operating permit, which is approved by the JHD (or by Ecology for landfills regulated by Chapter 173-306 WAC).

Landfill sites in Washington are also subject to Chapter 173-200 WAC, *Water Quality Standards for Ground Waters of the State of Washington*. This regulation includes a table of groundwater quality criteria for a number of primary and secondary constituents, radionuclides, and carcinogens. Washington's landfill regulations refer to these water quality criteria as the performance standards for landfills. Exceedances of these values can prompt additional actions.

6.2 Background Values

Groundwater background samples that have not been impacted by the facility are important for a successful statistical program. Background values developed from local samples allow a comparison of constituent values to natural conditions and enables tracking of natural changes in the site's groundwater. Any statistical test needs a minimum of four background samples. However, eight to ten background samples are recommended. The background sample size should be as large as feasible.

Periodically update background values because aquifer conditions may change over time. In some cases, a moving window approach is suggested with the most recent 8-10 sampling events used as the background. If there are no clear trends, then the newer data can be pooled with the older background data. Increasing trends in background do not necessarily suggest an off-site source of contamination. For example, background wells can be impacted by landfill gas, which follows the path of least resistance and does not necessarily travel downgradient.

Collect background samples from either the same well that subsequent compliance samples are collected from (intrawell) or from specific background wells (interwell). In interwell tests, the background values are usually collected from the upgradient wells. The Unified Guidance (Chapter 5) recommends multiple, ideally three or more, background wells for interwell testing. The following criteria are required for interwell tests:

- No significant natural spatial variation in concentration means or variance (stationarity),
- A consistent groundwater gradient,
- No seasonality or fluctuations in sample concentrations,
- Sample independence, and
- Background data do not include statistical outliers.

An intrawell test is appropriate if these conditions are not met. In intrawell testing, early samples collected from a well are compared to subsequent samples from the same well. The early samples are less likely to show impacts from the landfilling operations. Ideally, the background samples are collected before the landfill begins operation. Requirements of intrawell test include:

- Sample data do not exhibit temporal non-stationarity in the form of trends, autocorrelation, or other seasonal or cyclic variation, and
- Background data do not include statistical outliers.

6.3 Statistically Significance Increases

Under landfill regulations, a statistically significant increase (SSI) of a monitored constituent triggers an action. A SSI is declared when the change in a constituent concentration is greater than natural variability, unless it can be proven the cause of the increase involves contamination from some source other than landfill operations. To declare an SSI, the null hypothesis (sample concentration is the same as background concentration) is rejected, and the alternative hypothesis (that they are different) is accepted.

Statistical tests are based on a limited number of samples that were collected from the entire population. Since samples may not be completely representative, there is an inherent amount of statistical error with each test. False positives occur when the null hypothesis is rejected when the actual population would show that it should have been accepted. A false negative is the opposite – the null hypothesis is accepted when it should have been rejected. The false positive rate is usually set at 1 or 5 percent. In statistical tests, decreasing the false positive rate increases the false negative rate. For most constituents, a trend test with a statistically significant positive slope is considered an SSI. Section 4.3.1 of the Unified Guidance provides a checklist of statistical, system design, sampling, hydrogeologic, geochemical, analytical, and data factors to consider.

If a SSI does occur, water quality retesting should occur with samples collected prior to the next routine sampling. If there is a SSI but no resampling, it should be considered an exceedance and the facility should go into assessment monitoring.

6.4 Site-Wide False Positive Rates

Groundwater-monitoring programs at landfills are concerned with the Site Wide False Positive Rate (SWFPR) for constituents where formal statistics are applied. This is a function of the number of constituents, the number of wells, and the number of annual evaluations. With the inherent error in statistical tests, it follows the larger the numbers of constituents the greater likelihood of false positives. The EPA recommends a 10 percent annual target for false positives. Regulations specify which chemicals should be analyzed, but not all of those chemicals have to be included in the formal statistical testing. The goal is to monitor for chemicals that are likely to show up at a particular facility. Per the Unified Guidance, formal statistics should be performed on 10 to 15 detection monitoring constituents for most sites.

6.5 Assumptions and Requirements for Statistical Tests

All statistical models require that the data meet certain criteria. Consider the following items when choosing statistical tests to determine if the tests are appropriate.

6.5.1 Statistical Independence

Even though groundwater samples are collected from the same location at regular intervals, they can still be considered statistically independent if there is no statistical association between pairs of sampled measurements. The Unified Guidance says that allowing as much time as possible to pass between sampling events is the best way to achieve some amount of statistical independence. The appropriate length of time between samples will depend on the hydrogeological conditions and groundwater flow velocity. The Unified Guidance states that 1 to 2 months between samples may be appropriate. Seasonal or long-term trends or sampling at too short of an interval may also invalidate independence.

6.5.2 Stationarity

Many statistical tests require a stationary statistical distribution. The average (mean) and variance (how much the values typically vary from the mean) must be the same over time and space. Increasing, decreasing, or seasonal trends (seasonality) indicate that the distribution is not stationary. If

uncontaminated wells show spatial variation in constituent amounts, an intrawell statistical approach may be preferred over an interwell approach.

6.5.3 Statistical Outliers

Unusual values are considered outliers. Typically, outliers are high values an order of magnitude or more above the mean. Outliers in sample results can be because of many factors including measurement errors, laboratory errors, clerical errors, and contaminated samples. Statistical calculations are required to determine if a sample result is a statistical outlier. If outliers are present in a data set, the following actions should be taken:

- If the cause of an outlier cannot be documented, keep the observed value, as it may represent a contamination event or natural variability.
- Delete the observation if an error is found, but the correct value is unknown.
- Correct the value if possible.

Section 6.33 of the Unified Guidance provides an excellent discussion of outliers and the many considerations necessary for dealing with them.

6.5.4 Normal Distribution

The probability distribution of a population refers to a mathematical model that represents the statistical characteristics of the population. Many populations have a normal distribution. Parametric tests are statistical tests designed for data sets with normal distributions.

Populations of groundwater constituents, however, commonly have different distributions. Volatile organic compounds in groundwater often have a lognormal distribution. Other mathematical distributions are common for some data. If the distribution of the original population can be defined mathematically, it is possible to transform the raw data to a normal distribution and then use a test that requires normality. Chapter 10 in the Unified Guidance discusses tests for normality and how to transform non-normal data.

Use a non-parametric statistical test if it is not possible to transform the original data. These tests assume symmetry and constant variance of the data.

6.6 Non-Detections

Samples with values below the laboratory quantification limit or detection limit are called “non-detects”. The actual sample value may be anywhere between zero and the detection limit. Detection limits for a contaminant may change with advances in analytical procedures. Vinyl chloride, for example, has a detection limit of 1 µg/L with Method 8260, but Method 8260-SIM has a detection limit of 0.02 µg/L. It is important to use an analytical method with a detection limit that is low enough to detect chemical concentrations at the regulatory limit.

The Unified Guidance discusses three general methods to handle non-detects in statistical calculations including: simple substitution, Kaplan-Meier, and regression on order statistics (ROS). A value of one-half of the detection limit for the constituent is commonly substituted for the non-detect. Substitution should be used only if the sample size is small and non-detects comprise less than 15 percent of the sample data set. Kaplan-Meier and ROS are more sophisticated methods that require calculations, but there should be no more than 50 percent non- detects in order to get an accurate result from either of these methods. Chapter 15 of the Unified Guidance is a discussion of non-detects. Some statistical guidance suggest non-parametric tests be used if there are many non-detects in the data.

6.7 Statistical Tests

The three stages of groundwater monitoring may have different statistical requirements and use different tests to determine statistically significant increases or exceedances. This progression is more explicit for Chapter 173-351 WAC landfills, but the concepts and statistical test can be extended to the other landfill regulations.

Detection monitoring assumes the groundwater is clean or not impacted by the landfill. Such monitoring continues unless there is a statistically significant increase over background.

Assessment monitoring follows detection monitoring (for 173-351 landfills) if an increase above background is detected. With assessment monitoring, contaminants are assumed to be below the groundwater protection standard (Chapter 173-200 WAC criterion) but above background. Statistical tests are constructed to determine when the groundwater values are above the standard.

Corrective action refers to the stage of a landfill after a groundwater criterion is exceeded. As such, the statistical tests associated with corrective action are designed to determine when constituent values reach a consistent level below the standard.

One or more of the following tests may be appropriate to meet statistical requirements.

6.7.1 Basic Statistical Tests

Computations of basic statistics assist in determining which additional tests are appropriate for the data. Chapter 173-351 WAC requires quarterly calculations of mean, variance, standard deviation, coefficient of variation, standard error, and other statistics testing for homogeneity of variance and normality of the background data. Calculate these statistics for each compliance and background well.

6.7.2 Two Sample Tests

Two sample tests determine whether there is a statistically significant difference between the means of two populations. These tests can compare a single downgradient well to background data or can determine if background in interwell data sets should be updated. Welch's t-test is the commonly used parametric test, and the Wilcoxian rank sum is its non- parametric equivalent. The Tarone-Ware test is used to test if values are statistically below a standard, as in compliance monitoring.

6.7.3 Prediction Limits

Prediction limits are the preferred statistical method in the Unified Guidance during detection monitoring. The statistical power and properties of prediction limits make them preferable to analysis of variance (ANOVA) or tolerance limits when testing multiple sample groups. Prediction limits estimate the likely range of constituent concentrations based on the observed background concentrations. Contamination is indicated if values are outside of this calculated range. There are both parametric and non-parametric tests for prediction limits. Chapter 18 of the Unified Guidance discusses the variations, uses, and methodologies of prediction limits.

6.7.4 Retesting

Retesting, that incorporates verification samples into the statistical calculations, is encouraged by the Unified Guidance. Retesting can be applied to large monitoring networks to maintain statistical power and meet false positive objectives. Prediction limits are well suited mathematically for retesting, while other methods, such as tolerance limits, are not. If the original sample exceeds the prediction limit, then additional samples are collected at wells where the initial results exceed the limit.

One type of retesting is the 1-of-m strategy. 1-of-2 sampling, for example, includes the original sample and one resample. If the resample also exceeds the prediction limit, there is an exceedance. If the resample does not exceed the prediction limit, an exceedance is not declared. Chapter 19 of the Unified Guidance discusses retesting. As discussed earlier, samples need to be statistically independent, so sufficient time must elapse between sampling events. The Unified Guidance recommends that resampling occurs at an intermediate period (or periods) between regularly scheduled sampling events. If there is a SSI, but no resampling, it should be considered as an exceedance. In Chapter 173-351 WAC, this scenario dictates the facility should go into assessment monitoring.

6.7.5 Trend Tests

The Unified Guidance recommends trend tests as an alternative to prediction limits when the data are not suitable to those techniques. Section 17.3 of the Unified Guidance discusses several trend tests and their assumptions. Linear regression, Mann-Kendall, and Sen's Slope tests are all commonly used trend tests. For most constituents, trend test results indicating (1) a statistically significant decreasing slope, indicate that water quality may be improving, (2) a zero or insignificant slope, indicate that water quality is staying the same, and (3) a statistically significant increasing slope, indicates that water quality may be getting worse.

6.7.6 Confidence Intervals

When in assessment or compliance monitoring, groundwater constituent values are compared to a standard (Chapter 173-200 WAC criterion) or background if background is above a criteria. The Unified Guidance recommends confidence intervals as the preferred test during these phases of monitoring. Confidence intervals can be calculated around a mean, an upper percentile, or a trend line. The test determines how likely it is that a value is within a certain range. Chapter 21 of the Unified Guidance discusses the use of confidence intervals.

6.7.7 Double Quantification Rule

The Double Quantification Rule is new to the revised Unified Guidance and is discussed in detail in Section 6.2.2. It recommends that constituents detected in compliance wells that are not normally detected in background samples are not subject to formal statistics. Instead, if the constituent is above the laboratory reporting limit for two consecutive sample events, it should be considered a confirmed exceedance. The double quantification rule applies to most volatile organic compounds in detection monitoring because they are not normally present in background sampling.

7 Contaminant Chemistry and Water Quality Considerations

This chapter presents some considerations about the nature of the fate and transport of contaminants at landfill sites, as well as information about applicable groundwater criteria.

7.1 Contaminant Processes at Landfills

It is important to consider contaminant processes when interpreting landfill groundwater quality data. Some constituents detected in groundwater may not be present in landfill waste. They instead may be present in groundwater because of chemical changes brought about by the presence of the waste. For example, elevated iron, manganese, and arsenic can result from leaching of those metals from a landfill. Alternatively, the elevated levels may result from changes in groundwater pH and the effect this has upon solubility of these metals. Similarly, vinyl chloride may originate from waste and be detected because it has not biodegraded, or it may be the end product of the biodegradation of other volatile organic compound (VOC) contaminants released from the landfill (see Figure 4.1 below). Therefore, if any of these constituents are detected, more than one possible explanation of the source must be considered.

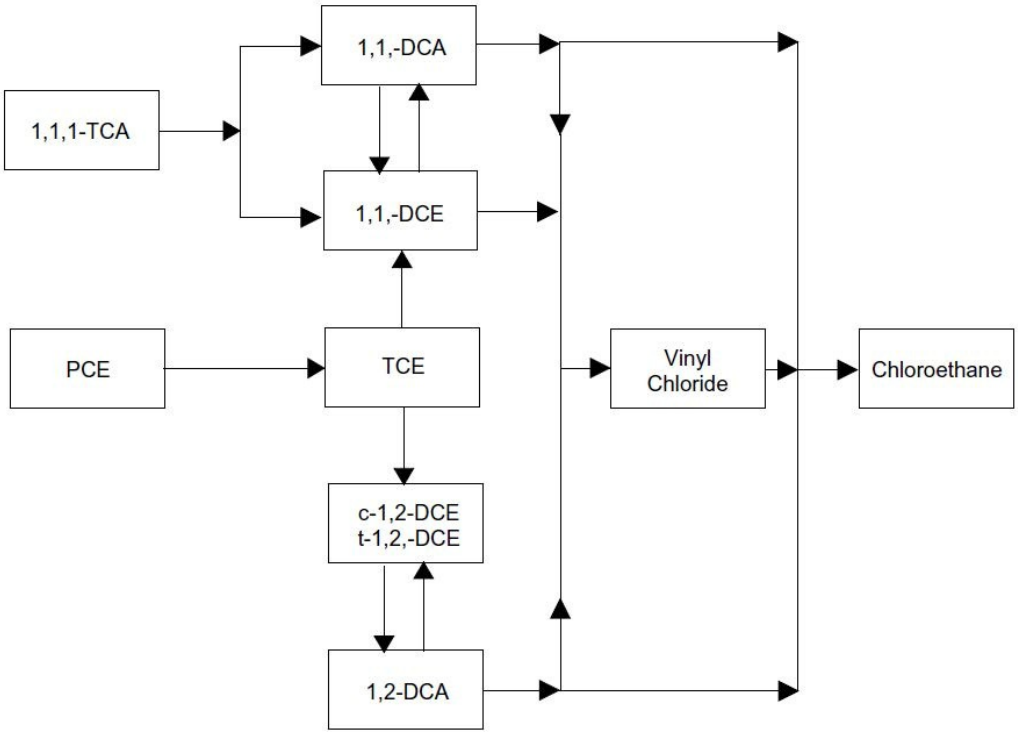

Figure 7.1. Some potential transformation pathways for chlorinated volatile hydrocarbons in soil systems (Simms et al., 1991, Drugun 1988).

7.2 Landfill Gas Migration

Landfill gas has a greater potential for migration than groundwater because of its greater mobility. Possible clues to landfill gas contamination can include detections of VOCs and/or increasing VOC trends in upgradient wells or wells in an aquifer separated by a dry layer beneath a landfill. Landfill gas can also lead to VOC contamination in downgradient wells.

It can be difficult to determine if elevated VOCs found within groundwater are due to leachate or if they are the result of partitioning of VOCs from landfill gas. One approach for evaluating this is to analyze landfill gas for VOCs, and determine whether these are the same VOCs that are detected in the groundwater. Another approach is to try correlating total VOC concentrations with concentrations of certain dissolved inorganic constituents. According to Kerfoot et al. (2004), such correlations may exist, since landfill gas can act as an acid or a reducing agent due to its carbon dioxide and methane content, respectively. Through geochemical processes, these changes can mobilize inorganic constituents within the vadose zone material. If a correlation exists between VOCs and concentrations of certain inorganic constituents, but no correlation exists with sodium or chloride, for example, in some instances this may indicate that VOCs within landfill gas have partitioned into the groundwater. This may produce different concentrations than expected from leachate impacts.

7.3 Leachate Considerations

To help determine if groundwater impacts are from landfill-derived leachate, the leachate is analyzed for its chemical constituents. Landfills that collect leachate are required to sample the leachate and input the results into Ecology's EIM database as discussed in section 8.2. The above section (7.2) discusses how to distinguish if contamination in groundwater near landfills is due to landfill-gas migration, or if it is due to leakage of leachate. It is also possible that groundwater contamination at landfills is from an off-site source.

7.4 Common Laboratory Contaminants

Detections of sample contaminants sometimes can be due to laboratory contamination. The most common laboratory contaminants include methylene chloride, acetone, 2-butanone (methyl ethyl ketone), cyclohexane, and phthalate esters. There are recognized techniques for discerning whether a particular detection is due to laboratory contamination, including methods for comparing concentrations in laboratory blanks with those in groundwater samples. Chapter 5 in EPA's "Risk Assessment Guidance for Superfund (RAGS) Part A" (1989) provides an explanation of these techniques.

7.5 Total versus Dissolved Metals for Chapter 173-351 WAC and Chapter 173-350 Landfills

In order for Washington State to have full delegation authority for Chapter 173-351 Landfills, the U.S. EPA requires that groundwater metals found in Appendix I and III of this rule be analyzed for total metals instead of dissolved metals. Therefore, under the revised Chapter 173-351 WAC requirements,

samples for Appendix I and III metals analyses will not be filtered in the field and these samples will be analyzed for total metals (see section 5.2 for further discussion of sample filtering). There are advantages in sampling for total metals because the groundwater standards (Chapter 173-200 WAC) and cleanup criteria (Chapter 173-340 WAC) are expressed in total metals. The 2018 update to Chapter 173-350 WAC also requires that certain metals must be analyzed for total, rather than dissolved, metals.

Total metals results may be higher than historical dissolved metals results for some sites. Also, elevated total metals can result from sources other than landfill waste. Outdated techniques involving removing three well-casing volumes at high flow rates can stir up metal particulates in well casings and/or neighboring formations. This can potentially lead to elevated total metals results. As such, all sites conducting total metals sampling should low- flow sampling techniques. Since this transition for some landfills may involve changes in both field equipment and QAPPs, the 2012 update of Chapter 173-351 WAC included a period of transition.

Occasionally the change to total metals may make it difficult to recognize trends in metal concentrations. The 2012 revision of Chapter 173-351 WAC requires sampling for both total and dissolved metals for eight sampling events to evaluate the relationship between dissolved metals and total metal concentrations. A statistical comparison, such as a t-test, can be made between the two populations to determine the viability of continued use of historical dissolved metal samples as background values.

The specific language in WAC 173-351-430 (2)(b) requiring that total metals background data be developed for existing MSWLF units under a detection monitoring program states that,

> (i) An owner or operator must follow the permit modification process in WAC 173-351- 720(6) to amend the sampling and analysis program to address (b)(ii) and (iii) of this subsection by May 31, 2013. Amendments must meet the standards of WAC 173-351- 410 (1) and (2).
>
> (ii) Beginning at the first sampling event after jurisdictional health department approval of amendments to the sampling and analysis program in (b)(i) of this subsection, independent samples must be collected from each monitoring well and analyzed for the parameters in (ii)(A) and (B) of this subsection. Samples must be collected and analyzed over eight sampling periods, which may be quarterly or semi-annually to coincide with routine monitoring as approved by the jurisdictional health department.
>
> (A) Total metals from Appendix I Inorganic Constituents 1-15.
>
> (B) Dissolved metals:
> Antimony (Dissolved),
> Arsenic (Dissolved),
> Barium (Dissolved),
> Beryllium (Dissolved),
> Cadmium (Dissolved),

Chromium (Dissolved),
Cobalt (Dissolved),
Copper (Dissolved),
Lead (Dissolved),
Nickel (Dissolved),
Selenium (Dissolved),
Silver (Dissolved),
Thallium (Dissolved),
Vanadium (Dissolved), and
Zinc (Dissolved).

(iii) After collecting and analyzing samples for total and dissolved metals for eight sampling periods, collection and analysis of Appendix I Inorganic Constituents 1-15 (total metals) must continue and collection and analysis of dissolved metals under (b)(ii)(B) of this subsection can cease.

Assessment monitoring conducted under WAC 173-351-440 in December 2012, when the revised version of Chapter 173-351 WAC goes into effect, also needs to evaluate the relationship between dissolved and total metals concentrations. The revised version of WAC 173-351-440(2) requires the same background data development for total metals under the same timelines as outlined in WAC 173-351-430 (2)(b).

Section 3.3 of this guidance document addresses the WAC 173-351-720(6) permit modification process that is referred to in WAC 173-351-430 (2)(b)(i) above.

The list of required geochemical indicator parameters for landfills regulated under Chapter 173-350 WAC is not as extensive as that for municipal solid waste landfills regulated under Chapter 173-351 WAC. The following three parameters must have analyses for both the total and the dissolved component: iron, magnesium, and manganese. The total metals analyses values are compared to the groundwater (and possibly cleanup standards), and the dissolved analyses values are used for geochemical evaluations. This includes cation-anion balancing and trilinear and/or stiff diagrams. If other pertinent constituents are identified based on the site-specific waste profile and/or leachate characteristics the owner or operator must propose to include those added constituents in the monitoring program. The jurisdictional health department will specify the extra constituents in the solid waste permit. Laboratory analysis methods much have sufficiently low detection limits to decide whether concentrations exceed water quality standards (Chapter 173-200 WAC).

7.6 Applicable Groundwater Criteria

This section discusses the criteria applicable when evaluating groundwater quality data at landfills within the state.

7.6.1 Other Criteria

Analytical values for constituents required under any of the four regulations must always be compared to the criteria in Chapter 173-200 WAC, *Water Quality Standards for Ground Waters of the State of Washington*. However, some constituents included in Appendices I, II or III of Chapter 173-351 WAC do not have Chapter 173-200 WAC criteria. When evaluating which criteria to apply, Appendix A in *Ecology's Implementation Guidance for the Groundwater Quality Standards* (revised 2005) provides a good starting point. That guidance cites Chapter 173-200 WAC as the source for regulatory authority in most cases. Drinking water standards from Chapter 246-290 are included in the guidance for constituents that do not have a groundwater standard. For all constituents applicable to landfills, if Chapter 173-200 WAC standards do not exist, the Chapter 246-290 WAC standards apply.

Groundwater standards may change over time as more information becomes available on the toxicological effects of various elements and compounds. Unfortunately, state regulations are not all updated at the same time. Chapter 173-200 WAC requires the most stringent criteria must be used for each parameter. For example, both Chapter 173-200 WAC and Appendix A in Ecology's *Implementation Guidance for the Groundwater Quality Standards* (revised 2005) list the criteria for lead as 50 µg/L. However, the current drinking water standard (Chapter 246-290 WAC) for lead is 15 µg/L. If Ecology's *Implementation Guidance for the Groundwater Quality Standards* were revised today, it would cite the 15 µg/L drinking water standard value as the applicable criterion.

7.6.2 Nitrite and Ammonia Standards

Chapter 173-200 WAC does not include specific criteria for either nitrite or ammonia. The Chapter 173-200 WAC implementation guidance does provide a limit of 1 mg/l for total nitrite (as N) based on the state drinking water standards, so this is the most relevant number for comparison purposes. Similarly, the Chapter 173-200 WAC implementation guidance provides a limit of 10 mg/l for total nitrogen, which includes nitrate (as N), nitrite (as N), ammonia & organic nitrogen. Therefore, ammonia results can be summed with these other forms of nitrogen and compared to this standard. In instances where the ammonia concentration alone exceeds 10 mg/l, it is useful to compare the ammonia concentration to this standard directly.

7.6.3 Polycyclic Aromatic Hydrocarbon (PAH) Concentrations

Laboratory analyses for PAHs are typically performed for many PAH compounds. Chapter 173- 200 WAC generically lists a 0.01 µg/L criteria for PAHs, and specifically 0.008 µg/L for benzo(a)pyrene. Supporting documentation about the development of Chapter 173-200 WAC indicates that the reported analytical concentrations of all PAH congeners should be summed without applying any weighting factors, then compared to this 0.01 µg/L PAH criteria. In addition to this analysis, sometimes it may be instructive to analyze the data using a MTCA approach. That approach involves a process of weighting the reported analytical concentrations values based on tables of toxicity equivalency factors (TEFs), which later allows an evaluation of the collective cancer risk of all the PAH congeners relative to benzo(a)pyrene.

8 Reporting

Washington State's landfill regulations require annual reports. Quarterly reports are not required under Chapters 173-304, 173-306, or 173-350 WAC; however, many JHDs require landfills operating under those rules to submit quarterly reports. Those facilities typically are sampling groundwater quarterly, and the owner/operators must complete statistical analyses for each sampling event and notify the JHD and/or Ecology if there are statistically significant increases. Chapter 173- 351 WAC requires both quarterly and annual reports. For efficiency, many facilities choose to combine their last quarterly report for each year with their annual report for that year.

If other environmental monitoring data are collected (e.g. gas, surface water, or leachate), those should be submitted to the JHD regularly and/or incorporated in the quarterly or annual reports. All four regulations require that owner/operators report to the JHD and/or Ecology annually about items such as the quantities of solid waste handled, status of financial assurance accounts, etc. That information should be submitted to the JHD and Ecology separately from the groundwater reports.

8.1 Regulatory Requirements

There are both similarities and differences in the four regulations' reporting requirements.

8.1.1 Chapters 173-304 and 173-306 WAC Landfills

Chapter 173-304 WAC requires that reports be submitted to both the local JHD and Ecology, while Chapter 173-306 WAC only requires that reports be submitted to Ecology. Among other things, both regulations require that annual reports:

- Be submitted by March 1 of each year.
- Provide the statistical results of quarterly monitoring.
- Provide groundwater flow rate and direction.

If quarterly monitoring indicates there is a statistically significant increase (SSI) above background, the facility must notify the JHD or Ecology within seven days of receipt of the sampling data. This notification must include constituent(s) that show an increase.

8.1.2 Chapter 173-350 WAC Landfills

WAC 173-350-500 requires an annual report that summarizes and interprets the data, submitted to both the JHD and Ecology by April 1 of each year. This regulation requires that annual reports include:

- All groundwater-monitoring results.
- Statistical results and trends.
- Any exceedances of Chapter 173-200 WAC standards.
- An evaluation of the collected groundwater geochemical data.
- Static water-level readings and potentiometric maps for each sampling event, as well as notations regarding any trends or changes.
- Leachate data, if collected.

If quarterly monitoring determines that a SSI has occurred, the facility is to notify the JHD and Ecology within 30 days of receipt of the sampling data.

8.1.3 Chapter 173-351 WAC Landfills

Chapter 173-351 WAC is different from the other regulations in that it includes requirements for both annual and quarterly groundwater reports. This regulation requires submittal of annual reports to both the JHD and Ecology by April 1 of each year. The annual reports must include:

- Summaries of statistical results and/or trends, including findings of statistical increases for the year.
- Summaries of groundwater flow rate and direction, noting any trends or changes.
- Potentiometric surface maps developed for each quarter or approved semi-annual period.
- Summaries of any changes or trends in cation-anion balances, trilinear diagrams, and general water chemistry for each well.

Chapter 173-351 WAC also requires quarterly reports submitted to both the JHD and Ecology within sixty days of receipt of the quarterly analytical data. These reports must include:

- All groundwater-monitoring data for that sampling period.
- A summary of statistical results, trends, and statistical calculations.
- Notification of any statistical increases and/or concentrations above Chapter 173-200 WAC criteria.
- Cation-anion balances and Trilinear diagrams.
- Static water-level readings and potentiometric maps with the flow rate and direction.
- Leachate results and analyses, if sampled.

If quarterly monitoring determines that a SSI has occurred, WAC 173-351-440 Assessment Monitoring requirements go into effect, as described in Section 9.0 of this guidance document. WAC 173-351-415 states that annual and quarterly groundwater reports must include completed forms developed by Ecology. The requirement for use of forms refers to the checklist available online at:

https://fortress.wa.gov/ecy/publications/summarypages/ecy070316.html.

8.2 Report and Data Submittal Format

Reports may be submitted to the JHD and Ecology in either hard copy or digital format. For Chapter 173-304 or 173-306 WAC landfills, Ecology (and the JHD, in some instances) recommends that electronic versions of all data collected up to that point (not just the most recent) be submitted.

WAC 173-351-415(3) requires that:

> All groundwater-monitoring data must be submitted consistent with procedures specified by the department. Unless otherwise specified by the department, all groundwater-monitoring

> data must be submitted in an electronic form capable of being transferred into readily available statistical software and the department's data management system.

Chapter 173-350 WAC, in section 173-350-500 (5)(d) states that:

> All groundwater-monitoring data must be submitted consistent with procedures specified by the department. Unless otherwise specified by the department, all groundwater-monitoring data for the previous year must be submitted by April 1st of each year in an electronic form capable of being transferred into the department's data management system.

Ecology's current data management system is the Environmental Information Management (EIM) database. Ecology is specifying through this guidance document that all owner/operators of landfills regulated by Chapter 173-351 or Chapter 173-350 submit all groundwater and leachate monitoring data directly to EIM. Although regulations do not currently require input of gas data into EIM, Ecology is modifying the database to accept landfill gas sampling data. Health District permits may require input of gas data into EIM, and eventually it will be required by landfill regulations.

Municipal Solid Waste Landfills (173-351) must submit data into EIM within sixty days after receipt of the quarterly analytical data. For landfills regulated under Chapter 173-350 WAC, data for the previous year must be input into EIM by April 1st of each year. The method for submitting data into EIM and submittal guidelines are available at http://www.ecy.wa.gov/eim/submitdata.htm. EIM requires that all survey data is relative to the NAVD88 datum. Many analytical laboratories can output results in an EIM-ready format. The EIM database must be setup for specific projects. If problems develop when setting up or importing data into EIM, contact Ecology for assistance.

Owner/operators of Chapters 173-304 or 173-306 WAC landfills are not required to submit their groundwater-monitoring data to EIM, but Ecology encourages them do so, or at least submit their lab data in an EIM-ready electronic format. Owner/operators can request an EIM-ready format from the lab, or manually fill out an EIM compatible spreadsheet. EIM spreadsheets can be downloaded from the EIM data submittal link (http://www.ecy.wa.gov/eim/submitdata.htm).

Landfill sites under a MTCA order require submission of MTCA data directly to EIM, in addition to the data submission requirements specific to the landfill regulations applicable to that site (Chapter 173-304, 173-306,173-350 or 173-351 WAC).

As well as data tables, owner/operators are urged to submit laboratory and field data sheets with their reports, since those items can be useful when data issues arise. Scanned images of these can be provided on CD or transmitted electronically.

8.3 Recommended Report Elements

The basic quarterly reporting requirement for Chapters 173-304, 173-306, and 173-350 WAC landfills involves notification of a SSI within a specified period. There is no requirement to submit a quarterly report, although some JHDs (or Ecology, in the case of Chapter 173-306 WAC landfills) may require

this. All Chapter 173-351 WAC landfills must submit quarterly reports and the regulation specifies a number of required reporting elements. Annual reporting is required for all four landfill types.

The tables below provide Ecology's recommendations for elements to be included in quarter, semiannual, and annual reports.

Table 8.1. Recommended quarterly or semi-annual report elements.

Information	304	306	350	351
SSI notification deadline after receipt of analytical data.	7 days	7 days	30 days	14 days
Report due date.	May be specified by JHD	May be specified by Ecology	May be specified by JHD	60 days after receipt of lab data
Site map showing landfill footprint, property boundary, all monitoring well locations, and other relevant information.	X	X	X	X
Groundwater data (see Section 8.2)	X	X	X	X
Description of statistical analyses performed (intrawell, interwell, Sen's Slope, etc.) and results, per the statistical methods described in Section 6.0 above.	X	X	X	X
Tables indicating: o All groundwater quality constituents exceeding Chapter 173-200 WAC standards o All groundwater quality constituents exceeding statistical limits or tests (including trend tests) o Any volatile organic or semi-volatile organic detections in groundwater o All gas or surface water exceedances	X	X	X	X
Discussion of all statistical or Chapter 173-200 WAC criterion exceedances, as well as potential causes.	X	X	X	X
Tabulated ash and soil data, including laboratory and field data.		X		
Tabulated leachate data including laboratory and field data, if collected.			X	X
Static water-level data for each monitoring well, potentiometric surface elevation maps depicting flow direction, and results of groundwater flow rate analyses.				X

Information	304	306	350	351
Cation-anion balances, including an explanation of greater than 5% or 10% difference, if needed.			X	X
Trilinear diagrams.			X	X
Signature and stamp of licensed professional that meets the requirement of Chapter 18.220 RCW.	X	X	X	X

Table 8.2. Recommended annual report elements.

Information	304	306	350	351
Report due date.	March 1	March 1	April 1	April 1
Site map showing landfill footprint, property boundary, all monitoring well locations, and other relevant information.	X	X	X	X
For each sampling event: static water-level data for each monitoring well, potentiometric surface elevation maps depicting flow direction, results of groundwater flow rate analyses, and a discussion of any trends or changes.	X	X	X	X
Tables indicating: o All groundwater quality constituents exceeding Chapter 173-200 WAC standards o All groundwater quality constituents exceeding statistical limits or tests (including trend tests) o Descriptive statistics o Any volatile organic or semi-volatile organic detections in groundwater o All gas or surface water exceedances	X	X	X	X
A statement indicating the laboratory used for water quality analyses, and also whether that lab is accredited by Washington State for each type of analysis performed.	X	X	X	X

Information	304	306	350	351
Time series plots for parameters exceeding Chapter 173-200 WAC standards and/or statistical limits or tests. Plots should include all wells in same aquifer for each parameter, with background well(s) noted. Wells with only non-detects should be noted but not graphed. Plots should: o Distinguish between detected and non-detected values using different symbols o Indicate applicable groundwater quality standards o Indicate statistical limits, if applicable o Have adjusted scaling to reduce crowding and make graph readable When applicable, it is also recommended that graphs with both short-term and long-term timescales be included, and that significant activities, such as closure dates, be indicated.	X	X	X	X
A discussion of all analyses performed and results. Statistics section should follow the methods described in Section 6 above, and the statistics discussion should describe all methods and assumptions, including how non-detect values were evaluated, results of parametric	X	X	X	X

8.4 Other Reporting Considerations

The following evaluation tools are required in Chapters 173-350 and 173-351 WAC. These tools are also useful for facilities permitted under Chapters 173-304 and 173-306 WAC, however, for those landfills sampling beyond the minimum required constituents would be necessary.

8.4.1 Anion-Cation Balances

Chapters 173-350 and 173-351 WAC both require cation-anion balancing. A check for the correctness of anion-cation balance analyses is described in Section 1030 E of *Standard Methods for the Examination of Water and Wastewater* (Clesceri, et al., 1998). The formula to calculate the anion-cation balance (in meq) as follows:

$$\%\ difference = 100\ x\ \frac{\sum(cations - anions)}{\sum(cations + anions)}$$

WAC 173-351-430(5)(a) specifies that if the following threshold limits are exceeded, the owner/operator must provide a summary explanation and examine whether the difference is due to a laboratory error, poor well conditions, or other ions not accounted for in natural or impacted groundwater conditions:

- A ten percent difference threshold is used if the total cation-anion sums are less than 5.0 meq/liter.

- A five percent difference threshold is used if the total cation-anion sums are greater than or equal to 5.0 meq/liter.

8.4.2 Graphical Representation of Groundwater Quality

Graphical representations of groundwater geochemistry are useful for comparing water quality data sets between different monitoring wells. Graphical methods enable visual evaluation performance and water quality trends for single wells or groups of wells for individual or periodically scheduled recording events. Two principal examples of graphical representation are trilinear diagrams and Stiff diagrams. Both methods plot and chart major anions and cations as means of illustrating groundwater geochemistry. Numerous commercial software programs are available and free software is available at the following U. S. Geological Survey website:

http://water.usgs.gov/nrp/gwsoftware/GW_Chart/GW_Chart.html.

9 Assessment Monitoring Under Chapter 173-351 WAC

An assessment monitoring program may be required at Chapter 173-351 WAC landfills if detection monitoring indicates increasing concentrations of monitored constituents. Assessment monitoring includes sampling for additional constituents as described in WAC 173-351-440.

Assessment monitoring is required if the analyses indicate there has been a statistically significant increase (SSI) over background for one or more of the constituents listed in Appendix I of Chapter 173-351 WAC. Analyses of samples for constituents listed in Appendix I and Appendix II of the regulation are part of detection monitoring at the landfill.

9.1 Statistically Significant Increases

Statistical analyses of groundwater data are required with each sampling event under the regulation. Recent constituent values are compared with background values using statistical procedures specified in the operating permit and/or QAPP. A SSI means the value of a constituent is greater than would be expected from past data variability. The statistical procedure will determine if the increase is statistically significant. Refer to the second paragraph in section 4.3 of the EPA's Unified Guidance.

An owner/operator can avoid assessment monitoring even if results show a SSI, if they can demonstrate that a source other than the landfill caused the contamination or that the SSI resulted from an error in sampling, analysis, statistical evaluation, or natural variation in groundwater quality. Consult the EPA's Unified Guidance if resampling is part of the demonstration.

9.2 Time Limits for Starting Assessment Monitoring

A groundwater report must be submitted to the JHD and Ecology within 60 days after receipt of analytical data from detection monitoring. The statistical analyses are a component of the report, so they must be completed within the 60-day period. From the time a SSI is noted, an owner/operator has:

- 14 days to send a notice of a SSI to the JHD and put a notice in the operating record.
- 90 days to demonstrate that a source other than the landfill caused the contamination, or to establish an assessment monitoring program.

9.3 Assessment Monitoring Requirements

Assessment monitoring includes sampling for the full set of constituents listed in Appendix III of Chapter 173-351 WAC. Requirements of the Assessment Monitoring program:

- Sample each downgradient well for the full set of Appendix III constituents within 90 days of noting a statistical increase.

- If any Appendix III constituents are detected, sample all wells four times within a 180-day period. At least one month must pass between each sampling event. Analyze for just the Appendix III constituents that were detected during the initial Appendix III sampling to establish background levels. Notify the JHD which constituents have been detected and place the notice in the operating record.

- After obtaining the results from the above sampling events, within 90 days, and quarterly after that, resample all wells for all Appendix I and II constituents and any previously detected Appendix III constituents.

- As long as a facility remains in Assessment Monitoring, resample for the full set of Appendix III constituents annually in all downgradient wells or an approved subset of the wells.

9.4 Possible Outcomes of Assessment Monitoring

Constituent values and statistical results determine the next steps:

- If concentrations for all Appendix III constituents are at or below background values for two consecutive events, an owner/operator can return to detection monitoring if they receive approval from the JHD.

- If Appendix III constituents are above background but below groundwater-protection standards (Chapter 173-200 WAC), owners/operators must continue to include the detected Appendix III constituents in the quarterly sampling.

- If one or more Appendix III constituents are detected at statistically significant levels above the protection standard (Chapter 173-200 WAC criteria), the site goes into corrective action. The owner/operator must notify the JHD, Ecology, and all appropriate local government officials within 14 days and do the following:

    - Install added monitoring wells and characterize the chemical composition, fate and transport, and rate and extent of contamination in all groundwater flow paths. At least one new well must be installed at the facility boundary in the direction of contaminant migration. This well must be sampled four times within a 180-day period to establish a background for Appendix III contaminants as discussed above.

    - Notify landowners or people who reside on the land that overlies the contaminant plume if any contaminants have migrated off-site.

    - Begin an assessment, selection, and implementation of remedial actions as required by the Model Toxics Control Act (Chapter 173-340 WAC).

    - Continue assessment monitoring as usual.

9.5 Assessment Monitoring Program Modifications

Owners/operators can propose deleting or changing groundwater-monitoring constituents or an appropriate subset of wells to be sampled. Suitable hydrogeology and chemical characteristics must be demonstrated, under WAC 173-351-450, for a modification to be considered. The frequency of sampling cannot be changed. It remains quarterly.

10 Remedial Action

The solid waste regulations are designed to protect human health and the environment. If groundwater quality criteria (Chapter 173-200 WAC) are exceeded as a result of landfill activities, a facility may be required to undertake cleanup actions. These cleanup actions are called "corrective actions" or "remedial actions". Older solid waste regulations use the term corrective action, but this section will use the term remedial action to be consistent with Washington's Model Toxics Control Act (MTCA), Chapter 173-340 WAC. If a site is in remedial action, the owner/operator should become familiar with these cleanup regulations and work with a knowledgeable consultant throughout the cleanup process.

10.1 Model Toxics Control Act (MTCA)

The MTCA regulation, Chapter 173-340 WAC, provides a process to accomplish effective cleanups of sites with releases of hazardous substances. MTCA applies to all facilities where there has been a release, or threatened release, of a hazardous substance that may pose a threat to human health or the environment. MTCA law (Chapter 70.105 RCW), MTCA regulations (Chapter 173-340 WAC), Uniform Covenants Act (Chapter 64.70 RCW), and MTCA focus sheets are all combined in Ecology publication No. 94-06. This publication is available on the Department of Ecology's web site at: https://fortress.wa.gov/ecy/publications/publications/9406.pdf. Anyone involved in remediation activities should become familiar with this publication. A good general description of MTCA is available in Ecology Focus Sheet No. 94-12, entitled, *Model Toxics Cleanup Act Cleanup Regulation: Process for Cleanup of Hazardous Waste Sites*, provided in Appendix E of this guidance document.

10.2 Solid Waste Regulations and Remedial Action

All solid waste regulations have a cleanup provision triggered by one or more exceedances of groundwater quality criteria (Chapter 173-200 WAC). A solid waste permit with the JHD does not exempt a facility from meeting the Chapter 173-200 WAC groundwater criteria. Ecology can use Chapter 173-200 WAC as a basis to direct owners and operators of landfills to meet groundwater quality objectives.

Some specific cleanup provisions relative to the four solid waste regulations include:

> Chapter 173-304 WAC –This regulation grants JHDs authority over remedial actions (WAC 173-304-490(2)(j) and (3)). However, this rule was written before the effective dates of MTCA and the groundwater quality rule, both of which establish Ecology's authority for cleanup actions and groundwater protection. Ecology is usually the lead agency on remedial actions, however, section WAC 173-340-110 allows Ecology to determine if another law is more appropriate and consider the success of the remedial action before assuming direct authority.
>
> Chapter 173-306 WAC - Ecology may require modifications to a facility or to a plan of operation. Ecology can also use MTCA or the groundwater quality rule to initiate remedial action.

Chapters 173-350 and 173-351 WAC - Both of these rules place Ecology in the lead role for remedial action, which it carries out using MTCA. The JHD may participate in all negotiations, meetings, and correspondence. The roles for Ecology and the JHD are found at WAC 173-350-900 and WAC 173-351-460 and -465.

When Ecology takes the lead for a remedial action, a solid waste permit is still required to address those facility functions not related to cleanup activities. The solid waste permit should reference the section of the regulation pertaining to remedial action or refer to an order administered by Ecology. The site continues to operate under a solid waste permit when cleanup activities are complete.

11 Ending Post-Closure Care

None of the four regulations list the requirements for ending post-closure care in a specific section. However, many requirements can be found in the following:

WAC 173-304-407 - General closure and post-closure requirements.
WAC 173-306-410 - General closure and post-closure requirements.
WAC 173-350-400 (7) - Limited purpose landfills - Post-closure requirements.
WAC 173-351-500 (2) - Post-closure care requirements.

11.1 Regulatory Requirements

Under Chapters 173-304 and 173-350 WAC, to discontinue post-closure activities the owner/operator must certify that post-closure activities are no longer necessary. For Chapter 173- 306 WAC landfills, the owner/operator must submit an affidavit stating why post-closure activities are no longer necessary. For all three of these regulations, these declarations must be signed by the owner/operator and a registered professional engineer. When post-closure care activities are complete under Chapter 173-351 WAC, the owner/operator must submit a certification or declaration of construction signed by an independent licensed professional engineer that post-closure has been completed in accordance with the post-closure plan.

Chapters 173-304, 173-306 and 173-350 WAC include the following definitions about the duration of post-closure care and the standards for ending it. Some JHDs may have their own county codes dictating standards for post-closure care.

> WAC 173-304-100 (59) - “Post-closure” means the requirements placed upon disposal sites after closure to ensure their environmental safety for at least a twenty-year period or until the site becomes stabilized (i.e., little or no settlement, gas production, or leachate generation).
>
> WAC 173-306-100 (43) - “Post-closure" means the requirements placed upon disposal facilities after closure to ensure their environmental safety for a thirty-year period or until the site becomes stabilized (i.e., cap integrity maintained, little or no settlement or leachate generation).
>
> WAC 173-350 (100) - "Post-closure" means the requirements placed upon disposal facilities after closure to ensure their environmental safety for at least a twenty-year period or until the site becomes stabilized (i.e., little or no settlement, gas production, or leachate generation).

Chapters 173-304, 173-306, 173-350 and 173-351 WAC have similar requirements for ending post-closure care. These regulations allow JHDs to authorize the owner/operator to discontinue post-closure maintenance and monitoring activities if they agree the landfill is stabilized. Chapter 173-306 WAC also uses stabilization as the standard. This regulation indicates Ecology may gradually reduce or discontinue post-closure maintenance and monitoring requirements if it determines that stabilization has been achieved.

Post-closure care in Chapter 173-351 WAC continues until the site is functionally stable. According to WAC 173-351-500, an owner/operator must estimate the time needed to become functionally stable and plan to perform post-closure care based on this estimate. WAC 173-351- 500(2) indicates that functional stability is achieved when a site does not present a threat to human health or the environment at the point of exposure for humans or environmental receptors. These threats are assessed by considering leachate, landfill gas, cover systems and groundwater. The required filing of environmental covenants to reduce exposure is also considered. WAC 173-351-500 provides standards to meet for each of the considerations.

Post-closure care may be extended beyond the 20- or 30-year period if a site has not stabilized for all four of these regulations.

11.2 Terminating Post-Closure Care at Chapter 173- 304 WAC Landfills

In February 2011, Ecology issued Preparing for Termination of Post-Closure Activities at Landfills Closed Under Chapter 173-304 WAC (Publication no. 11-07-006, available on-line at: http://www.ecy.wa.gov/pubs/1107006.pdf). This publication describes administrative recommendations, regulatory agency roles, and a definition for the end of post-closure care. Discussing landfill stabilization includes four stabilization indicator factors: settlement, gas production, leachate generation, and groundwater monitoring.

If data gaps exist for any of the stabilization factors, periods of confirmational monitoring may be required. At sites where groundwater or surface water monitoring data are inadequate, the frequency of sampling, number of analyzed parameters, or number of sampling points may have to be increased. When evaluating how much additional sampling is appropriate, key factors are:

- Have there been exceedances of groundwater protection standards or evaluation criteria?
- Are there statistically significant differences between the up-gradient and down-gradient groundwater data?

Ecology recommends that an operator proposing to end post-closure activities at a Chapter 173- 304 WAC facility provide the solid waste permitting agency with a report summarizing all relevant environmental information about the stability of the landfill. This will help the permitting agency assess the operator's proposal and support the permitting agency's decision.

Information to include in a post-closure care summary report is described in Publication no. 11- 07-006. Items specific to groundwater monitoring include:

- Information on the site hydrogeology with descriptions of the geology, hydrogeologic cross sections, drilling history, aquifers, seeps, and tidal influence (if present).

- Summary tables and discussion of groundwater elevations and velocity calculations, temporal and seasonal changes, and water level contour maps representative of the four quarters of the year.

- A summary of groundwater and surface water sampling with discussion of:

    - Any changes to the monitoring plan (including whether and how changes were approved).
    - Exceedances of groundwater quality standards (Chapter 173-200 WAC) or evaluation criteria.
    - Statistical evaluation of constituent trends.

- EPA's *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities - Unified Guidance* provides appropriate statistical methods for evaluating data.

- A comprehensive discussion with conclusions about site stabilization, including an evaluation of settlement and cover integrity, gas production, leachate production, and groundwater monitoring.

It is important to recognize that Chapter 173-304 WAC's criteria for showing that a landfill facility has stabilized are qualitative. Decision-makers will have to exercise judgment in making their findings on individual facilities. However, Publication no. 11-07-006 shows that data presented in support of terminating post-closure activities should be assessed while considering a number of general principles, which for groundwater monitoring include:

- The monitoring well network should be able to identify direction and velocity of groundwater flow across the facility.

- Groundwater quality sampling results should meet groundwater protection standards of Chapter 173-200 WAC at the facility's permitted point of compliance.

- Monitored analyte concentration trends should have slopes of zero or less (unless the cause for increasing slopes is not related to the landfill).

- Groundwater quality sampling results should indicate no statistically significant increases between upgradient and downgradient wells where the concentration of an analyte exceeds the groundwater protection standards in the upgradient wells.

While Publication Number 11-07-006 provides these general principles, it does not discuss time period(s) over which these factors should be evaluated. Because of the great variety of landfill sites, specific rules for time periods are not practical. Instead, professional judgment needs to be exercised while taking into consideration such site-specific factors as groundwater flow rates, contaminants present, effectiveness of monitoring network, etc.

Exceedances of Chapter 173-200 WAC secondary groundwater protection standards for constituents such as iron or manganese may serve as indications of broader chemical changes resulting from waste deposited at a landfill site. However, such contaminants may not pose much of a health risk themselves. As such, exceedances of secondary contaminants in general should not carry the same weight as primary or carcinogenic contaminant exceedances.

11.3 Terminating Post-Closure Care at Chapters 173- 306 and 173-350 WAC Landfills

Publication no. 11-07-006 is currently the only Ecology document with guidance on ending post-closure care activities at Washington landfills. This document specifically addresses Chapter 173-304 WAC landfills, but Chapters 173-306 and 173-350 WAC contain similar stabilization- based standards for ending post-closure care. This suggests that similar approaches can be applied to landfills covered by those regulations.

11.4 Terminating Post-Closure Care at Chapter 173- 351 WAC Landfills

Chapter 173-351 WAC, as revised November 2012, takes a similar stabilization-based approach as the other regulations. However, this regulation also relates stabilization to protection of human and environmental health and sets standards for assessing gas, settlement, leachate and groundwater. Chapter 173-351 WAC also requires an environmental covenant to help ensure ongoing protection of human and environmental health. The stabilization standards for leachate and groundwater contained in WAC 173-351-500(2)(b)(iii) are as follows:

The jurisdictional health department and owner/operator will consider at least the following factors when determining when a landfill unit is functionally stable or whether to decrease or increase the post-closure care period:

> (A) Leachate. Leachate production and quality must be such that maintenance and operation of the leachate collection system can be ceased beyond the post-closure care period without posing a threat to human health or the environment.
>
> (B) Landfill gas. Landfill gas production and composition must be such that maintenance and operation of the gas collection system can be ceased beyond the post-closure care period while meeting the criteria in WAC 173-351-200 (4)(a)(i) through (iii) and not pose a threat to human health or the environment from methane or non-methane compounds.
>
> (C) Settlement and cover integrity. The cover system must attain geotechnical stability for slope and settlement. Vegetation and other erosion controls must prevent exposing waste or otherwise threaten integrity of the cover system. The cover system must stabilize such that no additional care is required beyond the post-closure care period to ensure its integrity from settlement or erosion.

(D) Groundwater quality. Groundwater quality must remain in compliance with the protection standards established in WAC 173-351-440(7) at the relevant point of compliance.

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Washington State, 2009, Chapter 173-160 Washington Administrative Code, *Minimum Standards for Construction and Maintenance of Water Wells*.

Washington State Department of Ecology, 2011, *Preparing for Termination of Post-Closure Activities at Landfills Closed Under Chapter 173-304 WAC*, Washington State Department of Ecology, Waste 2 Resources Program, Publication no. 11-07-006. https://fortress.wa.gov/ecy/publications/SummaryPages/1107006.html

Washington State, 2011, Chapter 70.95 Revised Code of Washington, *Solid Waste Management — Reduction and Recycling*.

Note: Chapters of the Revised Administrative Code of Washington can be found at http://apps.leg.wa.gov/rcw/, and Chapters of Washington Administrative Code can be found at http://apps.leg.wa.gov/wac/.

Appendices

Appendix A. Definitions

Appendix B. Acronyms

Appendix C. Appendix A from Ecology Chapter 173-200 Implementation Guidance

Appendix D. Chapter 173-351 WAC Appendices I, II, and III parameters

Appendix E. MTCA Cleanup Regulation: Ecology Focus Sheet No. 94-129

Appendix A

Definitions

Aquifer – in the context of this document this term refers to any hydrostratigraphic unit (please see definition below). This definition is in contrast to the more common definition of an aquifer, which is a geologic formation, group of formations, or part of a formation capable of yielding a significant amount of groundwater to wells or springs.

Background - the quality of the environment (air, soil or water) which is unaffected by waste disposal operations.

Congener - a chemical compound similar in composition and effect to another compound.

Contaminant - any chemical, physical, biological, or radiological substance that does not occur naturally in the environment or that occurs at concentrations greater than natural background levels.

Contamination –

1) the concentration of a substance in groundwater that exceeds the Chapter 173- 200 WAC groundwater criteria, or

2) a statistically significant increase in the concentration of a substance in the groundwater where the existing concentration of that substance exceeds the Chapter 173-200 WAC groundwater criteria, or

3) a statistically significant increase above background in the concentration of a substance which
   - Is not specified in Chapter 173-200 WAC, and
   - Is present in the solid waste, and
   - Has been determined to present a substantial risk to human health or the environment in the concentrations found at the point of compliance.

Criteria - numerical values or narrative standards that represent the maximum allowable contaminant concentrations in the groundwater.

Downgradient - the location in the aquifer flow field that groundwater flows horizontally away from the facility of interest. The gradient and flow direction in the aquifer are determined from groundwater elevation data from monitoring wells.

Ecology - Department of Ecology.

Groundwater - that part of the subsurface water that is in the zone of saturation.

Groundwater Quality Standards - the criterion set for maximum allowable contamination of groundwater as set forth in Chapter 173-200 WAC, Water Quality Standards for Ground Waters of the State of Washington.

Hydrostratigraphic unit - any water-bearing geologic unit or units hydraulically connected or grouped together on the basis of similar hydraulic conductivity which can be reasonably monitored; several geologic formations or part of a geologic formation may be grouped into a single hydrostratigraphic unit; perched sand lenses may be considered a hydrostratigraphic unit or part of a hydrostratigraphic unit, for example.

Jurisdictional health department (JHD) - means city, county, city-county, or district public health department.

Landfill - a disposal facility or part of a facility at which solid waste is permanently placed in or on land including facilities that use solid waste as a component of fill.

Leachate - a liquid that has passed through or emerged from solid waste and contains soluble, suspended, or miscible materials removed from such waste.

Monitoring interval - the stratigraphic interval from which groundwater level measurements or groundwater quality samples will be obtained

Municipal solid waste (MSW) - a subset of solid waste which includes unsegregated garbage, refuse and similar solid waste material discarded from residential, commercial, institutional and industrial sources and community activities, including residue after recyclables have been separated.

Permeability - the ease with which a porous material allows liquid or gaseous fluids to flow through it. For water, this is usually expressed in units of centimeters per second and termed hydraulic conductivity.

Point of compliance - refers to specific definitions depending upon the WAC including:

- Per WAC 173-304 - that part of groundwater that lies beneath the perimeter of a solid waste facilities' active area as that active area would exist at closure of the facility.

- Per WAC 173-306 - that part of groundwater which lies beneath the perimeter of the active area of a disposal facility, as that active area would exist at the closure of the facility.

- Per WAC 173-350 - a point established in the groundwater by the jurisdictional health department as near a possible source of release as technically, hydrogeologically and geographically feasible.

- Per WAC 173-351 – This rule does not provide a simple definition, and instead WAC 173-351-300(6) describes a number of factors that must be considered when agreeing upon a point of compliance.

Post-closure - refers to specific definitions depending upon the WAC including:

- Per WAC 173-304 - the requirements placed upon disposal sites after closure to ensure their environmental safety for at least a twenty-year period or until the site becomes stabilized (i.e., little or no settlement, gas production, or leachate generation).

- Per WAC 173-306 - the requirements placed upon disposal facilities after closure to ensure their environmental safety for a thirty-year period or until the site becomes stabilized (i.e., cap integrity maintained, little or no settlement or leachate generation).

- Per WAC 173-350 - the requirements placed upon disposal facilities after closure to ensure their environmental safety for at least a twenty-year period or until the site becomes stabilized (i.e., little or no settlement, gas production, or leachate generation).

- Per WAC 173-351 - those actions taken by an owner or operator of a facility or MSWLF unit after closure.

Quality Assurance Project Plan (QAPP) – a written plan describing objectives and procedures for assuring reliability of the data while collecting and handling samples, analyzing data, etc.

Post-closure plan - a written plan developed by an owner or operator of a facility detailing how a facility is to meet the post-closure requirements for the facility.

Representative sample - a sample that can be expected to exhibit the average properties of the sample source.

Sampling and analysis plan (SAP) - a written plan describing sampling and handling techniques, frequency of sampling, and analyses requirements.

Screened interval - the open or screened section of the well through which groundwater recharges the well.

Semi-volatile organic analysis – analysis for volatile organic compounds using gas chromatography/ mass spectrometry (GC/MS) methods, which in the case of landfills typically relies upon EPA Method 8270.

Statistically significant increase (SSI) – a change in the concentration of a constituent that is large enough to account for natural variability as well as the detected change.

Upgradient - the location in the aquifer flow field that groundwater flows horizontally towards the facility of interest. The gradient and flow direction in the aquifer are determined from groundwater elevation data from monitoring wells.

Uppermost aquifer - a "geologic formation or group of formations underlying the facility which is capable of yielding monitorable quantities of water to an approved monitoring device. Site specific hydrogeologic conditions, defined in a comprehensive hydrogeologic evaluation, will dictate what is to be considered a monitorable quantity of water" (Ecology, 1988).

Vadose zone - that portion of a geologic formation in which soil pores contain some water, the pressure of that water is less than atmospheric pressure, and the formation occurs above the zone of saturation.

Volatile organic analysis - analysis for volatile organic compounds (VOCs) using gas chromatography/ mass spectrometry (GC/MS) methods, which in the case of landfills typically relies upon EPA Method 8260.

WAC - Washington Administrative Code.

Zone of saturation - that part of a geologic formation in which soil pores are filled with water and the pressure of that water is equal to or greater than atmospheric pressure.

Appendix B

Acronyms

Analysis Of Variance (**ANOVA**)

Cleanup Level and Risk Calculations (**CLARC**) database

Comprehensive Environmental Response, Compensation, and Liability Act (**CERCLA**)

Environmental Information Management (**EIM**) database

Environmental Protection Agency (**EPA**)

Jurisdictional Health Department (**JHD**)

Maximum Cleanup Level (**MCL**)

Model Toxics Cleanup Act (**MTCA**)

Municipal Solid Waste (**MSW**)

Polycyclic Aromatic Hydrocarbon (**PAH**)

Quality Assurance Project Plan (**QAPP**)

Regression on Order Statistics (**ROS**)

Resource Conservation and Recovery Act (**RCRA**)

Revised Code of Washington (**RCW**)

Risk Assessment Guidance for Superfund (**RAGS**)

Sampling and Analysis Plan (**SAP**)

Selected Ion Monitoring (**SIM**)

Site Wide False Positive Rate (**SWFPR**)

Statistically Significant Increase (**SSI**)

Technical Information Memorandum (**TIM**)

Toxicity Equivalency Factors (**TEFs**)

Volatile Organic Compounds (**VOC**)

Washington Administrative Code (**WAC**)

Washington State Department of Ecology (**Ecology**)