GUIDELINE 3 - HYDROGEOLOGIC INVESTIGATIONS, GROUNDWATER MONITORING NETWORKS, AND GROUNDWATER SAMPLING FOR SOLID WASTE MANAGEMENT FACILITIES

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I. Introduction

This document provides recommendations for hydrogeologic investigations, groundwater networks (systems), and groundwater monitoring for solid waste facilities. Its intended use is primarily for landfills, but it can also be used for other facilities including waste impoundments, waste piles, land treatment sites, and other similar facilities. This document presents the concept of the order in which a hydrogeologic investigation and groundwater network (system) should proceed and the type and level of information which should result. The document is intended to:

1. Establish the minimal scope of work for hydrogeologic investigations of solid waste landfills.
2. Provide permittees with a reference for use in preparing requests or proposals for hydrogeologic investigations of their landfills.
3. Increase consistency between hydrogeologic investigations conducted at different solid waste landfills.

The document does not require specific methods or procedures other than those provided by statute or rule. In the few instances where methods are specified, alternative procedures may be proposed.

This document has been prepared by the North Dakota Department of Environmental Quality (Department) for the purpose of assisting owners and operators of the sites of solid waste management facilities where hydrogeologic investigations are necessary to fulfill regulatory or permit requirements. Questions and comments are welcome by contacting the Division of Waste Management, North Dakota Department of Environmental Quality, 4201 Normandy St., 2nd Fl., Bismarck, ND 58503-1324, telephone 701-328-5166.

II. Preliminary Evaluation Report and Geotechnical Investigation Workplan

1. Introduction. The purpose of the Preliminary Evaluation Report is to summarize and evaluate existing information (North Dakota Administrative Code (NDAC) Section 33.1-20-03.1-01) for a preapplication for a potential location of a new solid waste facility or expansion of an existing facility. This report will be used by Department to review and comment on the proposed workplan.

   The following items should be included in the Preliminary Evaluation Report:

   A. Existing Conditions Plot Plan

      The existing conditions plot plan, referenced to the National Geodetic Vertical Datum, should show the following:

a. Property lines;

b. Location(s) and types of solid waste;

c. Locations and identification of previous soil borings and wells, including abandoned and destroyed wells and surface water monitoring points;

d. Highways and roads;

e. Surface water bodies including springs, wetlands, lakes, ponds, rivers and streams;

f. Buildings;

g. Engineering structures including drainageways, diversion ditches, drain tiles, manholes or other leachate monitoring points, lined areas, leachate collection systems;

h. Cross-section lines (for part II.A.2 below);

i. Scale, north-arrow, explanation, base-map sources and bench mark; and

j. Outcrops, roadcuts, faults, sinkholes, quarries and gravel pits (active and abandoned).

B. Preliminary Cross-Sections

Two preliminary cross-sections at orientations of 90 degrees from each other in which each cross-section line extends through the landfill should be prepared. Where sufficient data exist, the cross-sections should be drawn perpendicular and parallel to the direction of groundwater flow. The cross-sections should be based on available water well records, landfill operating records, geologic reports, geophysical studies and hydrogeologic studies. Sufficient information to prepare preliminary cross-section is not always available. When feasible, cross-sections should be developed and should show:

a. Soil boring logs, water well records, outcrops, or other geologic control;

b. Soil and bedrock stratigraphy;

c. Geologic structures;

d. Fill boundaries and depths;

e. Property boundaries of the landfill;

f. Surface water bodies as listed in II.A.1.e.;

g. Engineering structures as listed in II.A.1.g.;

h. Scale, vertical exaggeration, and orientation;

i. Existing and final contours; and

j. Other information as dictated by site conditions.

2. Available Information

Available information which pertains to the facility or the area of the facility should be reviewed and summarized. The summary should include:

a. A brief discussion of the regional and local hydrogeology.

b. A discussion of the reliability and availability of existing site information. This discussion should also identify areas with insufficient information.

c. If the proposed investigation is for an existing facility, a brief narrative of the site's history should be provided which includes a discussion of the types of waste accepted and the progression of filling which occurred at the site. The type and estimated location of any hazardous waste or asbestos should also be discussed and noted on the plan sheets.

d. A map of appropriate scale which shows locations of all wells (domestic, municipal, irrigation and industrial) within a two-mile radius of the landfill. Information on well depths, pumping rates, static water levels and source aquifers which can be obtained by reviewing water well records and interviews with well owners should be provided.

A. Sources of Information

The sources of information should include but are not necessarily limited to:

a. Water well and soil boring records of the Board of Water Well Contractors.

b. Existing geologic and hydrologic publications and maps of the area including those published by United States Geologic Survey (USGS), North Dakota Geological Survey (NDGS), North Dakota Department of Water Resources (DWR), and University of North Dakota or North Dakota State University Master's Theses and Doctoral Dissertations.

c. United States Department of Agriculture Natural Resource Conservation Services (NRCS) soil surveys.

d. USGS topographic maps.

e. Aerial photos from the ASCS, NRCS, North Dakota Department of Transportation, NDGS, or another source.

f. Existing site groundwater monitoring data.

g. Existing site surface watering monitoring data.

h. Waste hauling and disposal records, including hazardous waste and co-disposal waste records.

i. Characterization of the site from previous studies:

   1. Borings - type of drilling, classification of soils;
   2. Soils testing - types, laboratory methods, results;
   3. Monitoring well logs; and
   4. Mapping of outcrops, mined areas, mine sinkholes, and gravel pits (active and abandoned).

j. Climatological data from the National Weather Service.

k. USGS stream flow data - locations, date and time, methods of measurements.

l. Geophysical information including surface studies and borehole logs.

NOTE: All data should either be included in Appendices or should be referenced.

B. Evaluation of Existing Monitoring System

Each groundwater monitoring well's condition, construction, reliability, and usefulness for future monitoring should be evaluated. In order to make this evaluation, well construction logs, groundwater monitoring results and field inspections should be utilized. Any wells to be used in the monitoring network:

a. Must be screened in the proper aquifer(s) and intervals.

b. Should recharge a volume sufficient for the collection of samples for volatile organic analysis within two hours of purging.

c. Must comply or be upgraded to comply with the requirements of North Dakota Century Code (NDCC) Chapter 43-35 and NDAC Article 33.1-18.

d. Must be constructed to minimize the effects of frost heave and should be constructed in a manner consistent with Figure 1.

NOTE: Tables should be provided which summarize construction information for each well.

2. Site Characterization Workplan

A site characterization may be required (NDAC Sections 33.1-20-03.1-02 and 33.1-20-13-01). Based upon the information provided in the Preliminary Evaluation Report, a workplan for the site characterization should be submitted.

At a minimum, the site characterization workplan shall include the following:

A. Purpose. A statement of purpose and objectives of the subsurface investigation.

B. Proposal. The proposals for the investigation and their rationale. At a minimum, the following should be addressed:

a. The number, locations, and depths of all borings.[1]
b. The method(s) of soil sampling and classification.
c. The intervals and methods for collecting representative soil samples for laboratory testing.
d. A discussion of the procedures that will be used to store and ship soil samples to a laboratory and the length of time the samples will be available for inspection.
e. The type and number of laboratory tests to be conducted.
f. Proposed locations, depths, screened intervals, casing diameters and other construction details for piezometers. The rationale for selecting the design should be discussed. Consideration should be given to piezometer lag time.
g. The number, type, and location of field tests to be conducted. A description of the test methodology should be included.
h. The frequency, number, and method of water level measurements.
i. The types of maps, cross-sections, flow-nets, and other work products and supporting data that are expected to be produced.
j. Groundwater quality parameters, number of samples, and sampling methods should be incorporated into the plan if this phase of the investigation will address water quality.

C. Schedule. The time schedule for completion of the proposed procedures.

III. Site Characterization Requirements and Proposal for Environmental Monitoring System

A. Site Characterization

1. Purpose. The purpose of the site characterization is to determine the suitability of the site for the management of solid waste, provide geotechnical information for design and installation of a groundwater monitoring system, and provide geotechnical bases for design and construction of the facility. Specific hydrogeological features of the site must be delineated (NDAC Sections 33.1-20-13-01 and 33.1-20-08-03).

The purpose is accomplished by collection of soil and rock samples and by analysis of the physical and chemical properties, both in the laboratory and in the field.

2. Soil Survey. A soil survey of the facility is necessary if one has not yet been completed. The soil survey is intended to aid reclamation of the facility; therefore, the survey should include specific recommendations outlining horizons to be stripped and stockpiled as suitable plant growth material. The results of the survey should be included in the investigation report. The survey should be conducted by a practicing professional soil classifier registered with the North Dakota Board of Registration for Professional Soil Classifiers. View website: https://www.ndsu.edu/pubweb/soils/BRPSC/styled-4/

3. Soil Borings

a. Number and Locations. Soil borings should be located in all topographic features at a site, such as hills, hill slopes and valleys. Sites ten acres or less require a minimum of 10 borings; sites 10-50 acres require 20 borings; and sites larger than 50 acres require 20 borings plus an additional boring for every

[1]The preferred or required methods are discussed in the section on the subsurface investigation.

10 acres over 50 acres. More complex hydrogeologic settings will require additional borings.

b. Depth. Borings must be completed to a minimum depth of 25 feet or 10 feet below the water table, whichever is greatest. Generally, 2 out of 10 borings for small sites and 4 out of 20 borings for larger sites, must be completed to a depth of 50 feet below the lowest elevation of existing or anticipated waste disposal, whichever is lower. Borings should not necessarily be interrupted simply because the minimum depth has been achieved. Table 1 lists information which should be recorded while advancing the boring.

c. Drilling Method and Sample Collection. The preferred method of drilling is by hollow stem auger. Soil samples should be collected by split barrel (ASTM D1586) or thin-walled tube (ASTM D1587). Where necessary rock cores (ASTM D2113) should also be collected. Continuous sampling is preferred. Samples should be collected every 2-2.5 feet to a depth of 25 feet and then every 5 feet and/or at changes in soil classification.

d. Soil Classification. To confirm field classification, samples should be retained for subsequent laboratory classification using the Unified Soil Classification System (ASTM Standard D2487).

4. Laboratory Analysis of Soil Properties

Based on a review of water well records, existing soil borings and in-field examination of soil samples, the soil strata which significantly affect the site's hydrology should be identified. Aquifers, confining layers, perching layers, coal seams, coarse-grained bodies, and other important soils should be identified. Once these strata are identified, their physical and hydraulic properties should be determined so that an estimate of their ability to transmit or restrict groundwater movement can be made. Quantifying the soil properties should include both laboratory and in situ testing.

Samples for laboratory analysis should be selected to represent the areal distribution of each stratum. This soil sampling schedule will require the collection of a large number of thin-walled tube samples for potential analysis. Samples should be preserved and transported to the laboratory in accordance with ASTM Standard D4220.

a. Hydraulic Conductivity. Hydraulic conductivity tests should be conducted on the thin-walled tube samples; this may be accomplished by extrusion, trimming and isolation of the sample within a flexible membrane, triaxial apparatus, or other appropriate methodology. Such a test quantifies the vertical hydraulic conductivity of the enclosed sample. If the analytical results from several samples from the same stratum are within the same order of magnitude, it will usually be unnecessary to test all the samples collected from that stratum.

b. Particle Size Analysis. Particle size analysis should be conducted by standard test methods ASTM D422 and ASTM D1140. Analysis should be conducted on a sufficient number of samples to assist in correlating soils across the site and for the design of the monitoring wells.

c. Additional Laboratory Tests. Additional scientific and engineering tests should be conducted when necessary. These may include Atterberg limits, soil mineralogy, cation exchange capacity, moisture content, etc. Table 2 provides some typical laboratory methods.

5. Piezometer Construction

a. After soil sampling and laboratory testing to determine those strata of hydrologic importance, piezometers should be installed. Although they are often used to collect groundwater samples, piezometers are not necessarily designed as water quality monitoring wells. They are designed to allow measurement of hydrostatic pressure at discrete points in the soils and to perform in situ tests of soil properties. As such, they must be constructed to respond to changes in hydrostatic pressure in a reasonable amount of time. The design and construction of a piezometer should be based on the estimated hydrologic properties of the stratum. The lower the estimated permeability, the more critical the construction.

Piezometers must meet all the requirements of NDCC Chapter 43-35, and the Standards for Water Well Construction and Water Well Pump Installation of NDAC Article 33.1-18.

b. Location and Number. Sufficient piezometers and piezometer nests are needed so that hydrogeological conditions are determined throughout the permitted site. This requires locating piezometers to determine the groundwater flow directions as it moves across the entire site.

A set of three piezometers in the same hydrogeologic unit in a triangular pattern is the minimum needed to establish a generalized flow direction. The relationship between hydrogeologic units within the local and regional hydrogeologic system should be considered. Large sites and/or those having variable soil, topographic, or hydrogeologic conditions will require more than three piezometers.

c. Depth. One set of (three or more) piezometers should be placed to define the slope of the water table. If an underlying confined aquifer is present, additional set(s) of piezometers should be placed to determine the hydraulic head differences (hence the gradients) between the aquifers and the flow directions in the confined aquifers. If the upper (water table) aquifer is thick, piezometer nests should be installed to determine the gradient within the aquifer. A nest is a group of closely spaced (a few feet apart) piezometers screened at different depths.

d. Diameter. The diameter of the piezometer standpipe and the diameter of the screen should also be designed to reflect the estimated permeability of the water-bearing stratus under consideration. The higher the permeability, the smaller the diameter of the standpipe. Conversely, the lower the permeability, the larger the diameter of the screen. A piezometer placed in a highly permeable sand can likely be constructed of standard 2-inch PVC standpipe and screen whereas in a sandy clay, a 1-inch standpipe (or smaller) with a 4-inch (or larger) screen may be more appropriate.

e. Length. The length of a piezometer screen should generally be as short as possible. The piezometer is meant to measure the hydraulic head at discrete points. Screens should never interconnect separate aquifers.

6. In situ Testing

After the piezometers are installed, their water levels should be allowed to stabilize. Stabilization should be confirmed by periodic water level measurements. Once stabilization is reached, the stratum's horizontal hydraulic conductivity should be determined. Methods for determining hydraulic conductivity include bail tests, plug tests, slug tests, and pump tests.

B. Site Characterization Investigation Report

A report detailing the findings of the Site Characterization should be submitted. The report should address the following and include graphs, maps, tables and cross-sections to illustrate the discussions. Some typical figures are listed in Table 3.

1. Description of Geologic Units. The composition, structure and distribution of each soil, sediment, and bedrock unit, and the range of variation in each including the soil or rock description and classification; the lateral and vertical extent of the unit at the site; grain size distributions; mineralogy, cementation, and other characteristics as appropriate; strike, dip, folding, faulting, jointing, and other significant regional or local structural features; horizontal and vertical permeabilities; porosity, hydraulic conductivity, and other hydraulic properties as appropriate; and descriptions of lenses or other discontinuous deposits, voids and solution openings, layering, fractures, and any other inhomogeneities.

2. Description of Hydrologic Units. Descriptions of the hydrologic units within the saturated zone including their thickness, hydraulic properties (as appropriate), such as transmissivity and storage coefficient or specific yield; descriptions of the role of each as confining beds, aquifers, or perched saturated zones; and their actual or potential use as water supply aquifers.

3. Description of the Flow System. Description of the groundwater flow system, illustrated with potentiometric contour lines and streamlines on appropriate cross-sections and plans, and specifically describing the following and discussing their significance with respect to groundwater and contaminant movement:

   a. Local, intermediate, and regional flow systems.

   b. Groundwater recharge and discharge areas, and groundwater interaction with perennial or intermittent surface waters.

   c. Direction and rates of groundwater movement within the identified hydrologic units, including the vertical components of flow.

   d. Existing or proposed groundwater and surface water withdrawals.

   e. The role of inhomogeneities, fractures, and anisotropy in influencing or controlling groundwater movement.

   f. Seasonal or other temporal fluctuations in potentiometric head.

   g. The change in recharge rates that has occurred and will occur due to the presence of the facility.

h. The role of confining beds with regard to limiting downward movement of high-specific gravity, immiscible or poorly soluble components of leachate.

C. Environmental Monitoring Network Workplan

Purpose. A workplan or proposal for the monitoring well network (system) should be submitted (NDAC Subsection 33.1-20-13-02(3)). The workplan should include a written narrative which describes the proposed design and locations of the monitoring wells. All monitoring wells and piezometers shall be installed by a certified water well contractor or monitoring well contractor in accordance with NDCC Chapter 43-35 and NDAC Article 33.1-18. In addition, the wells should be consistent with Figure 1. The following items should be considered:

1. Location and Depth. The groundwater must be monitored both upgradient and downgradient from the site (NDAC Section 33.1-20-13-02). The number of monitoring wells and depths of those wells are site-specific should be determined based on the Preliminary Evaluation Report and Geotechnical Investigation. If more than one flow system exists, monitoring wells may be required both upgradient and downgradient in each of the potentially affected systems.

2. Rate of Recharge. Consideration should be given to the rate of recharge which is based in hydrologic properties of the soils and monitoring well construction. If possible, wells should be constructed to recharge a sufficient sample volume within two hours.

3. Casing. Length, diameter, and material.

4. Screen. Length, diameter, material, slot size and packing.

5. Well development. All monitoring wells should be developed and stabilized. Well development procedures should be described in the workplan. After constructing monitoring wells, natural hydraulic conductivity of the formation should be restored and all foreign sediment removed to ensure turbidity-free groundwater samples.

   A variety of techniques are available for developing a well. To be effective, they require reversals or surges in flow to avoid bridging by particles, which is common when flow is continuous in one direction. These reversals or surges can be created by using surge blocks, bailers, or pumps. Formation water should be used for surging the well. In low-yielding water-bearing formations, an outside source of water may sometimes be introduced into the well to facilitate development. In these cases, this water should be chemically analyzed to evaluate its potential impact on in situ water quality. The driller should not use air to develop the wells. All developing equipment should be decontaminated prior to use as should the materials of construction.

   Wells should be developed to be clay- and silt-free. If, after development of the well is complete, it continues to yield turbid groundwater samples, the owner/operator should redevelop the well. The recommended acceptance/rejection value of five Nephelometric Turbidity Units (N.T.U.) is based on the need to minimize biochemical activity and possible interference with groundwater sample quality. If turbidity less than five N.T.U. cannot be achieved then low-flow sampling methods should be used when collecting groundwater quality samples because filtration of samples is not allowed.

IV. Sampling and Laboratory Analysis

A. Introduction

A groundwater monitoring plan should be submitted to the Department prior to sampling. The Department will review this workplan and provide written comments. Once any necessary modifications to the workplan are completed, sampling may proceed. This plan should include at a minimum:

1. Well construction records and stabilization test reports for approval of the monitoring well network (system).
2. Sampling protocol.
3. Analytical methods and the Quality Assurance / Quality Control (QA/QC) program description.
4. Sampling schedule.
5. Statistical methods.
6. Reporting format and frequency.

B. Workplan Contents

1. Well Construction Details:

Well construction details (see Table 1) should be submitted with stabilization/recovery rate test results.

2. Sampling Protocol

Sampling protocol should include the following:

a. A statement of the purpose of monitoring (e.g., routine, background, enforcement, etc.).

b. A list of the parameters for which each well will be sampled and the order in which the samples will be collected from the wells (e.g., volatiles, metals, etc.).

c. The methods which will be followed for establishing static water level, stabilizing the well, evacuating of the well, and obtaining a sample.

d. A list and description of the field equipment which will be used for sampling such as the pump, bailer, bailer line, tape, meters, filters, containers, etc.

e. The amount of water in gallons and well volumes which will be evacuated from each well prior to sampling based on stabilization tests, pump tests or other methods which should be described in detail.

f. The order in which the wells will be sampled and rationale for this order.

g. The procedures and materials which will be used to clean equipment between wells, such as cleaning solutions and the volumes used.

h. Sample preservation methods such as filtering, acidification, cooling and holding times.

i. A sample chain-of-custody form which will be used by the sampler.

j. Shipping and handling procedures and time schedule from the field to the laboratory to the actual analysis.

3. Analytical Methods

Analytical methods and QA/QC program proposal should include the following:

a. The EPA or Standard Methods which will be used by the laboratory for each parameter or other methods may be proposed, but will have to be approved. All analyses must be conducted by a laboratory approved by the Department's certification procedures.

b. The lowest detection limits expected for the method and equipment to be used.

c. The types of laboratory equipment, makes, and model numbers.

d. The laboratory's equipment maintenance schedule.

e. The number and frequency of quality control samples (e.g., blanks, spikes, replicates, duplicates, etc.) to be analyzed. A minimum of one in ten is required in general and at changes of sample matrix.

V. Sampling Schedule and Parameters

A. Sampling Schedule

The scheduled sampling dates should be indicated in the groundwater monitoring plan so that the Department has an opportunity to split samples, inspect the wells, and observe the procedures used to collect the samples. The schedule should also specify which parameter list will be utilized for each sampling event. The list of parameters for which landfills monitor is subdivided into parts that are applicable to different types of facilities. For detection monitoring at municipal waste landfills (after background levels have been established), sampling and analysis should be conducted at least semiannually according to the following schedule:

Parameters (listed in Table 4.):	**Frequency:**
Parameters in Parts b, d, and e	One sampling event per year.
Subtitle D. Compliance Parameters - Parts a, c, g, and h	Two sampling events per year.

1. Full List of Parameters

The full list of parameters is analyzed before a facility is in operation, and periodically afterwards. The full list may be found in Table 4.

Facilities with known groundwater contamination may require more frequent analysis of the full list of parameters. The full list of parameters is used to characterize a broad range of water quality constituents.

a. General Parameters

General parameters consist of those listed in Parts a, b, d, and e of Table 4. These parameters are indicators of general water quality and of leachate migration and are used to signal the need for additional investigation. For some industrial facilities, this list may be modified based on the types of waste to be disposed.

b. Site-specific Parameters

Monitoring for additional parameters may be required for facilities with a history of accepting hazardous substances, for facilities with unique waste streams, and for facilities at which groundwater contamination has occurred. Each site will be evaluated individually. An evaluation of the waste characterization information for proposed or existing facilities is often beneficial in designing a groundwater monitoring program. If a significant pollution problem is determined and/or remedial action is warranted, the assessment monitoring list in Appendix II of 40 CFR Part 258 may be required.

c. General Comments on Sampling and Analysis

One sampling event is not sufficient to establish back groundwater quality. Seasonal variation, sampling variation, analytical variation, and random error occur. At minimum, the first four (4) rounds of sampling and analysis must be used by the owner/operator to establish background levels. Municipal waste landfills must analyze for constituents listed in Parts a, b, c, d, e, g and h of the extended list of parameters. For other types of solid waste facilities, the list of parameters can be specified through the permit application and review process based on the type of facility, the waste, etc. For municipal solid waste landfills beginning monitoring programs after October 9, 1993, the first four (4) rounds of sampling and analysis must occur within the first six (6) months of facility operation. For other landfills with monitoring wells, semiannual sampling and analysis of appropriate parts of the extended list of parameters is generally acceptable for obtaining background data and for detection monitoring after background levels are established. The Department may require more frequent monitoring, depending on the facility and the local hydrogeologic conditions.

In general, the opportunities for contaminating a sample increase as the number of persons handling the sample increase. The chain-of-custody document must list all persons who collect, transport, and receive the sample bottles. The use of an independent laboratory to collect, transport, and analyze the samples is strongly recommended. All analyses must be conducted by a laboratory approved by the Department's certification procedures.

2. Reports

Reports on sampling events are required to be submitted to the Department annually by March 1st for coal combustion residuals (CCR) facilities and by April 1st for all other solid waste management facilities. These reports should contain, at a minimum, the following:

a. The static water level for each well to the nearest 0.01 foot from the surveyed reference point.

b. The stabilization test results for each well.

c. The number of gallons of water and the number of well volumes removed before sampling.

d. Sampler's field comments regarding anything unusual about the well such as: obstructions removed before sampling, well seal deterioration, vandalism, unlocked caps, excessive sediment in or coloration of the sample, odor, unexpectedly high or low static water level, bailer lost in the well, etc.

e. A statement about any deviations in sampling or analysis techniques or equipment used from that stated in the workplan.

f. The laboratory results of each sample analysis along with the quality control sample (e.g., blank, spikes, duplicates) analysis. An analysis of a field blank for each sampling event for volatile organics must be included.

g. A water table or potentiometric map of each hydrogeological unit being monitored. This map should also depict the locations of any wells screened in the unit in relationship to waste disposal cells and other appropriate features.

h. Data should be provided in a readily comprehensible form, such as tables, in addition to copies of the lab reports.

VI. Data Analysis and Impact Identification

This section details the hydrogeological Evaluation Report requirements for presenting the analytical data and assessing the actual and/or potential impacts of the facility on the residents or environment of the surrounding area.

A. Summary

The author should provide a summary which presents the conclusions and briefly states the conceptual model that most adequately explains the hydrogeology and contaminant movement (if applicable). The supporting data pertinent to the conclusions should also be summarized.

B. Identification of Receptors

Based on the site investigation, the resources (receptors) which have been impacted or are to be protected should be identified from the list prepared for the Evaluation Report and the location indicted on maps and cross-sections of appropriate scale. These receptors include:

1. Aquifers. The report must identify the following beneath the facility:

a. All perched aquifers.

b. The first two aquifers or separate saturated zones.

c. All contaminated aquifers.

d. The next aquifer beneath the lowest known contaminated aquifer.

e. All confining/separating units.

If there are wells which have allowed or could allow contaminants to move from one aquifer to another, the potentially affected aquifer(s) should also be identified.

2. Wells. The report should identify all wells within one mile downgradient of the disposal facility or one mile downgradient of the leading edge of the plume of contamination.

3. Surface Waters. The report should identify any surface water bodies within one mile of the facility which have been affected or are to be protected.

4. Conduits. The report should identify and show on maps of appropriate scale all drain tiles, sewer lines or other potential conduits on or adjacent to the subject property which could intercept leachate or leachate-contaminated groundwater. The discharge point for the drain tile shall also be identified.

C. Data Presentation

1. Monitoring Points. The purpose of each monitoring point shall be explained. As an example, monitoring wells should be identified by the aquifer they are monitoring and whether they are upgradient, downgradient, or lateral to the solid waste unit or plume. Downgradient wells should be described as being in or near the area which might be expected to have the highest level of contamination, be on the edges of the plume, etc.

2. Tabulation of Data. The report should present all of the water quality and water level data in tabular form. If data is available but is judged as unrepresentative of actual groundwater conditions, the reasons for not using the data in the analysis should be stated. The discarded data must be included in the Appendices, but need not be tabulated in the report.

3. Graphical Presentation. If a sufficient amount of data is available, it should be presented in graphical form. This may include, but not necessarily be limited to:

a. Time versus concentration graphs.

b. Correlations or regression analysis.

c. Stiff, bar, radial coordinate, or pie diagrams for major ion analysis.

d. Trilinear diagrams.

e. Contour line (isogram/isopleth) maps of contaminant concentration, in plain view and cross-section.

f. Well hydrographs.

4. A statistical analysis and summary of the water quality data. The Department has prepared *Guideline 2 - Statistical Analysis Of Groundwater Monitoring Data From Solid Waste Management Facilities*, which is a summary of recommended statistical methods for the analysis. Refer to *Statistical Analysis of Groundwater Monitoring Data at RCRA Facilities, Unified Guidance*, U.S. EPA (2009) for full details and discussion of appropriate statistical methods to use in performing the analyses.

D. Impact Analysis

The Evaluation Report should discuss the actual/potential impact on each of the previously identified receptors. This should be based on the data which has been presented and assessed. Inconsistencies between groundwater quality data and groundwater hydraulics or between groundwater quality data and known or expected wastes and areas of disposal should be pointed out. The report should state all assumptions made and test the critical assumptions/estimates to determine the impact on the conclusions.

Where groundwater models are used as predictive tools, the report shall describe: the type and applicability of the model; the equation being solved; all model assumptions; and the initial and boundary conditions. The report shall provide complete documentation of the model or reference to the documentation. The report should also discuss how the accuracy of the modeling results have been or will be determined (e.g., calibration and sensitivity analysis).

E. Alternative Explanations: The report should state and discuss alternative explanations and why they were discarded from further consideration.

F. Recommendations for Further Study: If there is not enough information available to draw the conclusions on impacts or if there is more than one plausible explanation, recommendations for additional work and a workplan should be presented.

G. Recommendations: Where sufficient data exists to properly evaluate the facility, recommendations should be made concerning the necessity of additional action.

H. Example Calculations: An example calculation using actual data with units should be included for each type of calculation.

I. Raw Data: All raw data should be included as Appendices.

J. References: All references should be included.

VII. Well and Borehole Abandonment

A. Soil borings and monitoring wells

Monitoring well abandonment is as important as well installation. The objective of boring and well abandonment is to close off the boring or well completely in order to prevent future contamination of the groundwater. Abandonment of wells includes sealing both the inside and outside of the well casing. The materials used to abandon a well must be impermeable, continuous, and not subject to chemical or physical change. The methods used will vary with the type and location of the well or boring. Abandonment of soil investigation boreholes and monitoring wells must be performed by a certified water well contractor or monitoring well contractor in accordance with NDAC Article 33.1-18.

B. Wells In Future Fill Areas

If a well is in a particularly sensitive area, such as in an area that may be used for waste disposal in the future, extra precautionary measures must be taken. First, remove the well and seal the hole as described above. Then, it is recommended to dig a pit around the well 5 feet below the ground surface or 5 feet below the base of the proposed landfill excavation, whichever is deeper. Fill the pit above the abandoned borehole with compacted 1-foot (maximum) lifts of clay having a hydraulic conductivity of 1×10^{-7} cm/sec or less. Again, be sure to document the location and method of abandoning the well.

VIII. References

U.S. Environmental Protection Agency. 1986. RCRA Groundwater Monitoring Technical Enforcement Guidance Document. Office of Solid Waste and Emergency Response, 208 p. https://www.epa.gov/sites/default/files/documents/rcragwguiddoc-rpt_0.pdf

U.S. Environmental Protection Agency. 1988a. Guide to Technical Resources for the Design of Land Disposal Facilities. EPA/625/6-88/018, U.S. EPA, Risk Reduction Engineering Laboratory, Center for Environmental Research Information, Cincinnati, Ohio. https://cfpub.epa.gov/si/si_public_record_Report.cfm?Lab=NRMRL&dirEntryID=34908

U.S. Environmental Protection Agency. 2009. Statistical Analysis of Groundwater of RCRA Facilities - Unified Guidance. https://archive.epa.gov/epawaste/hazard/web/pdf/unified-guid-toc.pdf

U.S. Environmental Protection Agency. 2018. SESDGUID-101-R2, Design and Installation of Monitoring Wells. https://www.epa.gov/sites/default/files/2016-01/documents/design_and_installation_of_monitoring_wells.pdf

Figure 1. Observation Well Installation Diagram

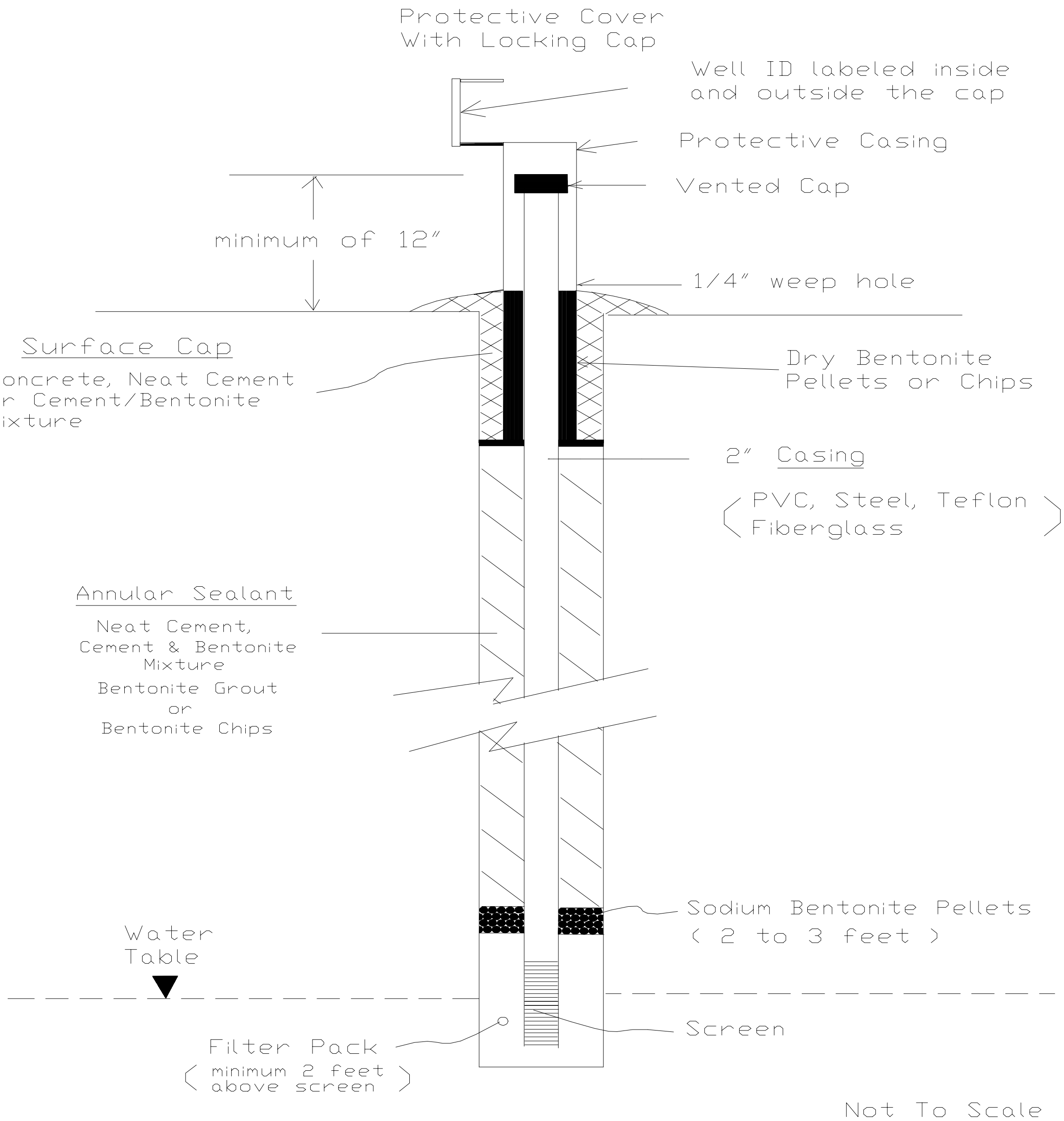

Table 1. Field Boring Log Information

<table>
<tr><th colspan="2">General</th></tr>
<tr><td colspan="2">Project name
Hole name/number
Date started and finished
Geologist's name
Driller's name
Sheet number
Hole location; map and elevation
Rig type (bit size/auger size)
Petrologic lithologic classification scheme used (Wentworth, Unified Soil Classification System)</td></tr>
<tr><th colspan="2">Information Columns</th></tr>
<tr><td colspan="2">Depth
Sample location/number
Blow counts and advance rate
Percent sample recovery
Narrative description
Depth to saturation</td></tr>
<tr><th colspan="2">Narrative Description</th></tr>
<tr><td colspan="2">Geologic Observations:</td></tr>
<tr><td>Soil/rock type
Color and stain
Gross petrology
Friability
Moisture content
Degree of weathering
Presence of carbonate
Fractures
Solution cavities</td><td>Bedding
Discontinuities; e.g., foliation
Water-bearing zones
Formational strike and dip
Fossils
Depositional structures
Organic content
Odor
Suspected contaminant</td></tr>
<tr><td colspan="2">Drilling Observations:</td></tr>
<tr><td>Loss of circulation
Advance rates
Rig Chatter
Water levels
Amount of air used and air pressure
Drilling difficulties
Changes in drilling method or equipment</td><td>Readings from detective equipment, if any
Amount of water yield or loss during drilling at different depths
Amounts and types of any liquids used
Running sands
Caving/hold stability
Void</td></tr>
<tr><td colspan="2">Other Remarks:</td></tr>
<tr><td colspan="2">Equipment failures
Possible contamination
Deviations from drilling plan
Weather</td></tr>
</table>

Table 2. Suggested Laboratory Methods for Sediment/Rock Samples

Sample Origin	Parameter	Laboratory Method	Used to Determine
Geologic formation, unconsolidated sediments, consolidated sediments, solum	Hydraulic conductivity	Falling head, static head test	Hydraulic conductivity
	Size fraction	Sieving (ASTM), settling measurements (ASTM)	Hydraulic conductivity
	Sorting	Petrographic analysis	Hydraulic conductivity
	Specific yield	Column drawings	Porosity
	Specific retention	Centrifuge tests	Porosity
	Petrology/Pedology	Petrographic analysis	Soil type, rock type
	Mineralogy	X-ray diffraction confining clay mineralogy/chemistry	Geochemistry, potential flow paths
	Bedding	Petrographic analysis	
	Lamination	Petrographic analysis	
	Atterberg Limits	ASTM	Soil cohesiveness
Contaminated samples (e.g., soils producing higher than background organic vapor readings)	Appropriate subset of Appendix VIII parameters ('261)	SW-846	Identity of contaminants

Table 3. Typical Figures Included in Geotechnical Investigation Reports.

Figure	Type or Features
Location Plan:	Based on USGS 7-1/2 minute series. Waste area boundary.
Area Map: (scale 1 inch = 500 feet or as appropriate)	Site in relation to natural and man-made features. Include 2,000 feet from perimeter of the facility. Waste and property boundary, lakes, ponds, springs, surface water diversions, and wells. Public supply watershed areas. Aquifers. Contour lines (contour intervals should be appropriate for local topography). Existing buildings and roads. Conservation areas and unique natural areas. Archaeological and historic sites. Zoning. Location of test pits and borings.
Soil/Geology Maps: (scale 1 inch = 100 feet or as appropriate)	Plan view soils or surficial geologic map of the disposal site.
Cross-Sections: (scale 1 inch = 100 feet or as appropriate)	Detailed cross-sections which shall sufficiently describe the geologic and hydrogeologic units identified by the investigation, prepared at a scale which clearly define the units.
Contour Maps: (scale 1 inch = 100 feet)	Contour map of the water table Contour map of the potentiometric surface of confined aquifers. Structure contour map of significant hydrogeological features (e.g., map of base of coal bed or of an aquitard forming a perched aquifer).
Miscellaneous: (appropriate scale)	Geological fence diagrams. Isopach maps of aquifers. Isopach maps of aquitards. Other figures as site specific features dictate.

Table 4. Full List of Parameters for Assessing Groundwater Quality at ND Landfills - 07/2020

Appendix I to NDAC Section 33.1-20-13-05 – List of Hazardous Inorganic and Organic Constituents can be found at: https://ndlegis.gov/information/acdata/pdf/33.1-20-13.pdf

a. Parameters measured in the field:

(1) Appearance (including color, foaming, and odor)
(2) pH[1]
(3) Specific conductance[2]
(4) Temperature
(5) Water elevation[3]

b. General geochemical parameters:

(1) Ammonia nitrogen
(2) Total hardness
(3) Iron
(4) Calcium
(5) Magnesium
(6) Manganese
(7) Potassium
(8) Total alkalinity
(9) Bicarbonate
(10) Carbonate
(11) Chloride
(12) Fluoride
(13) Nitrate + Nitrite, as N
(14) Total phosphorus
(15) Sulfate
(16) Sodium
(17) Total dissolved solids (TDS)
(18) Total suspended solids (TSS)
(19) Cation/anion balance

c. Heavy metals:

Group A:
(1) Arsenic
(2) Barium
(3) Cadmium
(4) Chromium
(5) Lead
(6) Mercury
(7) Selenium
(8) Silver

Group B:
(9) Antimony
(10) Beryllium
(11) Cobalt
(12) Copper
(13) Nickel
(14) Thallium
(15) Vanadium
(16) Zinc

d. Total organic carbon (TOC)

e. Chemical oxygen demand (COD)

f. Naturally occurring radionuclides:

(1) Radon
(2) Radium
(3) Uranium

g. Volatile organic compounds, both halogenated and nonhalogenated:

Halogenated:

Acrylonitrile	1,1-Dichloroethylene
Allyl chloride	1,2-Dichloropropane
Bromochloromethane	cis-1,3-Dichloropropene
Bromodichloromethane	cis-1,2-Dichloroethylene
Bromoform	trans-1,2-Dichloroethylene
Bromomethane	trans-1,3-Dichloropropene
Carbon disulfide	trans-1,4-Dichloro-2-butene
Carbon tetrachloride	Dichlorofluoromethane
Chlorobenzene	Dichloromethane (methylene chloride)
(monochlorobenzene)	1,3-Dichloropropene
Chlorodibromomethane	2,3-Dichloro-1-propene
Chloroethane	Pentachloroethane
Chloroform	1,1,1,2-Tetrachloroethane
Chloromethane	1,1,2,2-Tetrachloroethane
Dibromomethane	Tetrachloroethylene
1,2-Dibromo-3-chloropropane	1,1,1-Trichloroethane
1,2-Dibromoethane	1,1,2-Trichloroethane
Dichloroacetonitrile	Trichloroethylene
1,2-Dichlorobenzene	Trichlorofluoromethane
1,3-Dichlorobenzene	1,2,3-Trichloropropane
1,4-Dichlorobenzene	1,1,2-Trichlorotrifluoroethane
Dichlorodifluoromethane	Vinyl acetate
1,1-Dichloroethane	Vinyl chloride
1,2-Dichloroethane	

Nonhalogenated:

Acetone	Methyl isobutyl ketone
Benzene	Pyrene
Cumene	Styrene
Ethylbenzene	Tetrahydrofuran
Ethyl ether	Toluene
Methyl butyl ketone	m-Xylene
Methyl ethyl ketone	o-Xylene
Methyl iodide	p-Xylene

h. Pesticides:

Aldrin	Endrin
Chlordane	Heptachlor
Chloroform	Lindane
4,4 DDT	Methyl bromide
Dibenzofuran	Methyl methacrylate
Dieldrin	Methylene bromide
Dimethoate	Naphthalene
Endosulfan	Parathion

[1] Two measurements: in field, and immediately upon sample's arrival in laboratory.
[2] As measured in field.
[3] As measured to the nearest 0.01 foot in field before pumping or bailing.